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ISSUE RESOLUTION STATUS REPORT

KEY TECHNICAL ISSUE: REPOSITORY DESIGN AND THERMAL-MECHANICAL EFFECTS

Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission

Revision 3

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Change History of "Issue Resolution Status Report, Key Technical Issue: Repository Design and Thermal-Mechanical Effects"

Revision	Section	Date	Modification
Rev 0	All	September 1997	None. Initial issue
Rev 1	All	September 1998	General editorial and citation format changes
Rev 1	3.1		Table 1 revised to be consistent with repository safety strategy
Rev 1	3.3		Figure 1 replaces the four corresponding figures from Rev 0 Text made consistent with Figure 1
Rev 1	4.1.2		Review methods added
Rev 1	4.1.5		Section added to include GROA design control process review
Rev 1	4.2.2		Review methods added and subsection numbers revised
Rev 1	4.2.3		Acceptance criteria reworded for clarity, and two previous criteria were combined
Rev 1	4.3		Entire section expanded
Rev 1	5.0		Section expanded and renumbered
Rev 1	6.0		References added and changed as necessary
Rev 2	3.3.3	September 1999	Revised
Rev 2	3.3.4		Revised
Rev 2	4.3.3.1		Minor modification to acceptance criteria
Rev 2	4.3.3.2		Technical bases revised
Rev 2	4.3.4.2		Part of technical bases modified and section expanded
Rev 2	5.3		Section expanded and renumbered
Rev 2	5.4		Section revised
Rev 2	6.0		New references added

Change History of "Issue Resolution Status Report, Key Technical Issue: Repository Design and Thermal-Mechanical Effects", Cont'd

Revision	Section	Date	Modification
Rev 3		September 2000	Executive Summary added
Rev 3	1.0		Discussion on preclosure issues added—other significant changes have also been made
Rev 3	2.0		Discussion on preclosure issues added—other significant changes have also been made
Rev 3	3.0		Discussion on preclosure issues added—other significant changes have also been made
Rev 3	4.0		Review methods and acceptance criteria removed
Rev 3	5.0		Major revision
Rev 3	6.0		New references added

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EXECUTIVE SUMMARY

The focus of the Repository Design and Thermal Mechanical Effects Key Technical Issue (RDTME KTI) is the review of design, construction, and operation of the geologic repository operations area with respect to the preclosure and postclosure performance objectives, taking into consideration the long-term thermal-mechanical processes. Consequently, the RDTME KTI contains both the preclosure and postclosure subissues. In the past, this KTI focused more on the postclosure subissues than on the preclosure subissues. During the preparation of Revision 3 of this Issue Resolution Status Report, the RDTME attention was directed toward identification and resolution of preclosure subissues using the acceptance criteria developed in the Yucca Mountain Review Plan. The grouping of the preclosure subissues is tentative. It may be revised in the subsequent revision to make it more consistent with the Yucca Mountain Review Plan structure. Progress made in resolving preclosure subissues is limited for this revision because of the limited attention given so far to this aspect of the RDTME KTI. More work needs to be done before substantial progress can be made. The status of the RDTME KTI subissues is summarized in the following table.

Subissue	Closed	Open	Comment
Preclosure			
Design Control Process	Closed		Design control process hierarchy is simplified.
Seismic Design Methodology	Closed Pending		Awaiting review of Seismic Topical Report No. 3.
Preclosure Safety Analysis		Open	Resolution process for this subissue started during this revision. Limited review indicates that aircraft crash hazard analysis does not use sufficient data and assumptions are not justified.
Design of Geological Repository Operations Area		Open	Resolution process for surface facilities and EBS started during this revision. Concerns on areas such as adequacy of data, data reduction approach, modeling approaches, and assumptions for ventilation model are noted.
Retrievability		Open	Resolution process started during this revision. No review performed.
Design of EBS	Closed Pending		DOE to conduct preclosure performance evaluation for EBS, WP, and WF based on current design. DOE to collect and provide mechanical properties as functions of time.
Performance Confirmation Program		Open	Resolution process started during this revision. No review performed.
Repository Operations		Open	Resolution process started during this revision. No review performed.

Subissue	Closed	Open	Comment
Postclosure			
Thermal-Mechanical Effects		Open	Concerns related to modeling rockfall impact on drip shield and WPs are not resolved. Concerns related to thermal-mechanical effect on change in local hydrologic properties remain. Concerns related to screening out drift geometry change from model abstractions remain.
Repository Seals	Closed		10 CFR Part 63 does not have specific requirements for repository seals
Note: EBS—Engineered Barrier System DOE—U.S. Department of Energy WP—Waste Package WF—Waste Forms			

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ACKNOWLEDGMENTS FOR REVISION 0

Revision 0 of the Issue Resolution Status Report (IRSR) was prepared by M.S. Nataraja, Senior Geotechnical Engineer, Division of Waste Management (DWM), Engineering and Geosciences Branch (ENGB). The author acknowledges the supervision provided by R. Weller (Section Leader), N.K. Stablein (Acting Branch Chief), and the guidance provided by the High-Level Waste (HLW) Review Board. E. Barbely provided her usual enthusiastic secretarial support. A number of key technical issue leads have provided inputs at various stages of completion of this IRSR. The Performance Assessment (PA) and Integration Section of the PA and HLW Integration Branch reviewed the drafts and assisted the author in making this IRSR uniform with the other current IRSRs. Lastly, C.W. Reamer, in the Office of the General Counsel, reviewed the draft for any legal objections.

ACKNOWLEDGMENTS FOR REVISION 1

Revision 1 of the IRSR was prepared by U.S. Nuclear Regulatory Commission (NRC) staff M.S. Nataraja, DWM/ENGB, and S.M. Hsiung, G.I. Ofoegbu, R. Chen, A. Ghosh, and A.H. Chowdhury, Center for Nuclear Waste Regulatory Analyses (CNWRA). D. Rom, DWM, Uranium Recovery Branch, conducted the necessary NRC/U.S. Department of Energy (DOE) interactions and documented the progress made by the DOE under the subissue of design control process. P. Chaput, a summer intern with DWM, helped synthesize the inputs from several contributors. The authors thank W. Patrick for his technical review, B. Sagar for his programmatic review, and N.K. Stablein and R. Weller for their management reviews. Inputs and review comments provided by various Key Technical Issues (KTI) teams are greatly appreciated. Thanks also go to J. Wike for assisting with the word processing and to B. Long and B. Ford, Southwest Research Institute (SwRI), Publications Services, for editorial reviews.

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1 INTRODUCTION

In 1996, one of the primary objectives of the U.S. Nuclear Regulatory Commission (NRC) refocused prelicensing program was to direct its activities toward resolving the 10 key technical issues (KTIs) it considered to be most important to repository postclosure performance. This approach is summarized in Chapter 1 of NRC's High-Level Radioactive Waste Program Annual Progress Report: Fiscal Year 1996 (Center for Nuclear Waste Regulatory Analyses, 1997). Other chapters of this document address each of the 10 KTIs by describing the scope of the issue and subissues, path to resolution, and progress achieved during fiscal year (FY) 1996.

In this revision (Revision 3), issue resolution for preclosure related subissues is also included. The Acceptance Criteria (ACs) developed in the Yucca Mountain Review Plan (YMRP) for the U.S. Department of Energy (DOE) repository License Application (LA) are used as basis to document the progress on issue resolution. As a result of this addition, the Repository Design and Thermal Mechanical Effects (RDTME) KTI subissues are divided into two groups: preclosure subissues and postclosure subissues. To achieve this, the subissues in the original RDTME KTI as listed in Revision 2 of the Issue Resolution Status Report (IRSR) have been grouped into preclosure and postclosure subissues. Furthermore, additional subissues for preclosure are identified.

Consistent with Title 10 Code of Federal Regulations (CFR) Part 60 and a 1992 agreement with the DOE, staff-level issue resolution can be achieved during the prelicensing consultation period. Such resolution at the staff level however, would not preclude the issue being raised and considered during the licensing proceedings. The status of issue resolution at the staff level during prelicensing includes three categories: closed, closed pending further information, and open. An issue is considered closed if staff has no further questions regarding the model, approach, data, or other information pertaining to an issue and its subordinate subissues. Additionally, for an issue to be considered closed, it is required that the DOE approach and available supporting information acceptably address staff questions. No information beyond that currently available will likely be required for staff regulatory decisionmaking at the time of Construction Authorization (CA). An issue is considered closed pending further information if staff has no further questions regarding the model, approach, existing data, or other information pertaining to an issue and its subordinate subissues except that the staff is awaiting receipt of additional information from DOE and that the DOE approach and supporting information, together with the DOE specific commitment to provide additional information, acceptably address the staff's earlier questions. The commitment should be documented and should identify the information and DOE plan and schedule to provide the information. Further, an issue is considered closed pending further information if staff has identified additional information that must be provided for staff to have confidence that DOE has acceptably addressed staff questions. If the additional information has not been provided before the LA, the LA will include the remaining required information sufficient for staff to make determinations required by the regulations at the time of CA. Pertinent additional information could raise new questions or comments regarding a previously resolved issue. An issue is considered open if DOE has not yet acceptably addressed staff questions or committed to provide additional information regarding the model, approach, data, or other information pertaining to an issue or its subordinate subissues; additional information is required to produce an adequate basis for regulatory decision at the time of CA; or staff is identifying models, approach, data, and other information that DOE must provide for the staff to complete its prelicensing review and determine whether DOE has acceptably addressed staff questions. ~~Issue resolution at the staff level is achieved when the staff has no further questions or comments (i.e., open items) at a point in time, regarding how DOE's program is addressing an issue.~~ ~~There may be some cases where resolution at the staff~~

~~level may be limited to documenting a common understanding regarding differences in NRC's and DOE's points of view. Furthermore, Pertinent additional information could raise new questions or comments regarding a previously resolved issue~~.

An important interim objective of the staff efforts toward issue resolution is to provide DOE with feedback regarding issue resolution before the forthcoming Site Recommendation (SR) and LA. IRSRs are the primary mechanism that the staff will use to provide timely feedback to DOE regarding progress toward resolving the subissues composing ~~comprising~~ the KTIs. This report is the third revision of the IRSR on RDTME. This revision supersedes previous revisions of the IRSR. IRSRs include (i) ~~acceptance criteria~~ ACs ~~and review methods~~ for use in issue resolution and regulatory review, (ii) technical bases for the RDTME KTI ~~for the acceptance criteria and review methods~~, and (iii) ~~the~~ status of resolution including where the staff currently has no comments or questions, as well as where it does. Additional information is also contained in the technical documents, which summarize the significant technical work toward resolution of all KTIs during each reporting period. Finally, open meetings and technical exchanges with DOE provide opportunities to discuss issue resolution, identify areas of agreement and disagreement, and develop plans to resolve such disagreements.

~~In addition to providing feedback to DOE, the IRSRs guided staff's review of information included in DOE's Viability Assessment (VA). Also, the staff is currently using the IRSRs to develop a Yucca Mountain Review Plan (YMRP) for the DOE's repository LA. Current plans are to extract the acceptance criteria and review methods from the IRSRs and consolidate them in the YMRP. To avoid problems with potential inconsistencies between the YMRP and IRSRs, acceptance criteria and review methods may be removed from future versions of the IRSRs.~~

Revision 3 of the IRSR contains six chapters, including this Introduction in Chapter 1.0. Chapter 2.0 defines the KTI, all the related subissues, and the scope of the particular subissue or subissues addressed in the IRSR. Chapter 3.0 discusses the importance of the subissues to repository performance, including: (i) qualitative descriptions; (ii) reference to a Total System Performance Assessment (TSPA) flowdown diagram or to the preclosure performance objectives, whichever applicable; (iii) results of available sensitivity analyses; and (iv) relationship of postclosure related subissues to DOE's repository safety strategy (RSS) (i.e., DOE's approach to its safety case). Chapter 4.0 provides the ~~review methods and acceptance criteria, which indicate the~~ technical basis for resolution of the subissues and will be used by the staff in subsequent reviews of DOE's submittals. ~~These acceptance criteria are guidance for the staff and, indirectly, for DOE as well. The technical basis for the acceptance criteria are also included to further document the rationale for the staff decisions.~~ Chapter 5.0 concludes the report with the status of resolution, indicating those items resolved at the staff level and those items remaining open. These open items will be tracked by the staff, and resolution will be documented in future revisions of the IRSR. Finally, Chapter 6.0 includes a list of pertinent references.

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2 KEY TECHNICAL ISSUES AND SUBISSUES

2.1 PRIMARY ISSUES

The primary focus of the RDTME KTI is the review of design, construction, and operation of the geologic repository operations area (GROA) with respect to the preclosure and postclosure performance objectives, taking into consideration the long-term thermal-mechanical (TM) processes. Consideration of the time-dependent TM coupled response of a jointed rock mass is central to repository design and necessary for performance assessment (PA) at the Yucca Mountain (YM) site and consequently, the focus of both the preclosure and postclosure subissues of this KTI. In this revision, the preclosure related subissues have been expanded to include preclosure safety analysis (PCSA), retrievability, engineered barrier (EB) design, and repository design and operations.

Design for adequate postclosure performance requires an understanding of the TM response of the jointed rock mass during an anticipated compliance period of 10,000 years. Long-term TM response is anticipated to influence hydrological properties in the vicinity of the emplacement drifts, waste package (WP) degradation, radionuclide release within the engineered barrier system (EBS), performance of seals, and flow into and out of the emplacement drifts. Design for keeping the repository open for approximately 50–125 years (U.S. Department of Energy, 2000a) requires an understanding of TM response of the jointed rock mass as it influences drift, shaft, and ramp stability, and waste retrievability. ~~In this regard, it should be noted that DOE has indicated that it may implement an extended monitored geologic disposition program that could result in continued underground access for up to 300 years (U.S. Department of Energy, 1998a). In such a case, the TM effects on the stability of emplacement drifts could potentially be more severe. Consequently, an understanding on the TM response of the jointed rock mass becomes more important.~~

2.2 SUBISSUES

The RDTME KTI has been divided into subissues to facilitate addressing the breadth of technical concerns composing the preclosure and postclosure issues. It is expected that resolution of the subissues will lead to resolution of the issue. Some preclosure subissues address topics that are of regulatory concern but have regulatory guidance and precedence for resolving licensing concerns [e.g., implementation of radiation protections and as low as reasonably achievable (ALARA)], and some address topics of regulatory concern because they are, in general, at the limit of or beyond conventional engineering experience, and a lack of their resolution may jeopardize the safe preclosure operations ~~or effective postclosure performance~~ of the GROA, or both. The inclusion of the former in the IRSR is intended to facilitate the prelicensing consultation process and streamline the LA review process. The subissues related to postclosure performance address topics of regulatory concern and topics at the limit of or beyond conventional engineering experience. Topic resolution is important to ensure effective postclosure performance of the repository. ~~Although clearly interrelated, the subissues have been formulated to minimize redundancy. Alternatives, such as organizing the subissues by repository subsystem, would require, for example, seismic effects to be considered separately for the drifts, the seals, and the WPs, thus introducing extensive duplication. The four main subissues are stated in the next paragraph, with important considerations in each subissue noted parenthetically, as appropriate:~~ The main subissues for preclosure and postclosure are stated in the next two subsections.

2.2.1 Preclosure Subissues

Design Control Process—Implementation of an Effective Design Control Process Within the Overall Quality Assurance Program (QAP).

~~Each of the four subissues may, in turn, be addressed in terms of its principal components. For example,~~ Although implementation of an effective design control process permeates the entire DOE's high-level waste (HLW) repository program, it may be addressed in two components: the design control process employed for the design, construction, and operation of the exploratory studies facility (ESF) and the design control process used for the design, construction, and operation of the GROA. Each component must be consistent with DOE's QAP. Furthermore, to the extent that the ESF is incorporated into the repository, its design must fulfill the requirements for preclosure safety and postclosure performance.

Seismic Design Methodology—Design of the GROA for the Effects of Seismic Events and Direct Fault Disruption [including implications for drift stability, key aspects of emplacement configuration (i.e., fault offset distance, retrievability, and WP damage)].

The following three components have been identified for this subissue: (i) DOE's methodology to assess seismic and fault displacement hazard, (ii) DOE's seismic design methodology, and (iii) seismic and fault displacement inputs to the design and PAs. Note that DOE has elected to consider preclosure aspects of seismic design separate from those for postclosure, although the repository design eventually must be shown to meet both sets of requirements. While this IRSR deals with the second component (i.e., design methodology) and parts of the third component (i.e., design inputs), a companion IRSR within the Structural Deformation and Seismicity (SDS) KTI addresses the remaining components.

Preclosure Safety Analysis—Acceptability of PCSA for the GROA.

This subissue includes four components: (i) sufficiency of information on site and structures, systems, and components (SSCs) for conducting a PCSA; (ii) identification of hazards (both manmade and natural); (iii) identification of event sequences; and (iv) identification of SSCs important to safety including consequence estimation.

Design of GROA—Acceptability of GROA Design to Meet the Preclosure Performance Objectives.

This subissue includes four components: (i) design criteria and design bases, (ii) GROA design methodologies, (iii) design of surface facilities, and (iv) design of subsurface facilities. Although the seismic design methodology is a part of this subissue, it is not included in this subissue, but has been treated as a separate subissue for resolution. The fourth component of this subissue includes the TM effect on design of an underground facility component that was formerly under the TM Effect on Underground Facility Design and Performance Subissue in Revision 2 of this IRSR.

Retrievability—Preservation of Retrievability Option.

This subissue includes three components: (i) stability of underground opening and maintainability, (ii) feasibility and acceptability of retrieval plan, and (iii) temporary/permanent storage considerations.

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The first component ~~(stability of underground opening and maintainability)~~ may be resolved along with the fourth component (design of subsurface facilities) of the subissue related to design of GROA.

Design of EBS—Acceptability of EBS Design.

There is only one component to this subissue (i.e., acceptability of EBS design).

Performance Confirmation Program—Acceptability of the Performance Confirmation Program.

This subissue focuses on two areas: (i) feasibility of the performance confirmation program and (ii) design and performance verification during construction and operation. The second component will include aspects such as verification of geomechanical design criteria and design bases and EBS design.

Repository Operations—Acceptability of Repository Operations Related Programs.

The components related to this subissue will be developed and provided in the subsequent revision.

Permanent Closure, Decontamination, and Decommissioning—Acceptability of Permanent Closure, Decontamination, and Decommissioning Programs.

The components related to this subissue will be developed and provided in the subsequent revision.

2.2.2 Postclosure Subissues

Thermal-Mechanical Effects—Consideration of TM Effects on Underground Facility ~~Design and~~ Performance (including implications for drift stability, key aspects of emplacement configuration that may influence ~~thermal loads and associated thermomechanical effects, retrievability, and~~ the change in geometry and flow into and out of emplacement drifts ~~and fault setback distance~~).

This subissue—consideration of TM effects in and PAs—has two components: (i) ~~stability of the underground excavations with regard to safety during the preclosure period, waste retrievability, and potential adverse effects on emplaced wastes; (ii)~~ effect of seismically induced rockfall with respect to WP performance~~;~~ and (iii) changes of emplacement drift geometries and hydrological properties surrounding emplacement drifts due to TM perturbation of the rock mass. ~~All of these components have broad design and performance implications.~~

Design and Long-Term Contribution of Seals to Performance—Design and Long-Term Contribution of Repository Seals in Meeting the Postclosure Performance Objectives (including implications for inflow of water and release of radionuclides to the environment).

This subissue deals primarily with postclosure performance concerned with three main topics: (i) design and construction of seals (including material selection), (ii) long-term stability of seals and their components, and (iii) importance of seals in meeting the postclosure performance objectives. This subissue is considered closed because the proposed 10 CFR Part 63 provides no specific performance requirements for borehole, shaft, and ramp seals. ~~The RDTME and TSPA KTIs will jointly address these topics in the future~~. The design, construction, and material selection for seals will be reviewed in the design of GROA subissue.

3 IMPORTANCE OF ISSUES TO REPOSITORY PERFORMANCE

3.1 RELATIONSHIP OF THE POSTCLOSURE ISSUE WITH U.S. DEPARTMENT OF ENERGY REPOSITORY SAFETY STRATEGY

DOE ~~has~~ identified several principal factors of the postclosure safety case that it considers the most important factors affecting performance ~~formulated several hypotheses that, if confirmed, would demonstrate that waste can be contained and isolated~~ at the proposed YM site ~~for long periods of time~~ [~~DOE's~~ RSS, ~~dated January 2000 1998~~ (U.S. Department of Energy, 2000a ~~1998b~~)]. These principal factors ~~hypotheses~~ include:

(1) Seepage into ~~the emplacement~~ drifts ~~will be a fraction of the percolation flux~~;

(2) Solubility limits of dissolved radionuclide, ~~Bounds can be placed on thermally induced changes in seepage rates;~~

(3) Dilution of radionuclide concentration, ~~The amount of seepage that contacts WPs can be limited;~~

(4) Retardation of radionuclide migration in the unsaturated zone, ~~Engineered enhancements can extend the long period of containment of the inner barrier;~~

(5) Retardation of radionuclide migration in the saturated zone, ~~The amount of water that contacts waste can be limited;~~

(6) Performance of the drip shield, ~~The amount of movement of faults through the repository horizon will be too small to bring waste to the surface, and too small and infrequent to significantly impact containment during the next few thousand years;~~ and

(7) Performance of the WP barriers. ~~The severity of ground-motion expected in the repository horizon for tens of thousands of years will only slightly increase the amount of rockfall and drift collapse.~~

~~Testing these hypotheses~~ Addressing these principal factors and design assumptions requires an understanding of DOE's design and the effects of time-dependent TM coupled processes occurring ~~taking place~~ in the jointed rock mass on the GROA, including WPs ~~and seals~~. The relationships between the RDTME subissues and DOE's RSS are indicated in Table 1.

In addition to the ~~above~~ principal factors noted, ~~strategies~~, DOE assumed ~~has made an assumption~~ that the preclosure facilities (both surface and underground) can be designed to withstand the effects of vibratory ground-motion and fault displacements, and these facilities can be built and operated with minimal maintenance for ~~over~~ a period of 125 ~~150~~ years. DOE expects that the design actually provides for the repository to remain open for as long as 300 years after initial waste emplacement, if necessary (U.S. Department of Energy, 2000a) ~~It should be noted in this regard that DOE has indicated it may implement an extended monitored geologic disposition program that could result in continued underground access for up to 300 years (U.S. Department of Energy, 1998a).~~

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Table 1. Relationship Between Repository Design and Thermal-Mechanical Effects Key Technical Issue and the U.S. Department of Energy Repository Safety Strategy

	Hypotheses from Repository Safety Strategy						
	Seepage into Drifts	Solubility Limits	Dilution	Retardation in Unsaturated zone	Retardation in Saturated Zone	Drip Shield	Waste Package
Thermal-Mechanical Effects	X					X	X

3.2 IMPORTANCE TO PRECLOSURE PERFORMANCE

3.2.1 Design Control Process

The Quality Assurance (QA) requirements for the GROA are specified in the proposed YM site-specific regulation 10 CFR Part 63 (Subpart G). The QA requirements are based on the criteria of Appendix B of 10 CFR Part 50, and are applied to activities such as site characterization and repository design, construction, operations, decommissioning, and closure.

Appendix B includes 18 criteria that comprise an effective Quality Assurance Procedure (QAP). The application of criterion III for "design control" of repository SSCs is of particular interest here.

Design control is one of the most important of the 18 criteria because it defines the means by which the design organization will establish a design baseline, track changes with respect to the baseline, and document that regulatory requirements (RR)s related to design have been fulfilled. Meeting the QA requirements is an important aspect of demonstrating compliance with preclosure design criteria during the licensing review. Prelicensing reviews by NRC staff identified several weaknesses in DOE's QAP and design control process (Bernero, 1989). Also, in its own audit activities conducted in the past few years, many deficiencies were identified in areas such as data traceability, data management, software control, data qualification, and planning for scientific investigations (U.S. Department of Energy, ~~1998e,f,g,h,i,~~ 1998b,c,d,e;1999a). To address these deficiencies, DOE and its Management and Operating (M&O) contractor office are ~~in the process of~~ developing new administrative procedures to replace the existing QAP.

The staff considers implementation of an effective design control process by DOE to be an important programmatic issue with major preclosure performance implications. Consequently, NRC staff will continue to monitor the DOE's progress on implementing an effective design control process.

3.2.2 Seismic Design Methodology

The major preclosure performance objectives in the proposed 10 CFR Part 63 include (i) 10 CFR Part 20 requirements, (ii) numerical guides for design requirements, (iii) integrated safety analysis (ISA), (iv) retrievability, and (v) performance confirmation. DOE's designs for both the surface and underground facility SSCs must adequately address seismic effects and direct fault disruption to demonstrate compliance with these four performance objectives. Failure of any of the

~~structures, systems, and components~~ SSCs important to safety ~~(SSCIS)~~ due to vibratory ground-motion or direct fault displacement could severely affect GROA performance during the preclosure period of 100 to 150 years~~, with a possible extension to 300 years~~. Because of this long ~~operational~~ period for which there is no regulatory experience for meeting public and worker radiation safety requirements and because of the unusual requirements associated with retrievability of HLW, the seismic design is considered one of the most important factors affecting preclosure performance.

3.2.3 Preclosure Safety Analysis

The proposed 10 CFR Part 63 is a risk-informed and performance-based regulation. This regulation offers ample flexibility for DOE to demonstrate its case that the design of GROA meets preclosure and postclosure performance objectives. Consistent with this regulatory philosophy, 10 CFR Part 63 requires DOE to conduct a PCSA to provide evidence that the design meets preclosure performance objectives. The PCSA provides a systematic approach to determine the dose consequences to workers and the public. The conclusion of this analysis is a list of SSCs important to safety and safety controls that will be relied on for the repository design to meet the preclosure performance objectives. These identified safety controls may include administrative procedures. The reliability of the analysis results will depend on how well the analysis is executed. Consequently, the acceptability of the PCSA is considered important to determine compliance of DOE designs with preclosure performance.

3.2.4 Design of GROA

As discussed previously, the PCSA will help identify SSCs important to safety and safety controls in GROA. Also, the PCSA may produce design bases and design criteria for SSCs important to safety in addition to the design bases and design criteria used for the preliminary design. The design of the SSCs important to safety will need to be examined to ensure that all these design bases and design criteria are adequately included in the final design.

Consideration of TM effects on the underground facility is important in the design of an effective and efficient ventilation system, which, in turn, is important to meeting radiological safety objectives during the operational period. Thermal loads also have considerable effect on stability of the underground openings (Ahola, et al., 1996), which, in turn, affect ongoing access and monitoring, as well as waste retrievability, should that become necessary.

Furthermore, seismic effects will take place during the prolonged thermal environment. Depending on waste loading and other design features, the combined effect of thermal loads and seismic events may degrade the rock mass surrounding emplacement drifts. The rock mass may need to be reinforced with ground supports (e.g., concrete liners) to ensure operational and radiological safety of workers during the preclosure period. The condition of the rock mass will also influence retrievability, if support systems are not designed adequately to maintain stable openings. Consequently, the evaluation of TM effects is considered important to preclosure performance.

3.2.5 Retrievability

10 CFR Part 63 requires the GROA be designed to preserve the option of waste retrieval during the period when wastes are being emplaced and thereafter, until completion of a performance confirmation program and Commission review of the information obtained from such a program. The

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DOE retrieval operation, if required, is a reversal of the emplacement operation (U.S. Department of Energy, 1998f). This concept is valid only if (i) the emplacement drifts are not substantially deteriorated or collapsed and (ii) operation under the high WP temperature and radiation conditions will not adversely affect radiological safety of the workers. To date, this concept has not been demonstrated, and progress in this area needs to be monitored and reviewed.

3.2.6 Design of Engineered Barrier System/Subsystem

Performance of the WP barriers is one of the principal factors that DOE considers important in repository performance. To obtain reasonable assurance of the WP barrier performance, the EBS design needs to be thoroughly reviewed. If the EBS is not designed according to the design bases and design criteria necessary for the EBS to perform its intended function, such reasonable assurance may not be reached. The design of EBS is the focus for the preclosure concern. The performance of EBS is being dealt with in the Container Life and Source Term KTI.

3.2.7 Performance Confirmation Program

The proposed 10 CFR Part 63 requires the GROA be designed to permit implementation of a performance confirmation program. The results of this will be used by the NRC to determine if a permanent closure license can be granted. Consequently, review of the GROA design to ensure that a proposed performance confirmation program is feasible is essential. As promulgated by 10 CFR Part 63 (Subpart F), a performance confirmation program shall contain, among other things, plans to verify geomechanical design criteria, design bases, and the EBS design. These plans should to be implementable and can be completed before the end of retrieval option.

3.2.8 Repository Operations

As discussed in Section 3.2.3, administrative procedures or operational procedures may be identified as safety controls required for a particular facility design or operations to meet preclosure performance objectives. Consequently, the effectiveness of these administrative procedures is important to preclosure performance.

3.2.9 Permanent Closure, Decontamination, and Decommissioning

To be developed.

~~3.2.9 Design and Long-Term Contribution of Seals to Performance~~

~~This subissue is of primary concern to postclosure performance and does not affect preclosure radiological health and safety.~~

3.3 IMPORTANCE TO POSTCLOSURE PERFORMANCE

Figure 1 highlights the inputs from 4 of the 10 subissues of the RDTME KTI to postclosure PA. Subsections 3.3.1–3.3.4 describe the importance of the four subissues to postclosure performance.

3.3.1 Design Control Process

DOE's design control process plays a major role in demonstrating compliance with the design requirements and performance objectives. Although it may appear that the design requirements in the proposed rule are focused mainly on preclosure performance, many (especially for the underground facility) play a significant role in meeting postclosure performance requirements as well. Thus, the design control subissue dealing with traceability of design changes and flowdown from RRs is equally important to postclosure performance. The design control process subissue directly or indirectly affects all the Integrated Subissues (ISIs) under the engineered system shown in the flowdown diagram of TSPA (Figure 1).

3.3.2 Seismic Design Methodology

Design of the GROA for the effects of seismic events and direct fault disruption has several postclosure implications. The particular effects of seismic events and direct fault disruption, and consequently their importance to long-term performance, are design dependent. In general, the GROA design and the methodology used to develop that design must consider seismic effects on the WPs and other EBs and key aspects of the emplacement configuration, particularly fault offset distance.

The WPs, backfill, drip shields, and other elements of the EBS that DOE may choose to deploy, as well as the surrounding rock mass, will all be subjected to repeated episodes of seismic loading during the postclosure period. The potential effects on these engineered and natural components are complex functions of the presence and properties of the various barriers. For example, degradation of rock mass strength and consequent rockfall could be quite important if backfill is absent, but have relatively little effect if backfill is present. In contrast, the absence of backfill could tend to mitigate the effects of direct fault displacement because of the large free space available around the WP. Depending on design, backfill could act to more directly transfer load to the WPs, thus having a potentially adverse effect with respect to direct disruption by unidentified or random faults. The DOE design concept for backfill involves a partial filling with uncompacted material. The backfill constructed using this design could eliminate the concern that it may allow for load transfer to the WPs during faulting. These examples highlight the complexity of design considerations related to seismic effects and direct fault disruption. Furthermore, they point to the need for the PA methodology to be sufficiently flexible to address the performance implications of a range of possible designs.

In subsequent revisions of the IRSR, sensitivity studies employing the Total-system Performance Assessment (TPA) code (Mohanty and McCartin, 1998) will be used to evaluate the effects of these phenomena on repository performance. Processes such as rockfall and mechanical disruptions to WPs and other EBS components will be evaluated. The seismic design methodology subissue provides inputs to the "mechanical disruption of WP" ISI of the flowdown diagram for TSPA (Figure 1).

3.3.3 Thermal-Mechanical Effects

The potential influences of TM processes on underground design and performance during the postclosure period come into play with the early stages of construction. Construction methods employed for the underground facility, geometry of underground openings (shape, size, orientation, slopes, and waste emplacement configuration), distribution of thermal load, presence or absence of backfill, and quality and quantity of roof support are some of the parameters that may have a significant effect on the long-term performance of the repository (Ahola, et al., 1996). With the new Enhanced Design Alternative No. II (EDA-II) option, the temperature experienced in the rock-mass surrounding the emplacement drifts may decrease somewhat due to the design option of a continuous ventilation for about 50 years. Consequently, deterioration of the emplacement drifts may be reduced. However, the effect of such change needs to be examined. As waste emplacement proceeds, TM effects begin to manifest in the EBS and surrounding rock mass. TM stresses resulting from excavation-induced changes and heat produced by the WPs will be superimposed on the existing *in situ* lithologic stresses throughout the postclosure period. TM effects combined with seismic loads may affect drift stability, particularly with unbackfilled designs. The effects may also cause rock to fall from the rock mass surrounding the emplacement drifts. Potential rockfall is a concern that could affect WP and drip shield performance.

In addition, the effect of TM interactions on the hydrologic properties of the surrounding rock mass must be considered in design and PA, given that ground supports (including concrete liners) are currently designed to meet the requirements for only preclosure performance. In assessing the postclosure total system performance, DOE made it clear that the effectiveness of the ground support system will not be considered in the assessment. In other words, the ground support system is assumed to lose its function after closure. This approach is clearly conservative. However, by taking this approach, the potential effects on postclosure performance of deterioration of the rock mass surrounding emplacement drifts will need to be evaluated.

Current understanding is that, after the emplacement of waste, the drifts will be subjected to a sustained high state of stress for a long time (Ahola, et al., 1996). This high state of stress results mainly from thermal loading and may lead to significant deterioration of the rock mass surrounding the emplacement drifts. Subsequent collapse of the rock mass may eventually occur due to either long-term deterioration or seismic activities. Such collapse will obviously change the geometry of the emplacement drifts and, consequently, change the capture area for seepage in the vicinity of the emplacement drifts. The collapse will also affect the hydrologic properties in the vicinity, and local changes in hydrologic properties are likely to be large. It is obvious that these changes will affect the WP environment. Accordingly, an understanding of TM effects is important to the staff's independent evaluation of DOE's PA. Thus, the TM effects subissue provides direct inputs to all ISIs included in the EBS (Figure 1).

~~3.3.4 Design and Long-Term Contribution of Seals to Performance~~

~~Although no specific design or performance requirements are included in the proposed rule for borehole and shaft seals, sealing of all manmade openings will, nevertheless, be a matter of practical necessity. It has not been established by DOE that the contribution of seals to overall performance is insignificant. Some of the available results of NRC's TPA suggest that such contributions are small (inference based on limited analysis of unsealed open borehole scenario).[1] Staff has decided to keep this subissue open until the next revision of the IRSR when more definitive results are expected to be available to the staff. The seal design subissue is expected to provide inputs to the "quantity and chemistry of water contacting waste form ISI in the flowdown diagram of PA (Figure 1).~~

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[1]~~McCartin, T.J., and M.P. Lee, Preliminary Performance Based Analyses Relevant to Dose-Based Performance Measures for a Proposed Geologic Repository at Yucca Mountain, U.S. Nuclear Regulatory Commission, NUREG–1538, 1999 [in press].~~

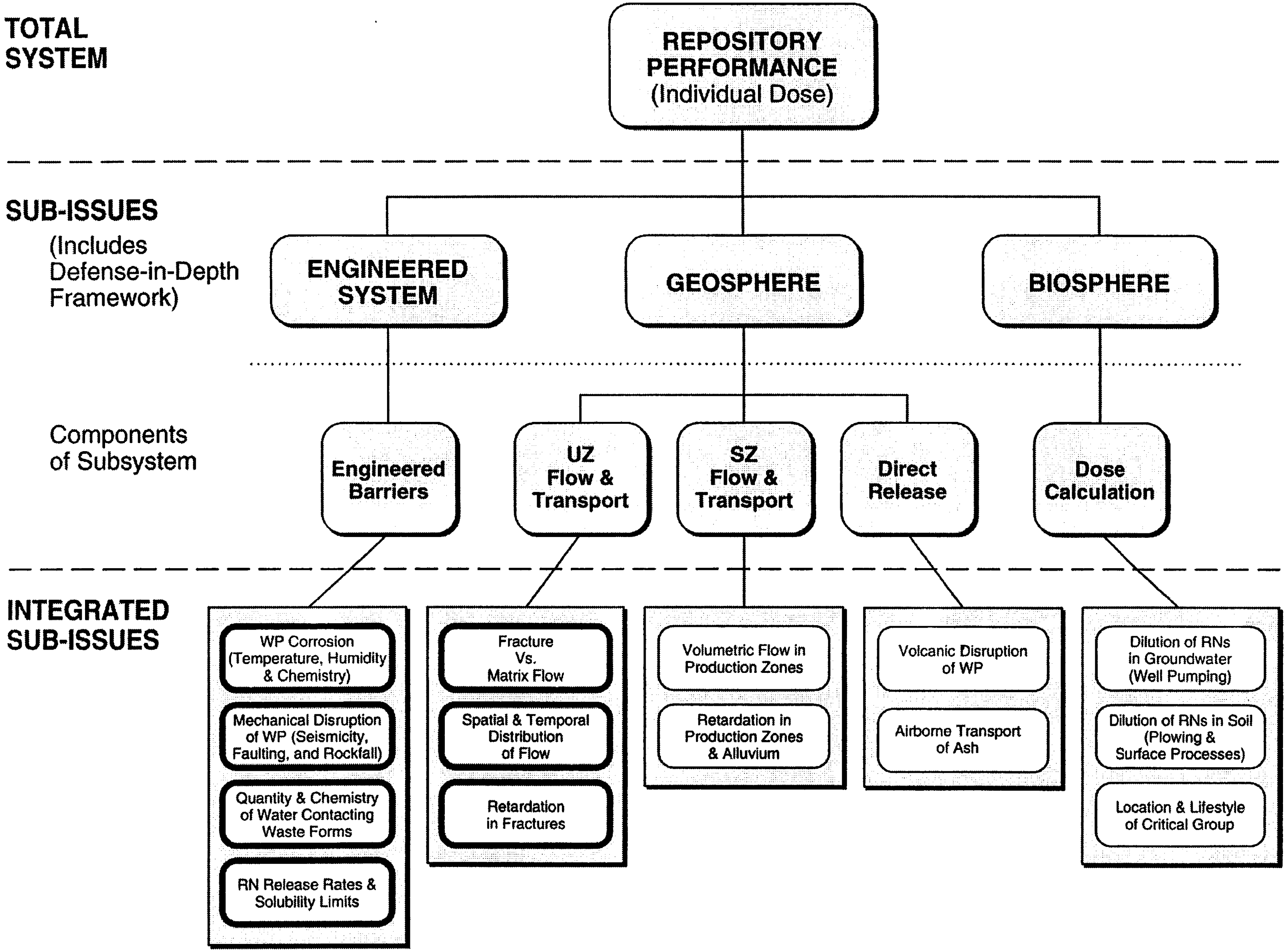

Figure 1. Inputs from repository design thermal-mechanical engineering subissues to postclosure performance

4 ~~REVIEW METHODS, ACCEPTANCE CRITERIA, AND~~ TECHNICAL BASES FOR SUBISSUES

~~Review methods and acceptance criteria for each of the four main subissues are presented and discussed in Sections 4.1 through 4.4. These criteria will also be used in reviewing DOE's VA and in evaluating the LA to ensure that the methods proposed by DOE have been properly implemented and the resulting design meets the pertinent RRs. The last subsection of each section~~ In this revision (Revision 3), the ACs and review methods for evaluating DOE's approach to abstracting RDTME KTI, and evaluating DOE's analysis of RDTME KTI in a TSPA have been removed. These will be transferred to the YMRP. This section contains only a discussion of the technical bases for the subissues that are related to the RDTME KTI. ~~acceptance criteria and review methods. Included are This section includes descriptions of DOE's approach, summaries of staff evaluations of DOE's approach, and results of independent work conducted by the staff.~~ The discussions related to concrete behavior are deleted since the use of concrete liners as the primary means for ground support is no longer an option in the design. Also, the structure of this section is modified to include the preclosure related issues that are added in this revision. The discussions for post closure subissues that are essentially the same as those presented in the RDTME KTI IRSR Revision 2. Technical bases for the newly added subissues related to preclosure are not included in this revision and may be added in the future. These newly added preclosure related subissues include: (i) acceptability of PCSA for the GROA; (ii) acceptability of GROA design, except for underground facility, to meet the preclosure performance objectives; (iii) preservation of retrievability option; (iv) acceptability of EBS design; (v) acceptability of the performance confirmation program; and (vi) repository operations.

4.1 PRECLOSURE RELATED ISSUES

4.1.1 Implementation of an Effective Design Control Process Within the Overall Quality Assurance Program

4.1.1.1 Background

The focus of this component of the RDTME IRSR is on the staff evaluation of DOE's implementation of design control process for design, construction, and operation of the ESF. According to the proposed 10 CFR Part 63 (Subpart G) QAP requirement, QA comprises all those planned and systematic actions necessary to provide adequate confidence that the geologic repository and its subsystems or components will perform satisfactorily in service. Section 63.143 requires DOE to implement a QAP based on the criteria of Appendix B of 10 CFR Part 50. The YM-specific regulation currently under development is anticipated to retain these or similar QA provisions. As a result of past DOE NRC interactions in the area of ESF/GROA design and associated QA concerns, NRC had identified serious deficiencies in DOE's design control process (Bernero, 1989).

It has long been recognized by NRC that it is impractical for the staff to conduct a thorough review of all DOE's design documents given the limited resources at NRC's disposal. Consequently, NRC has utilized a "vertical slice" (audit) approach in which the staff selectively reviews some important aspects of DOE's ESF/GROA design packages and observes DOE's internal reviews, looking for trends that can be used as examples to provide feedback and guidance to DOE. NRC has paid particular attention to the design of the ESF because it will eventually become a part of the GROA if the YM site is found to be suitable. Therefore, many RRs applicable to GROA would also be applicable to the ESF. In the past, DOE found it difficult to demonstrate to NRC the traceability of RRs and to provide the necessary documentary evidence to clearly show that all applicable requirements were indeed being applied to various design components. In order to thoroughly examine this issue, NRC conducted a phased in-field verification in 1995 to evaluate DOE's design control process.

There were a number of open items that resulted from this in-field verification and the past NRC-DOE interactions and from NRC's review of ESF-GROA design documents related to this subissue. All these open items are being monitored under the RDTME KTI, and a number of them were closed during FY1996 as a result of staff reviews and interactions with DOE. Some of the main FY1996 activities conducted to help resolve the remaining open items and subissues were reported under Section 7.3.2 of "NRC's High-Level Radioactive Waste Program Annual Progress Report for Fiscal Year 1996" (Center for Nuclear Waste Regulatory Analyses, 1997).

Past DOE audits identified severe deficiencies regarding the design control process (U.S. Department of Energy, 1998a,b,c,d,e; 1999a). An extensive effort is currently being made to correct these deficiencies. It is clear that to ensure an effective implementation of the design control process, constant monitoring by DOE of the progress will be required.

~~4.1.2 Review Methods~~

~~The review method for the design control process subissue during the prelicensing consultations consists of a combination of staff activities and DOE/NRC interactions. These activities and interactions include: (i) selective "vertical slice" review of design documents; (ii) review of the site characterization plan (SCP) and any test data gathered; (iii) attending meetings with DOE's design teams; (iv) observing DOE's audits and surveillances of its contractors; and (v) conducting independent audits, surveillances, and in-field verifications on focused topics. In addition, appropriate sections of the SR and LA will be reviewed using the acceptance criteria developed in this section of the IRSR to document the acceptability of DOE's design control process on an ongoing basis. The staff review of DOE's design control process will continue during repository construction and operation until final decommissioning of the facilities.~~

~~4.1.3 Acceptance Criteria~~

~~The staff will find DOE's design control process to be acceptable if the following generic criteria are satisfied:~~

~~Acceptance Criterion 1:~~ ~~The applicable RRs are identified;~~

~~Acceptance Criterion 2:~~ ~~The design bases associated with the RRs are defined;~~

~~Acceptance Criterion 3:~~ ~~The RRs of Acceptance Criterion 1 and the design bases of Acceptance Criterion 2 are appropriately translated into specifications, drawings, procedures, and instructions;~~

~~Acceptance Criterion 4:~~ ~~Appropriate quality standards are specified in the design documents;~~

~~Acceptance Criterion 5:~~ ~~Any deviations from the standards specified under Acceptance Criterion 4 are properly controlled; documented and justified;~~

~~Acceptance Criterion 6:~~ ~~Measures are established for selection of materials, parts, equipment, and processes that are essential to functions of SSCs that are important to safety and waste containment and isolation;~~

~~Acceptance Criterion 7:~~ ~~Design interfaces are identified, controlled, and appropriately coordinated among participating design organizations;~~

~~Acceptance Criterion 8:~~ ~~Procedures are established for review, approval, release, distribution, and revision of documents involving design interfaces;~~

~~Acceptance Criterion 9:~~ ~~Measures are established for verifying or checking the accuracy of design calculations (e.g., performing design reviews using alternate or simplified calculational methods);~~

~~Acceptance Criterion 10:~~ ~~If testing is employed for verification of design adequacy for its intended service life, the testing is conducted under the most adverse conditions;~~

~~Acceptance Criterion 11:~~ ~~The design verification is conducted by independent and qualified professionals who did not participate in the original design efforts; and~~

~~Acceptance Criterion 12:~~ ~~In addition to being applied to the original design, the design control process is also applied to design changes and to field changes, and these changes are properly documented.~~

4.1.1.2 Technical Bases for Review

The review of DOE's design control process has been molded by a number of past and continuing review activities, interactions, and correspondence on this subissue. It is important to keep in mind the historical background drawn from repository prelicensing interactions and regulations of similar nuclear facilities that has provided additional technical and review bases to the staff. Some of the important reviews, activities, interactions, and correspondence are described below.

ESF—GROA Relationship

The overall premise of staff reviews of DOE's design control process for the ESF is that the ESF will eventually become a part of the GROA if the YM site is found to be suitable for the disposal of HLW. Therefore, it is important that all site characterization activities, including the design, construction, and operation of the ESF be carried out in such a way that all RRs applicable to the GROA be considered applicable to ESF, unless it can be shown to be otherwise. The staff has used two main bases for judging the ESF construction and other testing activities: (i) design, construction, and operation of the ESF should not result in unmitigable impacts adversely affecting long-term waste containment of the EBS and isolation capabilities of the site; and (ii) design, construction, and operation of the ESF should not preclude gathering necessary site characterization information. In addition, the staff specifically looks for site characterization activities that might have a potential for test-to-test, construction-to-test, or construction-to-construction interference and, thus, adversely affect containment and isolation or DOE's ability to gather crucial data.

The staff has effectively applied these criteria to judge the adequacy of DOE's Site Characterization Plan (SCP) and various study plans (SPs) at different stages of the program and raised a number of objections, comments, and questions that have significantly affected DOE's program over the years. In response, DOE has developed a process that requires a "Determination-of-Importance-Evaluation" (DIE) at important stages of ESF construction and testing. Each DIE consists of a "Test-Interference-Evaluation" and a "Waste-Isolation-Evaluation," the results of which are used to make crucial decisions before major site activities are initiated. The staff may use the results of DIE reviews as bases for selecting certain design/site characterization activities for focused review.

Regulatory Basis

As mentioned earlier, Appendix B to 10 CFR Part 50 (Quality Assurance Criteria for Nuclear Power Plants adopted by the proposed 10 CFR Part 63) provides the underpinning technical/regulatory basis for the staff review methods and AC. Specifically, Criterion III of the 18 criteria described in Appendix B has been restructured into the specific criteria (listed under Section 4.1.3) for reviewing DOE's design control process. These criteria will continue to be used to review DOE's design control process employed during the GROA design, construction, and operation.

Staff Technical Positions

Additional bases are found in the staff technical positions (STPs) on: (i) Items and activities in the "HLW Geologic Repository Program Subject to QA Requirements" (NUREG–1318, Duncan, et al., 1988); and (ii) "Regulatory Considerations in the Design and Construction of the Exploratory Shaft Facility" [NUREG–1439 (Gupta, et al., 1991)].

NUREG–1318 (Duncan et al., 1988) provides guidance on approaches acceptable to the staff for identifying items and activities subject to QA in the HLW repository program for preclosure and postclosure phases. NUREG–1439 (Gupta et al., 1991) provides guidance on identifying RRs applicable to the ESF and describes an approach acceptable to the staff for implementation of proposed applicable 10 CFR Part 63 RRs. [Note: NUREG–1318 (Duncan et al., 1988) was developed using 10 CFR Part 60 and thus needs updating. However, the underlying principles of the STP still apply.]

QA Audits and Surveillances

From time to time, DOE conducts QA audits and surveillance of its contractors and subcontractors. The staff is invited to observe such audits and provide feedback. Over the years, the staff has chosen to observe numerous DOE audits and written Audit Observation Reports in which the staff has documented either its satisfaction or concerns related to particular issues. The staff has also conducted a limited number of independent audits of DOE and/or its supporting organizations and documented the results of such audits in trip/audit reports. Such reports and reviews are used as the bases for making generalized observations on the overall effectiveness of DOE's QAP.

Site Characterization Review

The staff has conducted detailed technical and programmatic reviews of DOE's SCP and several associated SPs. Review comments have been documented in NRC's documents, such as the Site Characterization Analysis (SCA) and SP reviews. The results of such reviews have been used by the staff as bases for identifying concerns related to DOE's QA and technical programs.

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Design Reviews

The staff has participated as observers during DOE's design reviews in which the participating design organizations coordinate their individual efforts and integrate different aspects of ESF and GROA design. Such design reviews used to take place at approximately the middle of a major effort (known as 50-percent design review) and toward the end (termed 90-percent design review). Depending on the design topic and the availability of resources, the staff has participated as observers and provided feedback to DOE on various aspects of ESF design. The staff has also, on a limited basis, conducted independent design reviews of specific design packages and documented the results of each review. For example, in accordance with NRC's "vertical slice approach," the staff has reviewed selected portions of ESF Design Requirements (ESFDRs), and various ESF Design Packages, such as Packages 2b and 2c, and DOE's Regulatory Compliance Review Report (RCRR). The results of the RCRR were transmitted to DOE on December 14, 1995 (Nataraja et al., 1995). The results of such observations and limited independent reviews have been used as technical bases for staff conclusions on the effectiveness of DOE's designs and design control process.

Meetings

DOE and NRC conduct several technical meetings on topics of mutual interest under the existing prelicensing agreement (Shelor, 1993). DOE makes presentations on several aspects of QA and design, and the staff provides feedback to DOE during or after such meetings. The meeting minutes document issues and concerns that are also used as bases for staff positions on the effectiveness of DOE's program. Appendix 7 meetings are effectively used by the staff to conduct free and open discussions on topics of mutual interest. Although no formal meeting minutes are kept of Appendix 7 meetings, the information is used as technical bases for staff conclusions regarding DOE's design control process.

On-Site Representatives' Inputs

NRC's on-site representatives (OSRs) attend a number of DOE's technical and management meetings and observe day-to-day proceedings at DOE and its M&O contractor offices. They also have access to site activities on a regular basis. They can acquire and review DOE's documents that are still under preparation and, thus, can provide feedback to DOE on a real-time basis. The OSRs reports are also used as bases for staff conclusions on DOE's design control process.

Site Visits and In-Field Verification

The staff visits the ESF periodically and observes construction and testing activities, reports on important matters, and provides written feedback in its trip reports. The staff has also developed a procedure for conducting in-field verification of DOE activities (such activities may include design, construction, or operation). These procedures are part of the HLW Division Manual, Chapter 0330 (U.S. Nuclear Regulatory Commission, 1995a). The primary objective of the in-field verification is to determine if DOE is acceptably implementing the site characterization program and constructing and operating the ESF. The first in-field verification of DOE's program was conducted in phases starting in April 1995, and the results were documented in the in-field verification report [NRC–VR–95–1, (U.S. Nuclear Regulatory Commission, 1995b)]. This report documents the objective evidence and technical bases for staff conclusions on the adequacy of ESF design and DOE's design control process.

Relevant U.S. Department of Energy/U.S. Nuclear Regulatory Commission Correspondence and Interactions

The staff has actively pursued the design control process subissue beginning with NRC's objection to DOE's SCP, specifically, the ESF Title-I design control process. The extensive correspondence and exchanges between NRC and DOE that have provided additional bases for the review methods and review criteria and positions taken by the staff on this subissue are listed in the appendix.

Summary of Technical Bases

The subissue regarding DOE's design control process is a very important and highly complex one that historically has played an important role in helping NRC staff monitor DOE's site characterization program. Staff activities at the management, programmatic, and technical levels have been used to evaluate the adequacy of the ESF design and the design control process in the context of the overall GROA design and DOE's QAP. The staff will continue to monitor DOE's program by conducting focused reviews of selected vertical slices of GROA design documents prepared by DOE. The historical background that can be traced in the various DOE/NRC correspondences and interaction minutes will continue to serve as bases for future staff reviews.

4.1.1.3 U.S. Department of Energy's Design Control Process for the Geologic Repository Operations Area

Selective Review and Results

To evaluate DOE's progress in implementing the design control process for the GROA, an Appendix 7 meeting was held at the M&O contractor's office during the week of June 8, 1998. The purposes of the meeting were to examine a number of design documents at different stages of preparation, and to select a limited number of them for comparison with the AC listed in Section 4.1.3 of the RDTME KTI IRSR, Revision 2.

Six documents considered to be both adequately developed and sufficiently representative of those describing underground facility systems and surface facility systems were identified for further review. The six documents reviewed in detail were: (i) Overall Development and Emplacement Ventilation System, (ii) Repository Subsurface Layout Configuration Analysis, (iii) Repository Ventilation System, (iv) Waste Handling Systems Configuration Analysis, (v) Site Gas/Liquid Systems Technical Report, and (vi) Surface Nuclear Facilities HVAC Analysis. These documents were developed using the design baseline included in the TSPA-Viability Assessment (VA).

The M&O Contractor also provided the following additional documents to facilitate the review: (i) a current version of the Controlled Design Assumptions (CDA) Document; (ii) a matrix which interrelates VA product documents with the CDA; (iii) Repository Design Requirements Document (U.S. Department of Energy, 1994a); and (iv) Engineered Barrier Design Requirements Document (U.S. Department of Energy, 1994b). These documents were used for comparison with design control process criteria.

For each of the six systems designated for review, the relevant technical documents were examined against the AC in Section 4.1.3 of the IRSR Revision 2. Where specific design criteria and assumptions were cited, cross-checks between documents were made to verify source documentation. The document citations for sections dealing with design criteria and design

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assumptions were also verified to relate to the topic discussed therein. Each reference section was crosschecked for each individual use of a reference to verify that the appropriate document was cited.

Staff verified that the checking processes are autonomous, and that the individuals performing design system checks were both independent and technically qualified. The staff found and examined evidence that verification records were maintained by the M&O contractor. As a result of the Appendix 7 meeting and the document review by staff, it was concluded that DOE is currently maintaining adequate oversight of the design control process. However, there is one area of concern, that being the control of changes to an original design and proper documentation of such changes.

Comparison with Acceptance Criteria

During the June 1998 meeting, the 12 ACs discussed in Section 4.1.3 of the IRSR Revision 2 were used by NRC staff as the guide on which to base any conclusions. Each of the M&O sources was checked for discrepancies dealing with the 12 criteria. Results of comparison with each criterion are listed below to illustrate the review process used by the staff. The majority of the items reviewed showed general agreement with the review criteria. Total agreement with all the review criteria, however, could not be established because of the evolving nature of the GROA design.

As mentioned previously, the documents evaluated here were developed using the TSPA-VA baseline design. From the middle of 1998, the M&O contractor conducted an extensive evaluation of repository design alternatives. The objective of the evaluation was to develop an enhanced design for the LA. At the end of the process, an enhanced design alternative was identified and recommended by the M&O contractor for DOE consideration (CRWMS M&O, 1999a). If this alternative is selected by DOE as the baseline for the LA, the previously mentioned documents will have to be reevaluated.

AC1: <u>The applicable RRs are identified</u>: In every system document reviewed, the RRs were listed in Section 4.4 of the respective documents (CRWMS M&O, 1997b,c,d,e,f, 1998a).

AC2: <u>The design bases associated with the RRs are defined</u>: In Section 4.2.1 of the Surface Nuclear Facilities HVAC Analysis, "The WHB and WTB ventilation systems are to accomplish the following confinement functions in accordance with 10 CFR 60.131" [waste handling building (WHB) and waste treatment building (WTB)]. The analysis then describes the functions the ventilation system will accomplish (e.g., minimizing the spread of radioactive material in the air) (CRWMS M&O, 1997e).

AC3: <u>The RRs of AC 1 and the design bases of AC2 are appropriately translated into specifications, drawings, procedures, and instructions</u>: It should be noted that some of the data used in the design are yet to be confirmed, or are to be used only to determine space and size requirements. Some examples of what has been done to date for each category of interest include:

a. Specifications: Using the 85 metric ton of uranium (MTU) value for the spent nuclear fuel (SNF), the drift spacing value of 28 m was derived (CRWMS M&O, 1997c).

b. Drawings: In the Repository Subsurface Layout Configuration Analysis, Figure 7-2 shows the repository layout with respect to geological boundaries, and incorporates its Criterion 4.2.3 (Deleterious Rock Movement).

c. Procedures: Since the design is still in early stages, procedures are yet to be developed.

d. Instructions: Section 7.3 of the proposed wet waste handling system description of the Waste Handling Systems Configuration Analysis implements the need to minimize exposure to personnel.

AC4: Appropriate quality standards are specified in the design documents: Every design/technical document reviewed has a QA Section (Section 2) that lists the governing QA documents. Section 4 of the system analyses lists the assumptions, criteria, design parameters, and codes and standards that will form the basis for the document (CRWMS M&O, 1997b,c,d,e,f, 1998a).

AC5: Any deviations from the standards specified under AC 4 are controlled properly: The use of the terms TBV (to be verified) and TBD (to be determined) is stated in Section 2 of all the technical documents; these are used when a specific value is unknown (i.e., cannot be measured at this time) or when the values are preliminary in nature (CRWMS M&O, 1997b,c,d,e,f, 1998a). There are instances where the (assumed) values differ from those listed in the standards, but this is because the current standards were revised after the design documents were finalized. The future revisions are expected to reconcile the differences.

AC6: Measures are established for selection of materials, parts, equipment, and processes that are essential to functions of SSCs that are important to safety and waste containment and isolation: Section 4.2.9 in Overall Development and Emplacement Ventilation Systems states, "Subsurface repository operation involves continuous ventilation of repository airways until closure. To provide radiological protection to repository workers, and to have a positive control on potential radiological exposure to as low as is reasonably achievable, the subsurface repository ventilation design will include isolated return airways, isolation barriers and separate ventilation between emplacement and development." In Section 7.4.8 of the document, the general equipment and processes which achieve compliance with Section 4.2.9 are described, including the maintenance of a pressure differential, the use of ventilation barriers, and the standards for a primary ventilation fan. Materials and specific parts and equipment are not discussed due to the early stages of the design.

AC7: Design interfaces are identified, controlled and appropriately coordinated among participating design organizations: DOE has developed QAP NLP-3-34, Mined Geological Disposal System (MGDS) Interface Control Documentation. DOE has defined four levels of MGDS interface, as described in its Configuration Management Plan. The four interface levels are designated A, B, C, and D. Levels A and B are *external* to a system, and levels C and D are *internal* (Ashlock, 1997):

Level A—Interfaces between the (CRWMS) and other external systems (e.g., waste producers).
Level B—Interfaces between the CRWMS elements (Repository, Transportation, Storage, and Waste Acceptance).
Level C—Interfaces within an element (MGDS) and between its systems (e.g., Surface Repository, Subsurface Repository, WP, and ESF configuration items).
Level D—Interfaces between subsystems internal to a MGDS system (Ashlock, 1997).

The interface control documents meet the standards of this criterion by maintaining guidelines for the interfacing organizations to follow.

AC8: Procedures are established for review, approval, release, distribution, and revision of documents involving design interfaces: M&O's QAP NLP–3–34 provides instructions for the management of Level C interfaces on the MGDS. During the Appendix 7 meeting, NRC staff were informed of the following: until such time as formal guidelines for the management of Level A and B interfaces are approved by DOE, a procedure similar to that of NLP–3–34 is being used for Level A and B interfaces (it is expected that formal written procedures similar to NLP–3–34 will be in place in the near future for Level A and B interfaces); Level D interfaces, which do not follow management by procedure NLP–3–34, are controlled by a process which requires formal design review by the parties potentially affected by the design in question (Ashlock, 1997).

AC9: Measures are established for verifying or checking the accuracy of design calculations (e.g., performing design reviews using alternate or simplified calculational methods): The M&O established Product Checking Group (PCG) verifies the design calculations through independent reviewers. The PCG is discussed in-depth under AC 11.

AC10: If testing is employed for verification of design adequacy, the testing is conducted under the most adverse conditions anticipated: The application of this criterion cannot be verified at this time since the systems are in design stages only. Application of this criterion will be verified and documented in future revisions to this IRSR.

AC11: The design verification is conducted by independent and qualified professionals who did not participate in the original design efforts: To address the issue of reviewer independence, the M&O contractor established an independent PCG. The PCG verifies the independence of reviewers for: (i) drawings, (ii) specifications, (iii) analyses, (iv) system description documents, (v) interface documents, and (vi) reports. By maintaining a database for checking, confirmation of the independence of reviewers, receipt and return dates, and back check dates can now be confirmed with relative ease (CRWMS M&O, 1998b).

The product checking procedures are identified in the Design Guidelines Manual (DGM) Section 10 (CRWMS M&O, 1997g). The DGM identifies the following topics:

1. Assembly of Engineering Documents for Discipline Check
2. Selection of a Checker
3. Tracking Checked Engineering Documents
4. Discipline Check of Input Lists and Engineering Documents
5. Final Check
6. Checking and Internal Processing of Engineering Change Requests
7. Checklists

AC12: In addition to being applied to the original design, the design control process is also applied to design changes and to field changes, and the changes are documented properly: In Section 4.3.6 of IRSR Revision 2, Overall Development and Emplacement Ventilation Systems that was checked and approved on September 19, 1997, it is stated, "Backfill in emplacement drifts is not required." Yet in the referenced CDA Key 046, dated May 8, 1997, this assumption has been withdrawn (CRWMS M&O, 1998c). This indication that the design uses the earlier assumption (CRWMS M&O, 1996a) shows a potential loss of control with respect to changes in, and evaluation of, design inputs. Similar examples were found at least once in all of the design systems reviewed by the staff. The M&O staff explained that the lapse was due to revisions and Document Change Notices in the design input documents, specifically the CDA. The future revisions to GROA designs are expected to reconcile the differences.

4.1.2 Design of the Geologic Repository Operations Area for the Effects of Seismic Events and Direct Fault Disruption

4.1.2.1 Background

This version of the RDTME IRSR focuses on design of the GROA for the effects of seismic events and direct fault disruption. To date, DOE has addressed the first two components of this subissue (i.e., hazard assessment methodology and seismic design methodology). Furthermore, DOE has limited the scope of its topical report (TR) on design methodology to preclosure aspects. Consequently, the following discussion is similarly limited to preclosure aspects. The third component of this subissue will be addressed in future revisions of the RDTME and other companion IRSRs.

~~4.2.2 Review Methods~~

~~The review method for the seismic design methodology consists of reviewing DOE's TR on seismic design methodology and the associated references using the criteria developed in this IRSR. In addition, meetings are used to discuss and clarify various staff comments and DOE's responses. The adequacy of the inputs to design and PAs will be evaluated using appropriate acceptance criteria during the review of DOE's third and final TR. DOE's implementation of the design methodology will be monitored during the LA review.~~

~~4.2.3 Acceptance Criteria~~

~~The staff will find the TR adequate for further review if, during an initial acceptance review of TR-2, the following acceptance criteria are satisfied:~~

~~Acceptance Criterion 1:~~ ~~The TR addresses all important-to-safety (or important-to-waste-isolation) topics pertaining to the scope of the TR.~~

~~Acceptance Criterion 2:~~ ~~The subject of the TR is currently undergoing prelicensing evaluation.~~

~~Acceptance Criterion 3:~~ ~~NRC's acceptance of the TR would result in increased efficiencies in the staff review of DOE's LA.~~

~~Acceptance Criterion 4:~~ ~~The TR contains complete and detailed information on each element of the scope of the report.~~

~~The staff will find the methodology proposed in the TR adequate for use in ESF and repository design if the following criteria are satisfied:~~

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~~Acceptance Criterion 1:~~ ~~Sufficient technical reasoning is provided for the proposed methodology.~~

~~Acceptance Criterion 2:~~ ~~If available, documented case histories of the performance of SSCIS designed using the proposed methodology are presented in the TR. In the absence of documented case histories, no serious problems have been identified that would impede applying the methodology.~~

~~Acceptance Criterion 3:~~ ~~The proposed methodology does not contradict established methodologies and principles tested and documented in the LAs for nuclear power plants and independent spent fuel storage installations.~~

~~Acceptance Criterion 4:~~ ~~Uncertainties associated with the proposed methodology that would significantly affect or impede the repository design process and development of inputs to PAs have been considered adequately.~~

~~Acceptance Criterion 5:~~ ~~The various steps involved in the proposed methodology are transparent.~~

~~Acceptance Criterion 6:~~ ~~To the extent that the proposed design methodology depends on site-specific test data, such data are available now, are being gathered now, or there are plans for gathering such data during site characterization and before submittal of the LA.~~

~~Acceptance Criterion 7:~~ ~~To the extent that the proposed methodology depends on analytical/computer models, such models have been verified, calibrated, and validated to the extent practical, or there are plans for such activities prior to LA submittal or during the performance confirmation period, as appropriate.~~

~~Acceptance Criterion 8:~~ ~~Any major assumptions or limitations to the proposed methodology are identified, and the implications regarding design and performance are discussed in the TR.~~

~~Acceptance Criterion 9:~~ ~~The contents of TR-2 are consistent with the contents of TR-1 and, taken together, the two TRs support the development of inputs for design and PAs, as described in TR-3.~~

4.1.2.2 Technical Bases for Review

Seismic Design Topical Report Approach

Among several approaches to resolving potential licensing issues is the use of TRs. Historically, the purpose of NRC's TR program has been to provide a procedure whereby licensees may submit reports on specific important-to-safety subjects to NRC staff and have them reviewed independently of any construction permit or operating license review. The benefits resulting from this program are a minimization of duplication of time and effort that the applicants and NRC staff spend on these subjects and improved efficiencies in NRC's reviews.

NRC staff has documented in its TR Review Plan (RP) (U.S. Nuclear Regulatory Commission, 1994) the conditions under which DOE can prepare a TR on a given issue (such as a design or analytical method) and submit it for staff review. Under this TR process, DOE submits an annotated outline (AO) of the proposed TR to get agreement of the staff on the scope and content of the report before spending significant resources. Subsequently, the completed TR is submitted for staff review that takes place in two stages, namely, an acceptance review and a detailed, independent technical review by the staff. The acceptance review in which the staff checks the general adequacy of the TR using the four criteria listed under Section 4.2.3 of the RDTME KTI IRSR Revision 2. The detailed technical review is conducted using the nine criteria listed in the same section. Considerable discussion with DOE may be required before the staff finally documents the status of the resolution of a particular issue or a subissue.

U.S. Department of Energy/U.S. Nuclear Regulatory Commission Decision to Use the "Topical Report" Approach for Seismic Design

DOE decided and the staff agreed that the issue of seismicity and fault displacement is an appropriate one to be dealt through the TR process. The issue of seismic design has a long history of potential for litigation and high public interest during licensing hearings of nuclear power plants. The TR approach is expected to facilitate efficient reviews during the limited licensing review period available under the Nuclear Waste Policy Act.

After discussions with the staff, DOE decided that the issue of seismicity and fault displacement is too unwieldy to be covered under one TR. Therefore, DOE developed a plan to address the issue using three TRs. The first TR (TR–1) deals with the proposed DOE's methodology to assess seismic hazards. The second TR (TR–2), which is one subject of this IRSR, deals with the proposed DOE's seismic design methodology. The third TR (TR–3), which is slated for completion during FY2002 ~~FY1999~~, deals with vibratory ground-motion and fault displacement inputs that will be used in repository design and PAs. Further details on these three TRs are discussed in following sections.

TR–1 Seismic Hazard. In its TR–1 (U.S. Department of Energy, 1994a), DOE has developed a five-step process for assessing the vibratory ground-motion hazard at the YM site. First, the seismic sources are evaluated. Second, the maximum magnitude and rate of occurrence of each source are estimated. Third, ground-motion/attenuation relationships are developed for the site region. Fourth, a probabilistic hazard curve for vibratory ground-motion is generated. Finally, multiple seismic hazard curves are developed to incorporate the various uncertainties. After completing a detailed review of TR–1 in several stages, the staff documented the status of the resolution of the subissues covered under TR–1 in its letter to DOE (Bell, 1996a), which stated that the staff has no further questions on TR–1 at this time.

TR–2 Seismic Design Methodology. TR–2, mentioned above, addresses preclosure seismic design methodology, keeping in mind that SSCs important to safety must ultimately be built to a single design that meets all requirements, including those for postclosure performance. The seismic design methodology and criteria in Rev. 0 of TR–2 (U.S. Department of Energy, 1995) were based on DOE's safety performance goals found in DOE Standard 1020-94 (U.S. Department of Energy, 1994c). Upon staff review and recommendation, DOE revised TR–2 [Rev. 1, (U.S. Department of Energy, 1996a)] substantially to make it compatible with NRC's NUREG–0800 (U.S. Nuclear Regulatory Commission, 1987) for the repository design (as applicable to surface facilities) and design basis events (DBEs) as clarified in a 10 CFR Part 60 rulemaking (U.S. Nuclear Regulatory Commission, 1996).

TR–3 Design Inputs. TR–3, which will develop and document all the seismic and fault displacement inputs for repository design and PA, is scheduled for completion early FY2002. A review process similar to the one adopted for TR–1 and TR–2 will be used for the review of TR–3. Only after the completion of the review of TR–3 can the staff resolve the seismic issue and potentially adopt the set of three TRs as an acceptable reference to the repository LA.

Preclosure Seismic Design Methodology Presented by the DOE

DOE's preclosure seismic design methodology and criteria are described in TR–2. If implemented properly, this methodology is expected to provide reasonable assurance that vibratory ground-motions and fault displacements will not compromise the preclosure safety functions of the SSCs important to safety.

The seismic design methodology and criteria implement the requirements of Part 60, including the latest amendments related to DBEs. Accordingly, the report summarizes DOE's approach to identifying categories-1 and -2 DBEs and establishes hazard probability levels that are appropriate for determining the two levels of design basis vibratory ground-motions and the two levels of design basis fault displacements.

DOE intends to use mean annual probabilities of 1×10^{-3} and 1×10^{-4}, respectively, as reference values in determining the frequency of the above two design basis vibratory ground-motions. Criteria for defining DBEs for both surface and underground facilities are provided for vibratory ground-motion and fault displacement design. In addition, the report provides criteria for fault avoidance, which is DOE's preferred approach for mitigating fault displacement hazards. Seismic design considerations for WPs are also discussed in TR–2.

After reviewing NUREG–0800 for potential use in repository design, DOE considers that specific criteria and guidance contained therein are appropriate for use in surface facility preclosure seismic design. TR-2 identifies several NUREG–0800 RPs, such as Standard RPs 3.7.1–3.7.3 and 3.8–3.10, along with specific exceptions, as applicable to the surface facility design.

Many of the standard seismic design methods that are applicable to the surface SSCs are also applicable to SSCs underground except that the vibratory ground-motions are appropriately attenuated to account for the depth below surface. Therefore, many of the RPs mentioned above for the surface facilities are also considered applicable at the repository level. However, the design of underground openings requires a combination of empirical and analytical approaches to account for the interaction of excavation-induced and thermally generated stresses superimposed on the *in situ* stresses. TR-2 describes the empirical methods, such as Dowding and Rozen's observational method (Dowding and Rozen, 1978), Rock Mass Quality Index Method (Barton, et al., 1974), and analytical methods, including the Quasi Static Method and Dynamic Analysis Method (Hardy, 1992) that will be employed by DOE in the design of the underground facilities.

In general, the TR-2 approach to fault displacement design is to avoid major faults, and whenever possible, to provide sufficient standoff distance between SSCs and faults. TR-2 adopts the guidance provided in NUREG–1494 (McConnell and Lee, 1994) in establishing design criteria.

Staff Review of Seismic Design TR–2

DOE requested a scoping review of the AO of TR–2 in August 1994 (Milner, 1994). The staff reviewed and transmitted its comments on the AO to DOE in November 1994 (Bell, 1994). DOE submitted a revised AO in January 1995 (Milner, 1995) that was considered acceptable. The staff notified its acceptance to DOE in its letter of February 14, 1995 (Bell, 1995a). DOE submitted Rev. 0 of TR–2 for NRC's review in October 1995 (U.S. Department of Energy, 1995).

Using the criteria given in Section 4.2.3, the staff concluded that the TR–2 contained sufficient information with sufficient detail to be considered for a detailed technical review. Staff acceptance of TR–2 for a detailed review was transmitted to DOE in their letter of December 1995 (Bell, 1995b).

A detailed technical review of Rev. 0 of TR–2 was conducted using the generic guidance available in the TR RP. In addition, the review criteria delineated in Section 4.2.3 were developed especially for this TR that deals with a specific design methodology.

After a detailed technical review of Rev. 0 of TR-2 and two Appendix 7 meetings with DOE (March 13–14, 1996, in Las Vegas and April 23, 1996, in San Antonio), the staff concluded that the TR-2 (Rev. 0) would not meet most of the criteria stated in Section 4.2.3 of RDTME KTI IRSR Revision 2. In addition, there were other major concerns with TR-2, Rev. 0, such as:

(1) A lack of adequate consideration of postclosure performance issues that might affect design;

(2) Incompatibility of DOE's proposed design methodology based on its Standard 1020 with the DBE definition provided in the amendments to 10 CFR Part 60;

(3) Inadequate consideration of existing models and codes for conducting dynamic analyses of jointed rock behavior for the design of underground facilities; and

(4) Lack of a clear rationale for the choice of criteria that will be used to deal with uncertainties in the DBEs for ground-motion and fault displacements.

These and other concerns were conveyed to DOE in the staff letter of May 1996 (Bell, 1996b).

As a result of the staff review and recommendations, DOE revised TR–2 and submitted the report to NRC in October 1996 (Brocoum, 1996). The most substantive change to the TR was that DOE dropped its proposed "performance-goal- based design" approach (derived from DOE Standard 1020) and adopted an approach that: (i) complies with the new definition of DBE provided in 10 CFR Part 60; (ii) adopts the existing review criteria from NUREG–0800 for the design of surface facilities and some of the SSCs underground; and finally, (iii) addresses the significant concerns raised during the review of TR-2, Rev. 0.

The staff completed a detailed technical review of TR-2, Rev. 1 using the same criteria that were used for the review of Rev. 0 and found Rev. 1 to be a significant improvement. The staff transmitted its review results along with several recommendations for clarifications in a letter in March 1997 (Bell, 1997).

DOE finalized TR-2 in its third version (Rev. 2), and submitted the report for staff acceptance on August 27, 1997 (Brocoum, 1997). Based on a verification review to check if all clarifications sought in the March 21, 1997, letter were provided, the staff concluded that all concerns raised by the staff have been addressed satisfactorily by DOE. After a detailed technical review, the staff concluded that DOE's methodology was acceptable based on the following:

(1) The methodology proposed by DOE utilizes the AC found in NUREG–0800 that have been used repeatedly and tested many times during the licensing hearings for many nuclear power plants. The technical bases for the criteria in NUREG–0800 and its references have been clearly documented. TR-2 identifies the appropriate sections of the particular RPs that will be used as guides for the seismic design of surface facilities and certain SSCs of the underground facility.

(2) TR-2 adopts staff guidance from appropriate STPs, namely NUREG–1451 (McConnell et al., 1992) and NUREG–1494 (McConnell and Lee, 1994). NUREG–1494 describes a methodology acceptable to the staff for investigating seismic and fault displacement hazards at the YM site. It also establishes criteria for defining the region of interest and the types of faults to be investigated. The STP emphasizes those faults that might have an effect on design and performance. NUREG–1494 (McConnell and Lee, 1994) provides additional guidance and clarification on avoiding faults within the preclosure controlled area of the repository.

(3) The empirical design methods and analytical/numerical methods that are proposed in TR-2 for the seismic design of the underground facility and the associated uncertainties are found acceptable to the staff.

(4) The approach for the fault displacement design and the technical bases for the criteria chosen are acceptable to the staff.

(5) Finally, all the comments made and concerns raised by the staff during Appendix 7 meetings and several rounds of reviews have been addressed in the revisions to TR-2 including the final set of clarifications sought by the staff on Rev. 1.

In summary, the staff accepted DOE's seismic design methodology proposed in TR–2; ~~however,~~ the staff is awaiting submittal of the ~~final resolution of this subissue will occur after the review of~~ DOE's TR–3 currently scheduled for completion by DOE in early FY2002 ~~FY2000~~.

4.1.3 Acceptability of GROA Design to Meet the Preclosure Performance Objectives

4.1.3.1 Design of Subsurface Facilities

TECHNICAL BACKGROUND

The discussion on the TM effects on design of underground facility was originally a part of the TM Effects of Underground Facility Design and Performance subissue in Revision 2. In this revision (Rev. 3), this discussion is used to provide the technical basis for the Design of Subsurface Facilities component of the GROA design subissue.

~~4.2.1.1 Acceptance Criteria~~

~~The TM design and analyses will be considered acceptable if:~~

~~Acceptance Criterion 1:~~ ~~Approved QA and control procedures and standards are applied to collection, development and documentation of data, methods, models, and codes.~~

~~Acceptance Criterion 2:~~ ~~If used, expert elicitations are conducted and documented in accordance with the guidance in NUREG–1563 (U.S. Nuclear Regulatory Commission, 1996b) or other acceptable guidelines.~~

~~Acceptance Criterion 3:~~ ~~TM analyses of the repository design are based on site-specific thermal and mechanical properties, spatial variation of such properties, and temporal variations caused by post-emplacement thermal-mechanical-hydrological-chemical (TMHC) processes, as appropriate, including consideration of seismic effects relevant to the YM site within the rock-mass.~~

~~Acceptance Criterion 4:~~ ~~The process to develop inputs to TM design includes consideration of associated uncertainties and documents the potential impacts on design.~~

~~Acceptance Criterion 5:~~ ~~The seismic and fault-displacement data inputs for design are consistent with those established in seismic design TR–3.~~

~~Acceptance Criterion 6:~~ ~~The methodologies used for the TM design and analyses are consistent with those established in DOE Seismic TR–2.~~

~~Acceptance Criterion 7:~~ ~~The TM design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. These models are tested as appropriate (verified, validated, and calibrated) to the extent practicable before the submittal of the LA. (For those aspects of the models for which long-term experimental data are needed, continued verification and validation during performance confirmation are considered acceptable as long as detailed plans and procedures for such continued activities are found in the LA.)~~

~~Acceptance Criterion 8:~~ ~~Both drift- and repository-scale models of the underground facility are used in TM analyses to establish the intensity and distribution of ground movement (rock deformations, collapse, and other changes that may affect the integrity or geometrical configuration of openings within the underground facility). The number and variety of models permit the examination of conditions along drift-parallel and drift-normal directions.~~

~~Acceptance Criterion 9:~~ ~~The principles formulating the TM analytical methodology, underlying~~

~~assumptions, resulting limitations, and various steps involved in the design procedures are clearly explained and justified.~~

~~Acceptance Criterion 10:~~ ~~Time sequences of thermal loading used in TM design and analyses are clearly defined.~~

~~Acceptance Criterion 11:~~ ~~The TM design and analyses consider the presence of roof supports (bolts, shotcrete, concrete, and steel liners, as applicable), consider the interaction between rock and roof supports, and address the degradation of supports with time under high temperature and moisture conditions as they affect the maintainability of stable openings during the extended preclosure period.~~

~~Acceptance Criterion 12:~~ ~~The results of the TM analyses, including the consideration of ground support (e.g., liners), are accounted for in the determination of maintenance requirements for the underground facility.~~

~~Acceptance Criterion 13:~~ ~~The design discusses maintenance plans for keeping the underground openings stable, with particular attention to maintaining the option for retrieval. (If the details of retrieval operations/plans are found in other sections of the LA, a reference to such sections would be acceptable.)~~

TECHNICAL BASES

Thermal Properties Characterization

The thermal properties required for TM analyses of the repository rock mass are:

(1) Thermal conductivity;
(2) Specific heat capacity; and
(3) Density.

The values of these properties provided by the YM Project (YMP) (i.e., DOE) are typically derived from laboratory tests on intact rock specimens (e.g., CRWMS M&O, 1998d, Table 4-3; Hardin, 1998, Table 3-5). One set of values is given for conduction-only analyses (CRWMS M&O, 1998d, Table 4-3), in which the effects of vaporization and water saturation are approximately accounted for through a dependence of thermal conductivity and specific heat on temperature near the boiling point of water. A different set of values is given for thermal-hydrological analyses (Hardin, 1998, Table 3-5) that explicitly account for vaporization and water-saturation changes. Comparison of predicted and measured temperatures in field-scale experiments, such as the DOE single heater test (Blair et al., 1999) and the DECOVALEX Bench Mark Test 3 (Stephansson, 1999), indicate that intact-rock thermal properties are adequate for characterizing the thermal response of a rock mass. Therefore, using intact-rock thermal properties to characterize the thermal response of the YM rock mass would be considered adequate.

Mechanical Properties Characterization: Continuum Rock-Mass Model

The mechanical properties required for TM analyses depend on whether the rock mass is modeled as a continuum assigned composite rock-mass properties or as a discontinuous medium consisting of a network of intact-rock blocks separated by fractures. The following rock-mass properties are required in a continuum rock-mass model:

(1) Poisson's ratio;
(2) Thermal expansivity;
(3) Young's modulus; and
(4) Strength parameters, such as friction angle and cohesion.

Characterization of the rock mass for the purpose of obtaining mechanical properties required to implement a continuum rock-mass model should address the following four features:

(1) Spatial variation of rock-mass mechanical properties from differences in intact-rock properties between the various stratigraphic units;

(2) Spatial variation of rock-mass mechanical properties from changes in the frequency, surface characteristics, and continuity of fractures;

(3) Spatial variation of rock-mass mechanical properties from changes in the nature and volume fraction of lithophysae; and

(4) Variation of mechanical properties with time as a result of degradation of the rock mass through a variety of processes such as progressive fracturing caused by sustained TM loading; alteration of fracture-wall rock from extended exposure to heat and moisture; and other appropriate thermal-hydrologic-mechanical-chemical (TMHC) processes within the rock mass.

Intact-Rock Mechanical Properties

Intact-rock mechanical properties for the YMP are given in CRWMS M&O (1997h) where the data are classified following the YM stratigraphy introduced by Buesch et al. (1995). Earlier compilations of YM intact-rock data such as Lin et al. (1993a) and Brechtel et al. (1995) present the data in terms of the TM stratigraphy of Ortiz et al. (1985), which recognizes five TM-stratigraphic units at YM. A difference between the Ortiz et al. (1985) stratigraphy and the more detailed Buesch, et al. (1995) stratigraphy that may be of most significance is the division of the repository host horizon (RHH) in the latter into four units: upper lithophysal unit (Tptpul), middle nonlithophysal unit (Tptpmn), lower lithophysal unit (Tptpll), and lower nonlithophysal unit (Tptpln). There may be significant differences in intact-rock properties among the four units (e.g., Peters and Datta, 1999). As a result, the TM behavior will be different for these four units, especially with the presence and absence of lithophysaes. In order to account for the different behavior, the intact-rock data for the four units need to be improved. In this regard, it may be more appropriate to follow the Buesch et al. (1995) stratigraphy in presenting intact-rock data for YM since it includes mire representative data.

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Effects of Fractures on Rock-Mass Properties for the Continuum Analysis

Mechanical characterization of the rock mass has followed the traditional approach (e.g., Barton, et al., 1974; Bieniawski, 1979) in which intact-rock and fracture characteristics are combined using empirical rules to obtain an index value that represents the quality of the rock mass. Rock-mass quality variations at YM were initially described following a probabilistic approach that assigned statistically calculated quality-index values to each of five quality categories within each of the TM stratigraphic units (e.g., Lin et al., 1993a). The percentage occurrence of each quality category was initially estimated through statistical analyses of borehole data. Subsequently, data obtained through fracture mapping of the ESF were used to develop a rock-mass quality (*Q*) profile along the ESF (Figure 2), which was, in turn, used to obtain better estimates of the percentage occurrence of the five quality categories within the stratigraphic units intersected by the ESF (CRWMS M&O, 1997a). The ESF *Q* data give the north-south variation of Q along the eastern boundary of the repository footprint (approximately between ESF stations 28+00 and 55+00 in Figure 2) within the Tptpmn stratigraphic unit. These data will likely be augmented with results from a recently completed cross drift that traverses the repository footprint in an approximately NW-SE direction and intersects all four RHH stratigraphic units (Beason, 1999).

The value of a rock-mass quality index, such as *Q* or the rock-mass rating (RMR) index of Bieniawski (1979), in mechanical analyses relies on the availability of empirical correlation functions that relate values of the index to values of mechanical parameters. For example, Serafim and Pereira (1983) present an exponential relationship between RMR and rock-mass Young's modulus (*E*) derived through analyses of measured deformations at a dam site. Also, Hoek (1994) and Hoek and Brown (1997) present empirical relationships for the estimation of *E* and the rock-mass strength parameters (friction angle, ϕ, and cohesion, *c*) from *Q*, RMR, or the Geological Strength Index (GSI).

Two sets of empirical *E*-vs-RMR data available from the literature (Bieniawski, 1978; Serafim and Pereira, 1983) are presented in Figure 3 along with similar data for YM presented at a recent DOE drift stability workshop (Lin, 1998). The figure also shows the Serafim and Pereira (1983) *E*-vs-RMR curve and a curve suggested for YM in the Lin (1998) presentation. It is important to note that the YMP data in Figure 3 have not been formally published by the DOE. The most recent *E* data for YM published by the DOE (CRWMS M&O, 1997a), which was used in the ground-support design analyses for the VA (CRWMS M&O, 1998d), were derived using the Serafim and Pereira (1983) relationship. An observation that stands out clearly from Figure 3 is that the YM data are sparse (six data points from ESF convergence analyses and one data point each from the plate-loading and Goodman-jack tests). The available YM data indicate that the Serafim and Pereira relationship may be inappropriate for the YM rock mass, but the data are insufficient to support a determination whether the difference between the YMP and the other two datasets in Figure 3 should be interpreted as a real difference in behavior between different rock masses or as the expected spread of *E* values [around the Serafim and Pereira (1983) predictions] at low to medium RMR values. The approach of attempting to fit the YMP data to a curve anchored at the intact-rock modulus (i.e., at RMR of 100), as illustrated in Figure 3, may not be appropriate. The shape of the *E*-vs-RMR curve for rock-mass qualities close to intact rock may significantly differ from the shape at low to medium qualities. In fact, laboratory data on the effect of microcracks on intact-rock stiffness (e.g., Ofoegbu and Curran, 1992) suggest that the stiffness of a rock mass would approach the intact-rock stiffness asymptotically as the rock-mass quality approaches intact rock. Therefore, because the shape of the *E*-vs-RMR curve may change significantly within the full range of rock-mass quality from lowest qualities to intact rock, it would be misleading to extend an *E*-vs-RMR curve beyond the range of the available rock-mass quality data.

The YMP should develop a sufficient number of data points to firmly establish the *E*-vs-RMR (or Q) relationship at YM over the range of rock-mass quality values encountered at the site, if it intends to use this approach in the LA design.

The values for the rock-mass strength parameters *c* and ϕ currently proposed for YM (CRWMS M&O, 1997a) were estimated by fitting straight lines to sets of σ_1-vs-σ_3 values (where σ_1 and σ_3 are maximum and minimum principal stresses) calculated using the Hoek-Brown failure criterion (e.g., Hoek, 1994; Hoek and Brown, 1997). This approach led to values for ϕ that are too high compared to the values suggested based on the rock-mass classification systems. For example, CRWMS M&O (1997a, Table 6) gives $\phi = 57°$ and $\phi = 58°$ for the lowest and highest quality categories of the TSw2 stratigraphic unit. On the other hand, the highest ϕ value from Hoek and Brown (1997, Figure 8) for the highest rock-mass quality (approaching intact-rock) is less than 53°.

The procedure presented by Hoek and Brown (1997) for estimating *c* and ϕ is based on the GS. The values of this index can be determined through geologic mapping of the rock mass following guidelines described by Hoek and Brown (1997) or estimated through correlations with *Q* or RMR. The values of *c* and ϕ obtained using this procedure (Ofoegbu, 1999) with the TSw2 section of the ESF *Q* data (Figure 2) are given as functions of *Q* in Figure 4. The figure shows ϕ varying from about 28° to about 35° as *Q* varies from about 0.73 to about 13.6. These values of ϕ are much smaller than the DOE values presented previously. The difference between the CRWMS M&O (1997a) ϕ values of 57–58° and the values in Figure 4 (28–25°) for the same range of *Q* values is quite significant in predicting the mechanical behavior of the rock mass in the vicinity of the proposed waste-emplacement openings (e.g., see the numerical-model results discussed presently).

Degradation of Mechanical Properties with Time

Rock-mass mechanical properties may degrade with time because of a decrease in the strength of intact rock under sustained long-term loading and a decrease in the shear strength of fracture surfaces due to wall-rock alteration caused by extended exposure to heat and moisture. Laboratory data (e.g., Lajtai and Schmidtke, 1986) indicate that the strength of hard intact rocks (e.g., granite, sandstone, or welded tuff) under slow or sustained loading may be much smaller than the strength obtained through conventional (usually rapid) laboratory-loading conditions. Under sustained loading, slow-growing fractures, such as may be driven by stress corrosion at crack tips, are able to extend and coalesce sufficiently to cause eventual rupture of the specimen. On the other hand, such fractures do not have sufficient time to grow under rapid-loading conditions. For example, Lajtai and Schmidtke (1986) presented unconfined compressive strength of crystalline igneous rocks from sustained-loading tests as low as 60 percent of the conventional unconfined compressive strength. Because the repository environment will be subjected to mechanical loading arising mainly from thermal expansion of rock under high temperatures that may be sustained for a few hundred years, at least, the strength of intact rock within the environment should be governed by behavior under sustained loading. As a result, the value of intact-rock unconfined compressive strength used in the repository design analyses should be a fraction of the value obtained from conventional laboratory testing. There is currently no data on the behavior of YM intact rocks under sustained-loading conditions.

Although widespread chemical weathering of the rock mass is not likely considering the ambient climatic conditions at YM, alteration of fracture-wall rocks at and near the repository horizon is

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considered likely because of possible exposure of such fractures to moisture under elevated temperatures for an extended period (Hardin, 1998). Alteration of fracture-wall rock could result in fracture apertures widening in some areas due to dissolution of minerals along the fracture surface. In addition, fracture apertures could be reduced due to precipitation of minerals (such as clay and calcite) that are much weaker than the surrounding rock. Such changes in fracture characteristics could weaken the rock mass, resulting in values for the rock-mass strength parameters c and ϕ significantly smaller than their values under current conditions. The effects of fracture-wall rock alteration on rock-mass properties may be expressed through a reduction of Q following the guidelines of Barton et al. (1974) for accounting for fracture skins that are different from the parent rock. However, the guideline requires a knowledge of the potential thickness of the altered fracture-wall rock and the surface-area fraction of the fracture surface that is covered by the altered rock. The difficulty of predicting such quantities raises doubts on the possibility of quantifying possible reductions of Q following the Barton et al. guideline. The effects of an order-of-magnitude reduction of Q on mechanical properties are illustrated in Figure 4, which shows the values of E, c, and ϕ estimated from the degraded Q values (by placing Q with 0.1 Q in the empirical equations identified in the figure). It should be noted that one order-of-magnitude reduction in Q is approximately equivalent to an 8-point reduction in RMR [using an empirical RMR-vs-Q relationship such as presented in Hoek (1994)]. The analyses results discussed presently indicate that such a reduction in the Q value would significantly affect drift-stability predictions. Consequently, the mechanical characteristics of the degraded rock mass should be accounted for in predicting future stability of the emplacement drifts.

Results from a Two-Dimensional Site-Scale Continuum Model

Finite element (FE) analyses of the emplacement drift area of the proposed repository conducted by NRC used a plane-strain model to examine the effects of the following on drift stability: (i) spatial variation of mechanical properties; (ii) mechanical degradation of the rock mass caused by sustained loading and fracture-wall alteration from extended exposure to heat and moisture, and (iii) mechanical degradation of the ground support. Input data for the analyses were derived from the ESF Q profile (Figures 2 and 5). Drift spacing was set at 28-m center to center for a thermal-loading equivalent of 85 MTU/acre following the emplacement-drift layout in CRWMS M&O (1997a). Drifts were modeled as 5 × 5-m squares, and concrete-lining support was simulated using beam elements placed at the edges of the openings. The model used for the analyses is discussed in detail in Ofoegbu (1999).

The results of the analyses and conclusions drawn based on such results are presented next.

(1) Analyses performed using nondegraded rock-mass properties (curves Y1, F1, and C1 in Figure 4) did not produce significant inelastic response. Also, analyses performed using curves Y2 or Y3 with any of the strength-parameter curves did not indicate significant inelastic response. These results indicate that stress-induced instability of the emplacement drifts (different from structure-induced instability that may result from loose-rock fall, for example) would be insignificant under the simulated thermal loading if: (i) mechanical degradation of the rock mass does not occur, or (ii) the rock-mass modulus followed the curve labeled YMP in Figures 3 and 4. Significant inelastic response (Figures 6 and 7) was obtained from analyses performed using nondegraded Young's modulus (curve Y1 in Figure 4) with degraded strength parameters (curves F2 and C2 in Figure 4). This parameter combination represents a simulation of an initial period of stress buildup in nondegraded rock mass followed by a period of mechanical degradation. The results illustrate the important roles of mechanical degradation of the rock mass and ground support in controlling the

intensity and distribution of potential stress-induced ground movement. Therefore, for these reasons, the possibility of rock-mass degradation needs to be addressed. Inelastic response is most intense in the pillar centers and in the roof and floor areas of the openings. With stiff drift support (Figure 6), inelastic response is most intense in the pillar centers in areas of higher rock-mass stiffness because of the occurrence of high horizontal stress and low vertical stress in the pillars as will be illustrated. On the other hand, loss of confinement caused by the simulated degradation of ground support causes increased inelastic response in the roof and floor, with higher intensity of the response occurring in lower-Q areas (Figure 7).

(2) The results in item (2) also illustrate the strong effects of Young's modulus on the calculated response, which occur because the magnitude of thermal stress is controlled by Young's modulus. Consequently, there is a strong need to establish the range of the *in situ E* data for YM site. The role of Young's modulus is emphasized further (Figure 8) through the results of a set of homogenous-medium models in which E, ϕ, and c were varied between the minimum and maximum Q values on curves Y1, F2, and C2 in Figure 4. With stiff drift support, the higher thermal stresses developed in the higher-Q model dominate the response, resulting in more intense inelastic straining in the higher-Q model. On the other hand, deactivation of the support system under constant temperature (which is a purely mechanical change) to simulate support degradation causes increased inelastic strain intensity in the lower-Q model. The response of the lower-Q model to support degradation is governed by the effect of loss of confinement on low-strength (i.e., low c and ϕ) rock mass.

(3) Thermal loading from the emplacement-drift pattern results in horizontal compression and vertical extension, which cause an increase in horizontal stress from an initial value of about 2 MPa and a decrease in vertical stress from an initial value of about 7.5 MPa (Figures 9 and 10). The largest decrease in vertical stress occurs in the pillar centers and roof and floor. As a result, the maximum principal stress would be horizontal and the minimum would be vertical, under the thermal regime. The orientation of the maximum principal stress would shift from approximately north-south in the pillars to approximately east-west in the roof and floor (Figure 10). These stress orientations would favor slip on gently ($\leq 30°$) dipping fractures that strike parallel to the drifts in the pillars or normal to the drifts in the roof and floor. Consequently, inelastic response in the roof and floor would be controlled by slip on a gently dipping dominant fracture set that strikes approximately normal to the proposed drift orientation. It should be noted that two-dimensional models oriented normal to the drifts will not be able to capture the effects of slip on such fractures. Therefore, other modeling approaches [e.g., three-dimensional model (3D)] should be considered to assess such effects.

Characterization of Mechanical Properties: Discontinuum Rock-Mass Model

TM analyses using a discontinuum model require two groups of mechanical properties:

(1) Mechanical properties for rock blocks: Rock-block properties include mass density, elastic or deformability properties, strength parameters, and post-failure parameters. Two basic elastic properties for an isotropic material behavior are Young's modulus and Poisson's ratio [sometimes bulk modulus and shear modulus are used (e.g., in UDEC)]. Strength parameters depend on the failure criterion chosen. For the Mohr-Coulomb failure criterion,

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the strength parameters are cohesion, friction angle, and tensile strength. Post-failure properties depend on the type of post-failure responses chosen. For the Mohr-Coulomb model, shear dilatancy (dilation angle) is required to describe post-failure behavior. In a discontinuum model, however, the presence of discontinuities will account for a good portion of the scaling effect on properties. Even so, some adjustment of block properties may still be required to represent the influence of heterogeneities and micro-fractures, fissures, and other small discontinuities on the rock-mass response (Itasca Consultant Group, Inc., 1996).

(2) Mechanical properties for fractures: Mechanical properties for fractures include basic elastic parameters (normal stiffness and shear stiffness), strength parameters (fracture friction angle, fracture cohesion, and fracture tensile strength), and post-failure properties (fracture dilation angle). Similar to block properties, fracture properties measured in the laboratory typically are not representative of those for real fractures in the field, and choices of appropriate parameters need to be guided by fracture properties derived from available field tests.

As discussed previously, there are several versions of intact-rock mechanical properties reported by DOE, and the latest are those of CRWMS M&O (1997h). Rock-mass mechanical properties were estimated for the five rock-mass quality categories using, mainly, an empirical approach (CRWMS M&O, 1997a).

Fracture strength parameters (cohesion and friction angle) were initially estimated and used in the ESF ground support design analysis (CRWMS M&O, 1996b). The estimate was based on an empirical relation for friction of rock joints proposed by Barton (1973). These parameters were further analyzed using the same empirical approach based on qualified field mapping data (CRWMS M&O, 1997a) and used in subsequent ground support analyses for the VA (CRWMS M&O, 1998d). Fracture tensile strength was assumed to be half of the fracture cohesion according to Lin et al. (1993b) in ESF ground support analyses (CRWMS M&O, 1996b) and assumed to be zero for conservatism in ground support analysis for the VA (CRWMS M&O, 1998d). Fracture shear stiffness was estimated in Lin et al. (1993b). Fracture normal stiffness is often assumed to be the same as fracture shear stiffness (e.g., CRWMS M&O, 1998d). It should be noted that the approaches used by DOE for estimating fracture mechanical properties (strength and stiffness) have considerable uncertainties. In order to conduct the discontinuum analysis with reasonable confidence, these approaches need to be tested (verified, validated, and calibrated). Furthermore, the associated uncertainties need to be quantified.

~~Temperature and Time Effects on Concrete~~

~~The primary ground support system under consideration for the emplacement drifts for the baseline repository design of the TSPA-VA was a concrete liner. The following discussion was developed for Revision 1 of the RDTME IRSR to address the technical concerns related to the use of a concrete liner in the elevated temperature environment. In April 1999, an enhanced design alternative was identified and has been recommended by the M&O Contractor to DOE for consideration as a baseline for the SR and the LA (CRWMS M&O, 1999). In the proposed enhanced design, a concrete liner is no longer under consideration. However, the discussion is retained in the current version of the IRSR pending issuance of the SR/LA report confirming that a concrete liner is not one of the ground support systems to be used.~~

~~A large amount of information regarding the behavior of concrete exposed to heat and moisture is~~

~~available in the literature. Although this information is generally limited to short-term heating (mostly under transient conditions), certain observations/findings are expected to be relevant to the YM environment, irrespective of the design of the concrete liner and should be considered in the repository design. A summary of information gathered through literature search is presented in the following subsections.~~

~~Thermal Properties at Elevated Temperature~~

~~The thermal properties of concrete at elevated temperature are not constant since the concrete is physico-chemically unstable (Harmathy, 1970). Estimating the thermal properties at higher temperatures is even more complex due to the development of decomposition and transition reactions.~~

~~In general, concrete contains two or three components. The two-component concrete is a mixture of coarse aggregate and cement paste while the three-component concrete consists of coarse aggregate, fine aggregate, and cement paste. The specific heat for cement paste may experience a 100-percent increase as the temperature increases from 100 to 150 °C and starts to decrease gradually until about 400 °C. From 400 to 500 °C, specific heat increases sharply again and peaks at 500 °C and eventually returns to values equivalent to those between 25 to 100 °C (Harmathy, 1970). The volume-specific heat for concrete follows a similar trend. The maximum wall rock temperature in the repository is approximately 200 °C. Consequently, the temperature-dependent behavior of the specific heat is an important issue to be considered in repository design.~~

~~The thermal conductivity of cement paste is very low and not subject to large variations. The concrete thermal conductivity is primarily determined by that of the aggregates. Concrete with aggregates containing high-crystalline rocks has relatively high conductivity at room temperature, and the conductivity gradually decreases as temperature increases (Harmathy, 1970). Concrete containing amorphous rock aggregates exhibits low conductivity (Kingrey and McQuarrie, 1954) and is relatively insensitive to the chemical composition. The thermal conductivity of this type of concrete increases slightly with an increase in temperature. Concrete with common lightweight aggregates has also relatively low conductivity owing partly to the high porosities (low density) of the aggregates (Harmathy, 1970).~~

~~Temperature Impact on Material Properties of Concrete~~

~~A study has indicated that Young's modulus and Poisson's ratio of concrete increase slightly as the concrete is heated from room temperature to about 50 °C due to the release of the majority of evaporable water in the concrete during heating (Marechal, 1972). Young's modulus and Poisson's ratio decrease afterwards at a relatively constant rate as temperature continues to increase. The reduction in Young's modulus can be more than 40 percent if the temperature reaches 200 °C while the reduction could be as much as 36 percent for Poisson's ratio. This reduction is not reversible (Marechal, 1972). Bulk modulus decreases at a faster rate than Young's modulus due to the fact that Poisson's ratio decreases at a relatively slower rate than Young's modulus.~~

~~Compressive strength of concrete has been observed to decrease as temperature increases. Concrete strength at a temperature of 200 °C is about 70 to 75 percent of that at room temperature. Limestone-aggregate-based concrete experiences even faster strength reduction owing to destruction of bonds and an increase in plasticity affected by temperature. At 200 °C, this type of concrete has~~

~~only about 57 percent of its original strength (Marechal, 1972).~~

~~Degradation of Concrete~~

~~Degradation of concrete could take place in several forms: creeping, chemical instability, and dehydration. Creep phenomenon is the focus of discussion in this section. Creep is a form of time-dependent degradation/damage through accumulation of micro-fractures (Baluch et al., 1989) formed in the concrete under load.~~

~~Concrete has been observed to experience a marked increase in creep when it is heated for the first time under load (Khoury et al., 1985; Baluch et al., 1989). Additional transient creep also originates in the cement paste and is restrained by the aggregate. This transient creep provides the heterogeneous concrete with some thermal stability for an applied constant stress level below 30 percent of the concrete strength. This phenomenon is due to the relaxation and redistribution of thermal stresses in the concrete. This relaxation process makes a stable structure possible (Khoury et al., 1985).~~

~~However, if the applied constant stress level is beyond 30 percent, the possibility for the concrete to fail during heating becomes greater. Experiments conducted by Khoury et al. (1985) have shown that concrete under heat may undergo creep failure at an applied constant stress level about 60 percent of the concrete compressive strength. The timing of the failure was not reported. It is suspected that the duration of creeping is short. This failure mechanism may be related to the differential thermal expansion coefficients between the aggregate and cement paste that lead to relaxation of stress. At a relatively lower stress level, this difference contributes to the stability of concrete structures. However, at a higher constant applied stress, microfractures in the concrete begin to accumulate and creep accelerates (Baluch et al., 1989). When the creep strain reaches a certain extent, the concrete may fail and stability of the concrete could be jeopardized. The amount of creep strain that is tolerable depends on materials involved.~~

~~As discussed earlier, concrete damage due to first-time heating could reduce concrete strength and make the concrete more susceptible to creep. In the emplacement area of the repository, the applied stress to the concrete liners from the thermal expansion and time-dependent degradation of the surrounding rock mass could be high. Subsequently, time-dependent degradation of concrete liner is possible. The extent of the degradation will depend upon the level of stresses applied. It should be noted that under certain combination of unfavorable conditions such degradation could take place at the early stage of the preclosure period.~~

~~The thermal expansion of the concrete could further jeopardize drift stability if the concrete structure is restricted from expanding, which may be the case for concrete liners for the emplacement drifts. Since the expansion capability is limited, the concrete tends to relax its excessive stresses through dislocations between aggregate and cement paste or even through the cement paste. This dislocation phenomenon leads to further degradation of the concrete structure and possible failure.~~

4.2 THERMAL-MECHANICAL EFFECTS ON UNDERGROUND FACILITY ~~DESIGN AND~~ PERFORMANCE

4.2.1 Background

The subissue of the TM effects on underground facility design and performance consists of two major components. ~~One is related to repository design while the other two areas focus on performance.~~ More specifically, these two components include: ~~(i) TM effects on underground facility design;~~ (ii) effect of seismically induced rockfall on WP performance~~;~~ and (iii) postclosure TM effects on flow into the emplacement drifts. ~~Review methods and acceptance criteria for each component are listed in separate subsections followed by a presentation of the technical bases to support these acceptance criteria and review methods. In this version of the IRSR, the technical bases presented for the TM effects are not complete. They will be updated in the future revision of this IRSR.~~

~~4.2.2 Review Methods~~

~~Review methods for the TM effects subissue consist of the following: (i) review of DOE's thermal strategy and its translation into design, construction and operation of the underground facility; (ii) review of DOE's TM models and associated TM analytical methodology; (iii) review of DOE's ground support designs; (iv) review of DOE's site characterization thermal testing and performance confirmation monitoring program; and (v) selective independent verification analyses. The staff will review DOE's documents related to TM analyses, and appropriate sections of SR and LA using the acceptance criteria developed in this section of the IRSR. The staff will also conduct site visits and audits to observe and document DOE's verification and validation of TM models used in repository design. (More detailed review methods will be developed in future revisions of this IRSR.)~~

4.2.2 Effects of Seismically Induced Rockfall on Waste Package Performance

~~4.2.2.1 Acceptance Criteria~~

~~The staff will find DOE's consideration of seismically induced rockfall acceptable if:~~

~~Acceptance Criterion 1:~~ ~~Approved QA and control procedures and standards are applied to collection, development and documentation of data, methods, models, and codes.~~

~~Acceptance Criterion 2:~~ ~~If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG–1563 (U.S. Nuclear Regulatory Commission, 1996b) or other acceptable approaches.~~

~~Acceptance Criterion 3:~~ ~~The seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the design and PAs as established in DOE's TR–3 reviewed and accepted by NRC.~~

~~Acceptance Criterion 4:~~ ~~Size distribution of rocks that may potentially fall on the WPs is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions) with adequate consideration of associated uncertainties.~~

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~~Acceptance Criterion 5:~~ ~~The analytical model used in the estimation of impact load due to rockfall on the WP is: (i) based on reasonable assumptions and site data; (ii) consistent with the underground facility (emplacement drift geometry and backfill) and WP designs; and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses.~~

~~Acceptance Criterion 6:~~ ~~The TM analyses that provide the background conditions on which seismic loads are superimposed consider time-dependent jointed rock behavior.~~

~~Acceptance Criterion 7:~~ ~~Rockfall analyses consider, in a rational and realistic way through dynamic analyses, the possibility of multiple blocks falling onto a WP simultaneously, and the extent of the potential rockfall area around an individual emplacement drift as well as over the entire repository as functions of ground motions.~~

4.2.2.1 Technical Bases for Review

Seismicity is a disruptive event that needs adequate consideration in both repository design and PA. Seismicity could affect WP performance by producing rockfall that may damage WPs. The potential effects on the performance of WPs are twofold. The first possible effect of rockfall is to rupture WPs by the impact produced by the falling rock. The second aspect is that rockfall may cause damage to the container outer pack in a manner that corrosion of the WPs will accelerate and thus reduce the intended service life of WPs. In order to perform an adequate assessment of the effect of rockfall due to either TM load or seismicity, a number of factors will need to be understood better, such as the design of WPs, repository design (ground supports and backfills), and potential size of rockfall. Equally important is the availability of a reasonable model/approach that can be used to perform such an assessment.

The analyses of rockfall should explicitly account for four basic aspects: (i) size distribution of individual block that can potentially fall, (ii) possibility of multiple blocks falling onto a WP simultaneously; (iii) vertical and lateral extent of the region undergoing rockfall, and (iv) effects of repeated rockfall on the (corroded) canister due to repeated seismic events. These aspects of rockfall analyses are discussed in this section, with emphasis on specific needs for analyses, appropriateness of methodologies, and sufficiency of input considerations and associated uncertainties. The discussion is based mainly on data from YM site characterization activities, current DOE approaches, and ongoing modeling efforts at NRC/Center for Nuclear Waste Regulatory Analyses (CNWRA). The ultimate goal of these analyses is to give technically adequate estimation of the volume range and quantity of rock blocks that have the potential to fall onto the WPs so as to evaluate the effects of such rockfall on the integrity of the WPs. Because characterizing rockfall is a recently initiated ongoing effort, the technical bases provided in this section of the IRSR are not completely developed and, therefore, should be considered preliminary.

Size Distribution of Individual Blocks and the Probability of Rockfall

The size distribution of individual rock blocks is controlled by geometrical characteristics of the fracture network. In characterizing a fracture network, fractures are often grouped into primary sets, and each fracture set is modeled by parameters such as orientation, spacing, dimension, location, and persistence. These geometric parameters of the discontinuities are statistical in nature. Besides primary fracture sets, a random fracture set is often simulated to account for fractures that are random in nature and could not be accounted for in the primary sets. It is through fracture network modeling that the size distributions of individual rock blocks are estimated. Some examples of fracture network modeling in the recent geological engineering practice include the commercial code FRACMAN (Dershowitz et al., 1993), analyses based on Key Block theory (Goodman and Shi, 1985; Shi, 1996), and some other commercial and noncommercial software such as FRACNTWK (Kulatilake, 1998), Stereoblock (Hadjigeorgiou et al., 1998), and DRKBA (Stone Mineral Ventures, Inc., 1998).

At YM, an earlier attempt to estimate size distribution of rock blocks was made by Gauthier et al. (1995) using a modified (log-space) version of the Topopah Spring fracture spacing distribution developed by Schenker et al. (1995). It is a two-dimensional analysis based on the North Ramp Geotechnical (NRG) core hole, the ESF data, and the assumption of cubic and parallelepiped blocks. Assumptions of cubic or parallelepiped block shape may distort the estimation of size distribution of *in situ* blocks due to various assumptions with regard to the extent of fractures in the third dimension. Recently, DOE[2] conducted Key Block analyses in three dimensions using DRKBA (Stone Mineral Ventures, Inc., 1998). In this software, fracture sets are identified based on clustering of fracture poles projected on stereonets, and probabilistic distributions of fracture parameters (Fisher constant, orientation, spacing, and trace length) are determined for each set. Fracture planes are then simulated by a Monte Carlo technique from probability distributions of fracture parameters. Finally, volume distributions of the key blocks per unit drift length are determined for various lithologic units (Tptpul, Tptpmn, Tptpll, and Tptpln) and for different drift orientations.

Volume distributions of the key blocks are used in estimating the probability of various sized rock blocks that may fall into the emplacement drifts.[3] In this preliminary analysis, key block failure as a function of time is estimated based on an underground rockfall database compiled by Smith and Tsai (CRWMS M&O, 1995a) and an approach used by Gauthier et al. (1995) that relates the effect of seismic and tectonic events to the incidence of rockfall. The study considered rockfall frequencies obtained by Smith and Tsai (CRWMS M&O, 1995a). Gauthier et al. (1995) adopted the CRWMS M&O (1997i) approach for treating the uncertainties and selected the high-, best-, and low-estimates for rockfall frequency as 9.4×10^{-3}, 9.4×10^{-4}, 9.4×10^{-5} per year per km, respectively. The study further estimated numbers of rockfalls and predicted occurrence rate (or return period) for rockfall greater than a certain block size using the following equation and volume distribution of the key blocks obtained from DRKBA analyses.

$$\text{OccRate} = (100\% - \text{cum}\%) * f\xi_i * L \qquad (1)$$

where

OccRate — occurrence rate for rockfall greater than the block size

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[2]CRWMS M&O, *Key Block Analysis—Preliminary Results,* Las Vegas, Nevada, Civilian Radioactive Waste Management System Management and Operating Contractor, 1999.

[3]Ibid.

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cum%	—	cumulative percentage of the block size
$f\xi_i$	—	unit length rockfall frequency
L	—	drift length

There are some inherent assumptions in this latest DOE approach to rockfall estimation that do not appear to be technically defensible and thus, limit the practical application of this study. First, in the study, rockfall frequency determined by Gauthier et al. (1995) is based on the frequency of earthquake occurrence. This assumes that rockfall is induced by seismic events, which are dynamic processes. However, the Key Block method is a purely static geometric approach. It does not consider dynamic processes of seismic activity, nor does it consider failure mechanisms such as the possibility of failure propagation (or falling of multiple rock blocks) due to falling of one particular key block. In fact, results from recent dynamic modeling show that, in most cases, multiple rock blocks will fall instead of a single key block during a ground-motion event (see section *Possibility of Simultaneous Rockfall and Vertical Extent of Potential Rockfall*). In the staff's opinion, the Key Block analyses can be used to estimate rockfalls that are random in nature and occur under gravity, as well as the likely failure initiation location of a rockfall event. Rockfalls due to thermal load and/or earthquake ground-motion events need to be determined through thermal and dynamic analyses. In the case of earthquake-induced rockfall, rockfall frequency depends on the frequency of ground-motion events. In thermal-load induced rockfall, frequency may be a time function of the evolution of the thermal load and the degradation of rock properties.

Second, the DRKBA Key Block analysis assumes that the likelihood of a rockfall event and the number of key blocks are equal everywhere along emplacement drifts. This analysis further assumes that the same volume distribution of the key blocks applies everywhere in the repository located in the same lithologic units. These assumptions do not appear to be realistic because fracture network characteristics vary significantly from place to place. Modeling of the fracture network should be more detailed and should distinguish regions with different fracture network characteristics that affect mechanical behavior. Furthermore, in DOE Key Block analyses, the amount of rockfall does not depend on the level of ground-motion, characteristics of ground-motion (such as frequency content, spectrum characteristics, etc.), rock block and fracture TM properties.

Possibility of Simultaneous Rockfall and Vertical Extent of Potential Rockfall

TM analyses at the drift scale up to 100 years (Ahola et al., 1996, Chen, et al., 1998) show that thermal loading causes significant stress redistribution around the drift. The study considered a single drift in a rock mass that had a regular joint pattern with two joint sets (subhorizontal and subvertical). The analyses were conducted using the computer code UDEC (Itasca Consulting Group, Inc., 1996). Figures 11 and 12 compare the distribution of principal stresses following drift excavation and after 100 years of heating under a 100 MTU/acre thermal loading density. The thermal load increased the maximum compressive stress, and rotated its direction from vertical to horizontal. The location of the highest compressive stress region shifted from the side walls to roof and floor areas of the drift. Failure along side walls due to concentration of compressive stresses and lack of lateral support in underground mines and tunnels is a frequently observed phenomenon. When such compressive stress is rotated and shifted to the roof area, a similar phenomenon could occur and thus cause rockfall.

This study also reveals that thermal load could increase failure of intact rock blocks. Other studies have observed this phenomenon (Tsai, 1996; CRWMS M&O, 1995b). Although failure zones in most cases were localized to the immediate areas around the drift, in some cases they extended to the middle of the pillar in rock masses that are weaker and have a higher thermal expansion coefficient (Figures 13 and 14). Although failure of intact rock in discontinuum analysis may not be the direct evidence of explicit rockfall, it represents a failure or damage state and indicates the need to establish a criterion for determining the vertical extent of potential rockfall with appropriate modeling methodologies and input parameters (e.g., joint patterns representative of the site).

Rockfall phenomena were analyzed by simulating the behavior of an unsupported emplacement drift undergoing repeated seismic ground-motion after subjecting it to *in situ* stress and, in some cases, a time-decaying thermal load generated by the emplaced wastes (Chen, 1998; 1999). The analyses used the distinct element computer code UDEC (Itasca Consulting Group, Inc., 1996). Modeling results show that, in most cases, multiple rock blocks (rather than a single rock block) fall simultaneously under seismic ground-motion. Fracture patterns have controlling effects on the amount of simulated rockfall. In these analyses, a regular fracture pattern refers to a fracture network with two or more sets of fractures of infinite length and constant orientation and spacing (Figure 15a). An irregular fracture pattern refers to a fracture network defined by certain statistical distributions of fracture parameters such as orientation, spacing, trace length, and gap length (Figure 15b). The complexity of fracture patterns increases with increasing number of fracture sets, decreasing spacing, and increasing variations of parameters. Modeling results show that with increasing complexity of fracture patterns, the number of rock blocks falling, the extent of the rockfall region, and the overall drift instability increase. Figure 16 compares simulated rockfalls for two slightly different irregular fracture patterns. Case A contains two fracture sets, whereas Case C has an additional fracture set with relatively large spacing. This figure shows that adding the third fracture set increases the amount of simulated rockfall significantly. In general, the amount of simulated rockfall for a heated drift is less than that of an unheated drift with the same fracture pattern because the thermal compressive stress tends to reduce fracture normal displacement. A similar phenomenon was observed by Fairhurst (1999). A second ground-motion event usually produces little additional rockfall.

Dynamic modeling results also show that the stress distribution is altered significantly by thermal load and, to a lesser degree, by dynamic load. As mentioned previously, the superposition of thermal stresses on excavation-induced mechanical stresses changes the location of the maximum principal stress from drift sidewalls (nearly vertical) to roof and floor (nearly horizontal). In most cases, a zone of tensile minimum principal stress occurs in the roof and floor. Figure 17 shows that the extent of the region with tensile minimum principal stress (positive stress) is greater for an irregular fracture pattern (lower plot) than that for a regular fracture pattern (upper plot), causing more extensive rockfall in the case of an irregular fracture pattern.

It is desirable to establish a criterion that could be used to determine the maximum vertical extent of potential rockfall. The extent of rockfall will depend on factors such as level of ground-motion, joint pattern, individual block sizes, thermal and mechanical properties of the rock mass, joint shear and normal displacements, joint shear and normal stresses, and joint strength.

Dynamic modeling results show that of all these factors, fracture pattern may have the most significant effect on rockfall. Therefore, analyses using a regular fracture pattern such as the one shown in Figure 16 may not be conservative. An ongoing effort at CNWRA is to simulate fracture network patterns representative of the *in situ* conditions based on mapping and scanline data from the ESF and Cross Drift. Future dynamic analyses will incorporate more realistic fracture patterns and recent changes in DOE repository design.

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Approach for Assessing Effects of Rockfall on Waste Package Performance

In the following, an approach to evaluating the effects of rockfalls on WP performance that was implemented in the SEISMO module of the TPA code is discussed (Manteufel et al., 1997; Mohanty and McCartin, 1998). This approach represents the first attempt by NRC to address rockfall and is used to assess the number of WPs ruptured due to rockfall induced by seismicity in the repository thermal environment. Rockfall due to instability of emplacement drifts caused by TM load can also be evaluated in a similar manner. It is recognized that the rockfall conceptual model developed using this approach is based on a series of assumptions. Some of these assumptions may be conservative and some not. A systematic effort is ongoing to quantify rockfall due to seismicity and its effect on WP and drip shield performance using site representative data and the most current design (Hsiung et al, 2000; Gute et al., 2000). The results of the investigation will be used to develop a more representative rockfall model.

Conceptual Model

The SEISMO module adapted in NRC's TPA code (Version 3.2) evaluates the potential for direct rupture of WPs due to rockfall induced by seismicity in the repository thermal environment. The code takes the volume of rockfall as input to perform impact analysis to determine integrity of WPs. The magnitude of the impact load is essentially a function of the size of the falling rock block and the distance of this rock block from the WPs. The volume of rockfall is in turn a function of rock conditions, *in situ* stress, thermal load, and magnitudes of seismic events. In the following paragraphs, discussions related to the conceptual model will be provided in the following sequence: (i) how variations of rock conditions are accounted for in the model, (ii) how falling rock size is related to the magnitude of seismicity, (iii) how the time dependency of the seismic events is accounted for; (iv) how impact load and impact stress are calculated, (v) how rupture of WPs is determined, and (vi) how the number of WPs ruptured is determined. A flowchart showing the steps of calculation in SEISMO is provided in Figure 18.

Joint Spacing and Rock Conditions in TSw2 Unit

It is recognized that not all rocks falling from the roof of the emplacement drifts will have an effect on WPs. The effective size of the rock falling on a WP is considered to be controlled by joint spacing (width and length) and height of the falling rock block and the falling distance of the rock block before it impacts the WPs. The falling distance is controlled by the diameters of emplacement drifts and WPs. Another factor that affects the falling distance is the number of rockfalls taking place at the same location.

The falling distance for the second rockfall is no doubt longer than that for the first rockfall at the same location. Consequently, the associated energy will apparently be higher and impact will be greater if the WP is not already covered by rock debris. The ability for assessing the effect of repeated rockfalls at the same area is not currently provided in the SEISMO module. One can indirectly evaluate the effects of repeated rockfalls by changing the baseline falling distance provided in the input file for the TPA code. In the future revision of the SEISMO module, the capability of evaluating the effect of repeated rockfalls on WPs will be included.

The joint spacing information provided in a Sandia report (Brechtel et al., 1995), which summarizes data collected from NRG holes, is used to bound the five rock conditions. A range of joint spacing is assigned to each rock condition. Since each rock condition represents a range of joint spacings, a uniform distribution function covering the range of joint spacings is assumed for each rock condition.

As discussed earlier, dividing the TSw2 unit into five rock conditions as implemented in the current version of SEISMO based on joint distribution information using NRG hole data is arbitrary. As more information regarding joint distribution in the TSw2 unit becomes available, it may be possible to develop a continuous function to describe the rock condition in the TSw2 unit such that the assumption of five rock conditions can be removed from the SEISMO module.

Determination of Size of Rockfall

The size of a falling rock can be calculated by joint spacing (width) × joint spacing (length) × height of the rock block. At this time, the SEISMO module assumes, for simplicity, that the width of a falling rock is equal to its length, and the joint spacing is controlled by the rock condition. The maximum heights of the falling rock blocks are assumed to be equal to the heights of calculated yield zones induced by *in situ* stress, thermal load, and various levels of ground accelerations.

The height of the yield zone for each rock condition subjected to ground acceleration is estimated from the results of numerical modeling using the UDEC computer code (Ahola et al., 1996) based on three case studies. The height of the yield zone is a function of rock condition and magnitude of ground acceleration. Using the height of yield zone for calculation of the size of falling rock tends to give an upper bound value. Consequently, the determination of the vertical dimension of the rock that is falling in the SEISMO module is made through sampling a uniform function between the minimum vertical dimension and the maximum vertical dimension. The maximum vertical dimension is assumed to be equal to the height of yield zone while the minimum vertical dimension is assumed to be equal to the average joint spacing of a rock condition.

Investigation is currently under way to devise a more acceptable approach for determining the size of the falling rock using available joint information at the YM site.

Fractional Coverage of Rock Conditions and Determination of Number of Waste Packages Ruptured

Based on the Sandia report (Brechtel et al., 1995), rock condition 4 appears to contain a larger portion of the TSw2 Unit. About 62.9 percent of the area can be characterized as rock condition 4 and rock condition 5 occupies roughly 35.6 percent of the area. Rock conditions 1, 2, and 3 take up only 1.5 percent of the area in total. Due to a lack of specific information, the 1.5 percent is equally divided into the three rock conditions.

If a seismic event triggers rockfall for a particular rock condition, rockfalls are not expected to take place in the entire area of that rock condition. In fact, only a small fraction of the rock under that rock condition will fall in response to a seismic event because of the inherent variation associated with the rocks. Another fraction of the rock may fall at a later time when a separate seismic event, having the same or greater intensity, takes place. Rockfall could also take place at a relatively smaller magnitude event if the rock has been sufficiently weakened due to repeated seismic events. The size of the fraction may be related to the event magnitude, joint dip angles, and incidence angle of incoming seismic waves, etc. At this time, there is little information available to determine such a relationship. Consequently, CNWRA experts developed a continuous function relating the fractional area of rockfall

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to the magnitude of seismic ground accelerations based on experience in the field. This function is implemented in the SEISMO module for TPA Version 3.2. As currently implemented, this function is rock-condition-independent, that is, the same fraction is applied to all rock conditions in estimating WPs affected by rockfall. This function represents our current thinking. Modification to the function may be necessary at a later date when more technical information becomes available. Also, this function should be made rock-condition-dependent. It is intuitive that, for a particular seismic event, weaker rock should experience relatively larger area of rockfall compared to stronger rock conditions.

Seismic Hazard Parameters

The SEISMO module requires a history of seismic events over the time period of interest. The history of seismic events is generated by the TPA executive SAMPLER utility module. The input required for generating event history includes ground acceleration sampling points and the corresponding recurrence times. These two pieces of information form a prescribed seismic hazard curve.

In determining the recurrence of seismic events, the horizontal acceleration hazard curve provided in DOE's Seismic Design Methodology for a Geologic Repository at YM report (U.S. Department of Energy, 1995) for surface facilities is used. The effect of surface/depth attenuation can be investigated using the SEISMO module. At the time of preparing ~~this~~ Revision 2 of this IRSR, new information generated through expert elicitation regarding potential seismic hazards at the YM site became available (U.S. Department of Energy, 1998e). This new information will be included as the base case in a subsequent version of the SEISMO module.

As noted earlier, the seismic recurrence sampling is handled by the SAMPLER utility module in the TPA code. Ten discrete sampling accelerations can be used to describe a seismic hazard and should provide a relatively good representation of that hazard curve. Evaluation of the sensitivity of results to various hazard curves is possible using SEISMO by giving the ground acceleration sampling points and corresponding recurrence times representative of the seismic hazard curves to be analyzed.

Impact Load and Stress Calculations

The approach used for dynamic or impact load determination in the SEISMO module is approximated based on the principle of conservation of energy. This approach assumes that the potential energy associated with freely falling rock is converted completely to strain energy imparted to the WPs during impact. Several other assumptions are also made: (i) a WP can be treated as an equivalent spring with a spring constant, $k$wp, (ii) the deformation of WPs is directly proportional to the magnitude of the dynamically applied force, (iii) no energy dissipation takes place at the point of impact due to local inelastic deformation of the WP material, and (iv) the inertia of the WP resisting an impact may be neglected.

Based on the previous assumptions, the impact load can be approximated using the following equation (Popov, 1970):

$$P_{\text{dyn}} = W\left(1+\sqrt{\left(1+\frac{2hk_{\text{wp}}}{W}\right)}\right) = W\left(1+\sqrt{\frac{2h}{\Delta_{\text{st}}}}\right) \tag{2}$$

where

P_{dyn}	—	impact load
W	—	weight of the rock falling
h	—	falling distance of rocks to WPs
Δ_{st}	—	spring deformation
k_{wp}	—	stiffness of the WPs

k_{wp} of a WP is defined as the load necessary to produce a unit deflection at the center of a simply supported beam.

The WP supports are considered to be flexible in the SEISMO module. In the current conceptual design, a WP will be sitting on four equally spaced v-shaped thin beams with one vertical cylindrical bar on either side of the v-shaped beam. However, only the two supports at the ends of a WP are considered. Originally, Δ_{st} in Eq. (2) is the static deflection of the object impacted. In order to account for the deformability of WP support, Δ_{st} is made to be equal to

$$\Delta_{st} = \frac{W}{k_{wp}} + \frac{W}{2N_p k_b} \qquad (3)$$

where k_{wp} is stiffness of the WP, $N_p = 2$, which is the number of the supports at the end of a WP, and k_b is stiffness of the vertical bars.

k_b can be calculated by

$$k_b = \frac{AE}{L} \qquad (4)$$

and k_{wp} can be calculated by

$$k_{wp} = \frac{48EI}{L_{wp}^3} \qquad (5)$$

where A and L are the cross-sectional area and height of the vertical bar.

L_{wp}	—	length of the WP
I	—	$\pi R_{avg}{}^3 t$
t	—	thickness of WP considering both inner and outer layers
R_{avg}	—	average of the outer and inner wall radius of the WP

No information regarding the shape and dimension of the bar is currently available.

From the impact load, the equivalent static stress resulting from the impact can be calculated by adopting a simple concept of two spheres in contact and assuming that the pressure is distributed over a small circle of contact with the sphere representing rock has an infinite radius (Timoshenko and Goodier, 1987), the impact pressure, p, can be obtained by

$$p = \frac{3}{2\pi}\left(\frac{16P_{\text{dyn}}}{9\pi^2}\frac{1}{\left(c_{\text{wp}} + c_{\text{rock}}\right)^2 R_{\text{wp}}^2}\right)^{\frac{1}{3}} \tag{6}$$

where

R_{wp}	—	radius of lower sphere or WP
c_{wp}	—	material constant for lower sphere or WP
c_{rock}	—	material constant for upper sphere or rockfall

$$c_{\text{wp}} = \frac{1-\mu_{\text{wp}}^2}{\pi E_{\text{wp}}} \tag{7}$$

$$c_{\text{rock}} = \frac{1-\mu_{\text{wp}}^2}{\pi E_{\text{rock}}} \tag{8}$$

where

E_{wp}	—	modulus of elasticity of lower sphere or WP
μ_{wp}	—	Poisson's ratio of lower sphere or WP
E_{rock}	—	modulus of elasticity of upper sphere or rockfall
μ_{rock}	—	Poisson's ratio of upper sphere or rockfall

The assumption made for the WPs, spherical in shape instead of a cylinder, is believed to give a conservative calculation of impact stress since the contact area calculated using this assumption is smaller than that from assuming a cylindrical shape.

Failure Criterion

To judge the failure of a WP, a maximum allowable strain failure criterion is adopted in the SEISMO module. If the impact stress calculated using Eq. (6) induces a total strain at the contact of impact exceeding 2 percent (Timoshenko, 1956), the WPs are assumed to be ruptured. This assumption should provide a conservative approach for estimating failure of WPs. The potential damage that rockfall can cause to the SNF cladding is currently not accounted for in the SEISMO module.

Limitations of the SEISMO Approach

Although the current SEISMO module does not link seismicity with corrosion, over time, corrosion could weaken WPs and make them more susceptible to failure by seismically induced rockfall. Conversely, the damage resulting from rockfall could weaken WPs and make them more susceptible to corrosion over time. In the current SEISMO module, these conditions are not included. These conditions may be considered in the future revision of the SEISMO module.

For calculation of the rockfall impact load, the falling rocks are assumed to remain intact (that is, all energy generated through dynamic impact is transferred to the WP). If rock is allowed to break, the effective impact stress on the WP should be smaller since some impact energy will be absorbed by breaking the rock. Consequently, assuming that the falling rock blocks remain intact is conservative in assessing integrity of WPs.

The SEISMO module in its current form does not take into consideration cumulative damage due to repeated rockfalls. Some work will need to be done to address this limitation.

U.S. Department of Energy Total System Performance Assessment–Viability Assessment and Technical Basis Document

The DOE completed the VA report (U.S. Department of Energy, 1998f) of the YM site in 1998 at the direction of the U.S. Congress. The VA "describes the strategies that DOE has developed to deal with uncertainties associated with estimates of long-term repository performance and to ensure that public health and safety will be protected before and after the repository is permanently closed" (U.S. Department of Energy, 1998f). This VA report also contains three key components of site characterization—testing, design, and TSPA.

From a technical perspective, the TSPA portion of the VA [Volume 3 of the VA (U.S. Department of Energy, 1998g), referred to as TSPA-VA] and the Technical Basis Document (TBD) (CRWMS M&O, 1998f), which contains supporting analyses used in the TSPA-VA, have the most relevance to the RDTME KTI. Of these two documents, the TBD contains greater detail. A summary review of the TBD and the referred documents related to RDTME is provided in the following section. The main focus of the review is placed on the TBD, Section 10.5.1, Rockfall.

Technical Basis Document, Section 10.5.1: Rockfall

Section 10.5.1 of the TBD addresses the rockfall model, which describes the likelihood of earthquake-induced rockfall, potential size of rockfall, and the consequence to WP integrity and radionuclide releases. The possible effects of seismic disturbance (vibratory ground-motion or fault displacement) include rockfall damage to WPs and change in flow pattern near the emplacement horizon. From DOE's perspective, rockfall is expected to be the primary source of WP disturbance (CRWMS M&O, 1998f).

Available Rock Block Size in the Exploratory Studies Facility

The distribution of rock block sizes determined in CRWMS M&O (1997a), which was based on the joint spacings obtained from the scanline mapping in the ESF, was used in the TBD to assess rockfall effects on WP disturbance. The rock block size was estimated using the approach suggested by Palmstrøm (1996)

$$V_b = \beta\, J_v^{-3} \tag{9}$$

where V_b is the block size (volume), β is the block shape factor, and J_v is the volumetric joint count. Separate equations are available for determining β and J_v (Palmstrøm, 1996). For simplicity, the joints are assumed to intersect at right angles to form a block (CRWMS M&O, 1997a). The rock size distribution was conveniently divided into four rock quality designations.

Estimation of Rockfall Due to Ground Motion

It is difficult to estimate the extent of damage and rockfall of underground excavations subjected to ground-motions. The level of damage and amount of rockfall as a result of vibratory ground-motions depend heavily on the related rock mass conditions (rock types), state of stresses, and ground supports. An empirical equation proposed by Kaiser et al. (1992) was used in the TBD to estimate the damage to underground excavations caused by shaking. This equation was developed for assessing rockburst-induced tunnel damage for underground mines in Sudbury, Ontario, Canada, and is qualitative in nature. This equation was modified in the TBD to account for the effect of rock mass conditions, as follows:

$$DL = \frac{\ln\left(\frac{PGV}{5}\right)}{\ln(2)} - 2.33 + 1.33\,IC \qquad (10)$$

where DL is the damage level, a qualitative damage index; PGV is the peak ground velocity; and IC is the measure of rock condition related to rock wall quality, failure potential, local mining stiffness, support effectiveness, and temperature (CRWMS M&O, 1997a).

It is worth noting that Eq. (10) was developed for assessing tunnel damage caused by rockbursts. The ground shaking signals associated with rockbursts are of relatively short duration and high frequency (Hsiung et al., 1992), whereas earthquakes involve longer duration and relatively lower frequency ground-motions. Consequently, applicability of the damage level assessment empirical equation to the YM site needs to be verified.

The IC values in Eq. (10) were assigned to each of the four rock quality designations based on an assessment of ESF data (CRWMS M&O, 1997a). The technical basis for assigning these values is not provided in the TBD. Because the rock quality designations are related to rock block sizes as indicated in the previous section, DL can be related to the available rock block sizes through Eq. (10). (Note that the rock size referred to here and for the rest of this paragraph means rock mass.) However, this relationship did not seem to be used in Section 10.5.1.6, Development of Rockfall Model Source Term, to determine the rock size needed to assess damage to WPs. Instead, two additional terms were introduced: size of rock expected from DL and size of rock from a probability density function (PDF). The rock size from a PDF was compared with the critical rock size required to damage WPs. If the former is larger, the WP impacted is judged to be damaged. No discussion is provided in the TBD regarding how the size of rock expected from a given DL is determined, nor does it present clearly how the size of rock is determined from a PDF.

Furthermore, there appears to be a miscalculation of DL, for example, in Tables 10-28 and 10-30a where DL values are consistently underestimated. A close examination of the DL values provided in these tables indicate that they were determined using

$$DL = \ln\left(\frac{PGV}{5}\right) - 2.33 + 1.33\,IC \qquad (11)$$

Figure 19 graphically shows the difference of *DL* values calculated for various peak ground velocity (PGVs) using these two equations. The calculated *DL* value is about 40 percent smaller for strong rock and about 30 percent smaller for the medium rock if Eq. (11) is used. It is not clear which equation was intended to be used in the TBD. If Eq. (11) is the correct equation, DOE needs to provide justification. If the use of Eq. (11) is a mistake, this mistake needs to be corrected and the rockfall effect on WP damage reevaluated.

~~*Determination of Peak Ground Velocity*~~

~~To sample the *PGV* for estimating rockfall, the TBD indicated that the annual probability of exceedence curve for horizontal *PGV* from Figure 7-8 of the Probability Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada, Final Report, Volume 1 Text was used. (The same figure was reproduced in the TBD.) The referenced report is dated June 15, 1998. This report has been subsequently revised and published on September 23, 1998. Figure 7-7 of the revised report contains the annual probability of exceedence curve for horizontal *PGV*. Figure 7-7 of the revised September report and Figure 7-8 of the June report are substantially different in shape and annual probability. The new curve appears to produce higher *PGVs* than the one used in the TBD. The effect of the revised curve on WP damage should be evaluated.~~

Waste Package Damage Criteria

The TBD considered two forms of rockfall damage to WPs: through-wall cracks and crack initiation. The rock size necessary to cause these two types of damage was estimated by dynamically modeling the rockfall impact on WPs (CRWMS M&O, 1996c,d). The dynamic analysis conducted in the two reports published by CRWMS M&O (1996c,d) assumed that the rock was spherical in shape. The report stated, "This assumption provides a bounding approach to the problem since the most severe effect of impact on the WP will be determined without any failure on the rock surface." This assumption appears to be reasonable. In a CNWRA analysis, (Gute et al, 1999) the effects of several types of impact contacts were analyzed. The results indicate that a spherical rock would appear to cause the most damage to the WPs and thus would represent a bounding case. Work is continuing in this area, however, to determine whether the strain energy distribution through the thickness of the WP wall, at the point of impact, can provide additional information as to the relative significance of rock size and shape.

The FE analysis conducted in both reports models a section of the WP (in the middle span) about 1.5 m in length. This length is about the distance between two adjacent pedestal supports. Both reports (CRWMS M&O, 1996c,d) postulate that, "since the middle section of the WP provides a smaller length than the full WP length, the finite element model is conservative." This assertion is based on the understanding that the bending stress on a beam is directly proportional to the square root of the beam length (CRWMS M&O, 1996c,d). In both reports, the beam length is assumed to be the length of a WP. The assumption of conservativeness does not seem to be justifiable because the beam length used in calculating bending stress is the length between two adjacent supports (for a simply supported beam). In the case of the support configuration proposed for the WPs, the beam length is 1.5 m. Consequently, using the 1.5-m section for modeling is reasonable and not necessarily conservative as both reports have stated.

In determining the fall height of a rock, degradation (thinning as a result of corrosion) of WPs was considered (CRWMS M&O, 1996c,d). The fall height is the vertical distance between the bottom of a rock before it falls and the top of the WP. The bottom of the rock before it falls was fixed to coincide with the crown of the emplacement drift (CRWMS M&O, 1996c,d). While assuming a fixed full height appears to be a good first approximation, it does not allow for consideration of the increased height of fall for subsequent rockfalls at the same location. In that situation, the fall height will be greater and so will be the effect of the same size rock. In addition, the vertical velocity of the WP and the initial velocity of the rock when it becomes dislodged due to the seismic ground-motion have not been taken into consideration.

Another area of concern pertaining to the work documented in the reports (CRWMS M&O, 1996a,b) is the use of a maximum normal stress failure criterion to establish rupture of the WP outer barrier due to rockfall. Specifically, the M&O CRWMS 1996b report states, in assumption 4.3.15,

> "The materials are assumed to reach the ultimate tensile strength at the maximum percent elongation. The basis for this assumption is that the failure criteria are based on the ultimate tensile strength of the materials, and not on the path followed by the curve in the plastic region of the stress-strain diagram. Hence, the stress distribution results are conservative in this analysis."

Except under a very limited set of special conditions (e.g., extremely low temperature) a failed tensile test specimen of a ductile metal will exhibit failed surfaces that are at a 45° angle with respect to the specimen's cross section. This is clearly indicative of failure due to shearing. When subjected to more general types of three-dimensional model (3D) stress conditions, the appropriate failure criterion should be based on the same failure mode as was observed for the tensile test specimen. Moreover, it can be demonstrated by a simple Mohr's circle diagram that there are generalized 3D stress states that will fall within the acceptable bounds of the maximum-normal-stress-theory, but will fall well outside the bounds of an acceptable out-of-plane shear stress. Development of a generalized failure criterion for ductile metals is not a trivial matter and more work needs to be done in this area. However, it needs to be emphasized that the use of the maximum-normal-stress-theory as a failure criterion for predicting the rupture of the WP outer barrier is both inappropriate and nonconservative.

Damage to Fuel Rods

The TBD acknowledged that rockfall could cause mechanical failure of spent-fuel rods or shattering of a glass/ceramic waste form through shock and container-wall deformation even if a WP is not breached due to rockfall (CRWMS M&O, 1997a). The damaged fuel rods increase the probability of radionuclide releases when the WP is finally breached due to either rockfall or corrosion. The TBD also presented some results of an analysis of the effects of rock configurations on fuel rod damage. Rockfall effects on fuel rod damage and related dose calculation were discussed in Section 6 of the TBD. The evaluation of these effects will be included in the IRSR of the Container Life and Source Term KTI.

Time Periods for Waste Package Damage Assessment

The TBD calculated WP damage for four time periods: 0 to 1,000 years, 0 to 10,000 years, 0 to 100,000 years, and 0 to 1,000,000 years. In each time period, 500 event times were randomly drawn

(CRWMS M&O, 1997a, Section 10.5.1.6). Consequently, the event frequency for each time period is 0.5 event/year, 0.05 event/year, 0.005 event/year, and 0.0005 event/year, respectively. It seems clear that more emphasis of rockfall effect was placed on early times of the repository performance because the event frequency considered is much higher. No discussion is provided in the TBD why the emphasis was placed on early time periods, especially from 0 to 1,000 years in which the WP experienced little degradation and rockfall was deemed to have no effect on WP damage.

In determining the rockfall model source term, "the fall of a single rock size (the largest possible for the PGV selected) per event" (CRWMS M&O, 1997a, Section 10.5.1.6) was modeled. This approach appears not to be conservative. CRWMS M&O recognizes this and stated in the TBD that, "clearly, many rocks fall during an earthquake. Future analyses will incorporate multiple rockfalls into the integrated corrosion-rockfall WP degradation model."

4.2.3 Thermal-Mechanical Effects on Flow into Emplacement Drifts

In the current DOE approach to repository design, the ground-support system for the emplacement drifts would be designed to maintain stability of the openings during the preclosure period only. That is, no credit would be taken for the effectiveness of the ground-support system, and no technical evaluation of such effectiveness would be provided for the post closure period. As a result, the support system is assumed to have completely lost its effectiveness in the analyses of the postclosure behavior of the emplacement openings (e.g., U.S. Department of Energy, 1998f, Section 2.2.6.1).

The expected behavior of unsupported underground openings under sustained rock mass degradation includes cave-in of the roof, collapse of the sidewalls, and progressive damage of the surrounding rock mass, resulting in an altered zone within, above, and below the repository horizon. The consequent changes in the geometry of the openings (gross shape and size and roughness of the drift surface) and in the fracture porosity and permeability within the altered zone are of interest in assessing the quantities of water flow that may contact the WPs. Change in the geometry of the openings could have significant effect on the potential water dripping into the emplacement drifts. For example, the threshold value of percolation flux at which dripping would begin decreases as the drift surface becomes irregular from rockfall (Hughson and Dodge, 1999). Also, an increase in the altered-zone permeability may result in increased magnitudes of percolation flux at the repository horizon.

The TM effects on flow into emplacement drifts will be addressed jointly by the RDTME and Thermal Effect on Flow KTIs.

~~4.2.3.1 Acceptance Criteria~~

~~The staff will find DOE's consideration of TM effects on input to hydrological flow assessment acceptable if:~~

~~Acceptance Criteria 1:~~	~~Approved QA, control procedures, and standards were applied to collection, development and documentation of data, methods, models and codes.~~
~~Acceptance Criteria 2:~~	~~If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG-1563 (U.S. Nuclear Regulatory Commission, 1996b) or other acceptable approaches.~~

~~Acceptance Criteria 3:~~ ~~Time-dependent changes in size and shape of the emplacement drifts due to thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) are estimated taking into account uncertainties in the context of their impacts on the performance.~~

~~Acceptance Criteria 4:~~ ~~Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are estimated taking into account the uncertainties in the context of their impacts on performance.~~

4.2.3.1 Technical Bases for Review

The focus of the technical bases provided in the following paragraphs is placed on AC 3 and 4. Thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) will affect inputs to hydrological flow assessment in two ways: changes in fracture permeability and porosity associated with rock deformation, and changes in geometry of underground openings. Both effects have been recognized within DOE's program. The assessment of the impact of thermal loading on the fracture porosity and permeability throughout the host rock, particularly near the emplacement drifts and within the intervening pillars is one of the issues that was presented to a panel of experts assembled by DOE to examine the role and assessment of near-field/altered-zone coupled effects (Geomatrix Consultants, Inc., 1998). Also, the fraction of WPs exposed to seepage, referred to as seepage fraction, f_s, is a key input into the assessment of WP degradation and, ultimately, dose to individuals in DOE's TSPA-VA code (Wilson, 1998). The parameter f_s depends on the distribution of seepage on the drift wall, for which the size and shape of the drift are key inputs because of their effects on the capture area for drift seepage (Wilson, 1998; Birkholzer, 1998).

Changes in size and shape of emplacement drifts may result from drift-wall collapse and consequent enlargement of the roof (e.g., Figures 7 and 16). Changes in fracture permeability and porosity may result from both elastic deformations (caused by reversible thermal expansion of rock) and inelastic deformations (associated with failure in shear or tension). Adequate assessment of thermally induced changes in porosity and permeability requires consideration of both elastic and inelastic processes, because the magnitude of thermally induced elastic deformations may be small relative to the potential magnitude of inelastic deformations that may result due to failure caused by rock-mass degradation. For example, the assessment of permeability changes suggested by Elsworth (1998), which is based purely on consideration of elastic deformations, is likely to give only a lower-bound estimate of the potential permeability change.

It is DOE's decision to design the ground supports to maintain stability of the emplacement drifts for the preclosure period only, therefore, the continuing function of the ground supports beyond permanent closure cannot be assured. Consequently, the underground openings must be assumed to be unsupported during the postclosure period. Postclosure response within the underground facility will be controlled by thermal stresses imposed on a rock mass that may be experiencing progressive degradation of strength and elastic properties caused by sustained loading and extended exposure to heat and moisture. The expected behavior around unsupported underground openings under such conditions includes collapse of the surrounding rock into the openings and consequent cave-in of the roof area, leading to changes in geometry (size and shape) of the openings and changes in hydrological properties (such as fracture porosity and permeability) in the vicinity of the openings (see Figure 16).

An assessment of such potential changes in porosity and permeability as well as changes in emplacement-drift geometry will be considered by other KTIs as appropriate.

4.3 DESIGN AND LONG-TERM CONTRIBUTION OF REPOSITORY SEALS IN MEETING POSTCLOSURE PERFORMANCE OBJECTIVES

This subissue is closed.

~~This subissue will be addressed in subsequent revisions of this IRSR.~~

~~4.3.1 Review Methods~~

~~The review methods will be developed in subsequent revisions of this IRSR, if necessary.~~

~~4.3.2 Acceptance Criteria~~

~~The acceptance criteria will be developed in subsequent revisions of this IRSR, if necessary.~~

4.3.1 ~~Technical Bases~~

~~Technical bases will be described in future revisions to this IRSR.~~

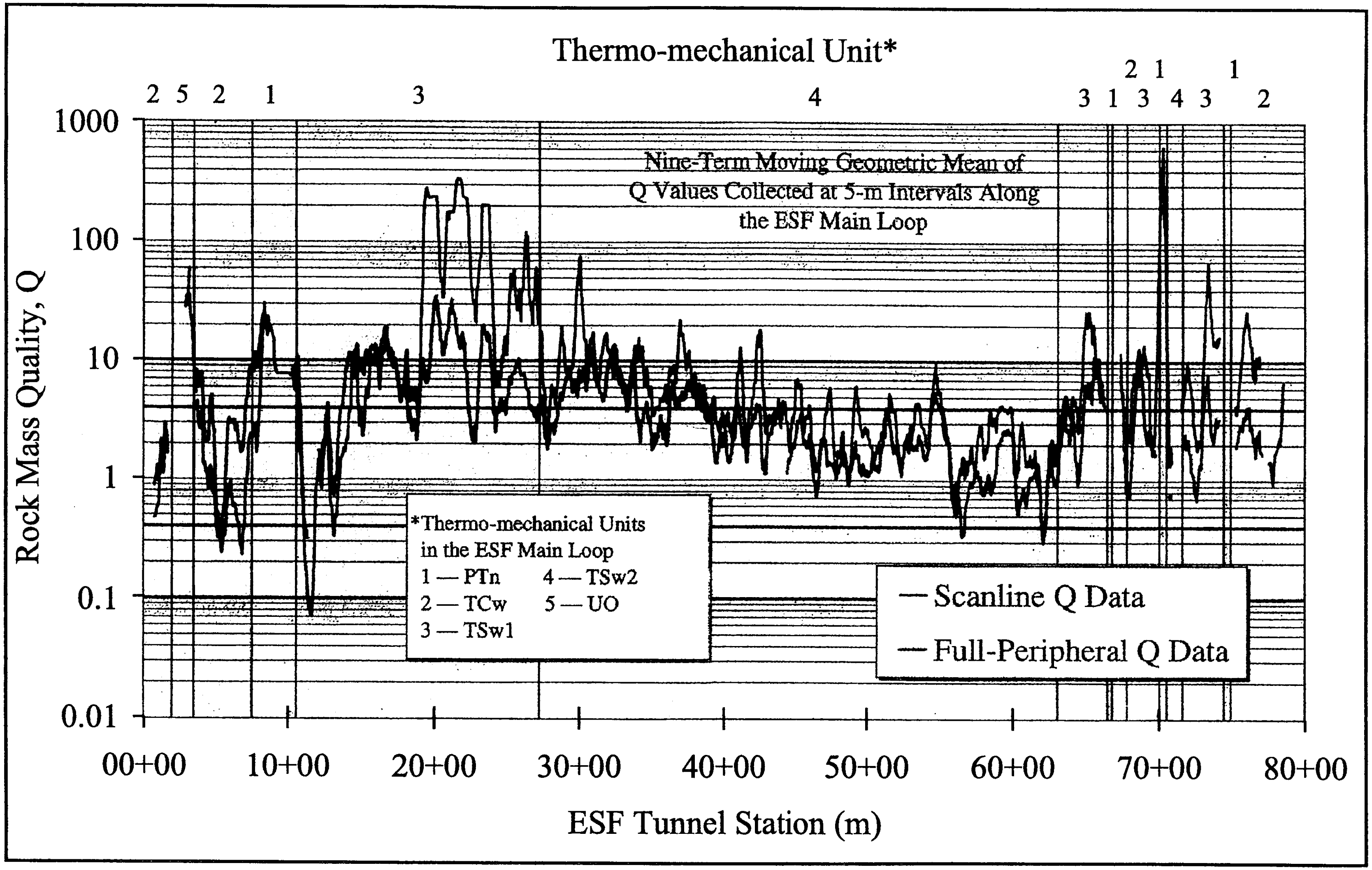

Figure 2. Profile of rock-mass quality, *Q*, along the Exploratory Studies Facility (CRWMS M&O, 1997a)

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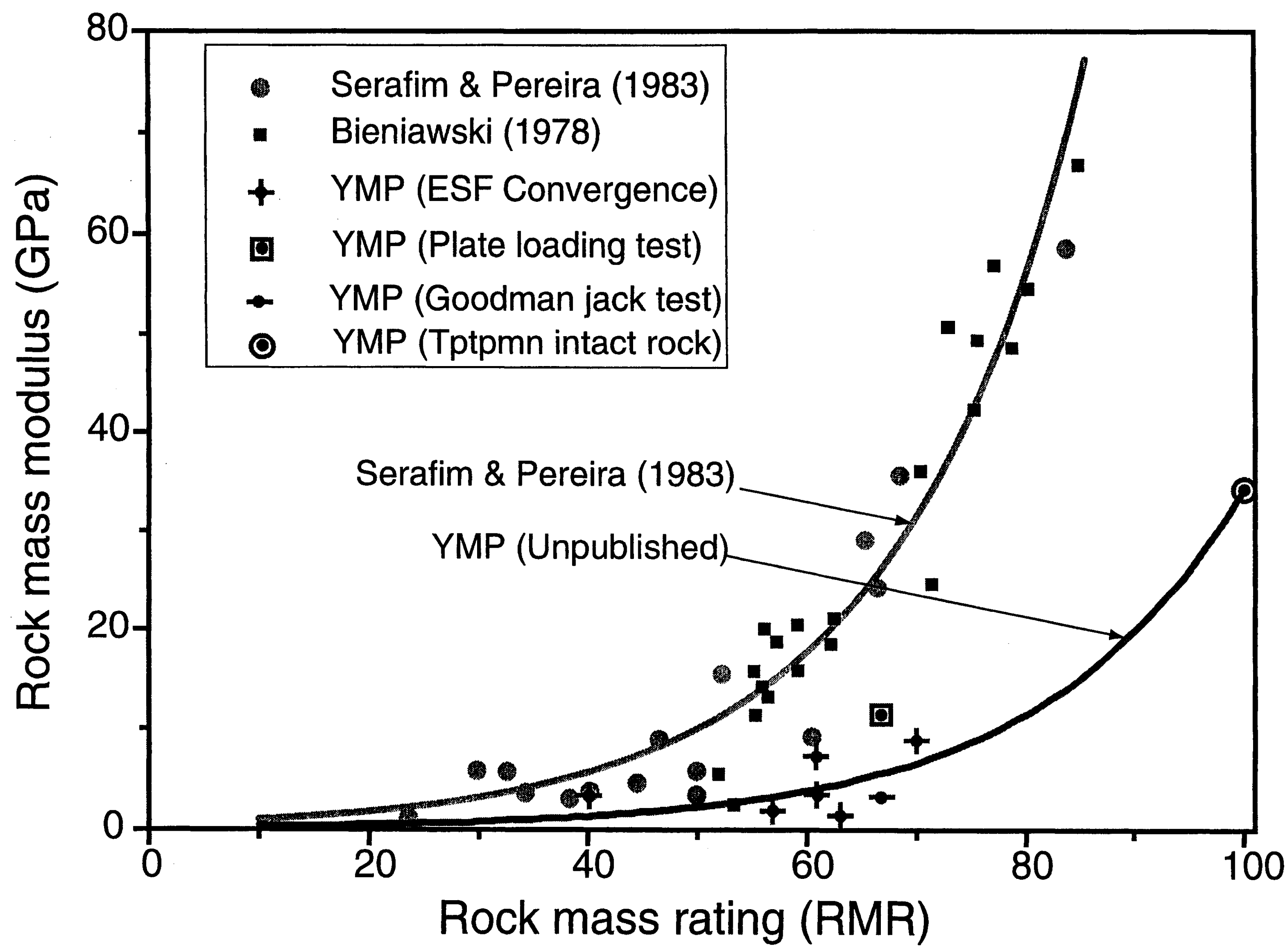

Figure 3. Variation of rock-mass modulus with rock-mass rating based on data available from the literature and the Yucca Mountain Project. The figure shows a curve suggested recently for YM tuff (Lin, 1998), the validity of which is questionable because the curve was derived by extrapolation of sparse rock-mass modulus data to intact rock.

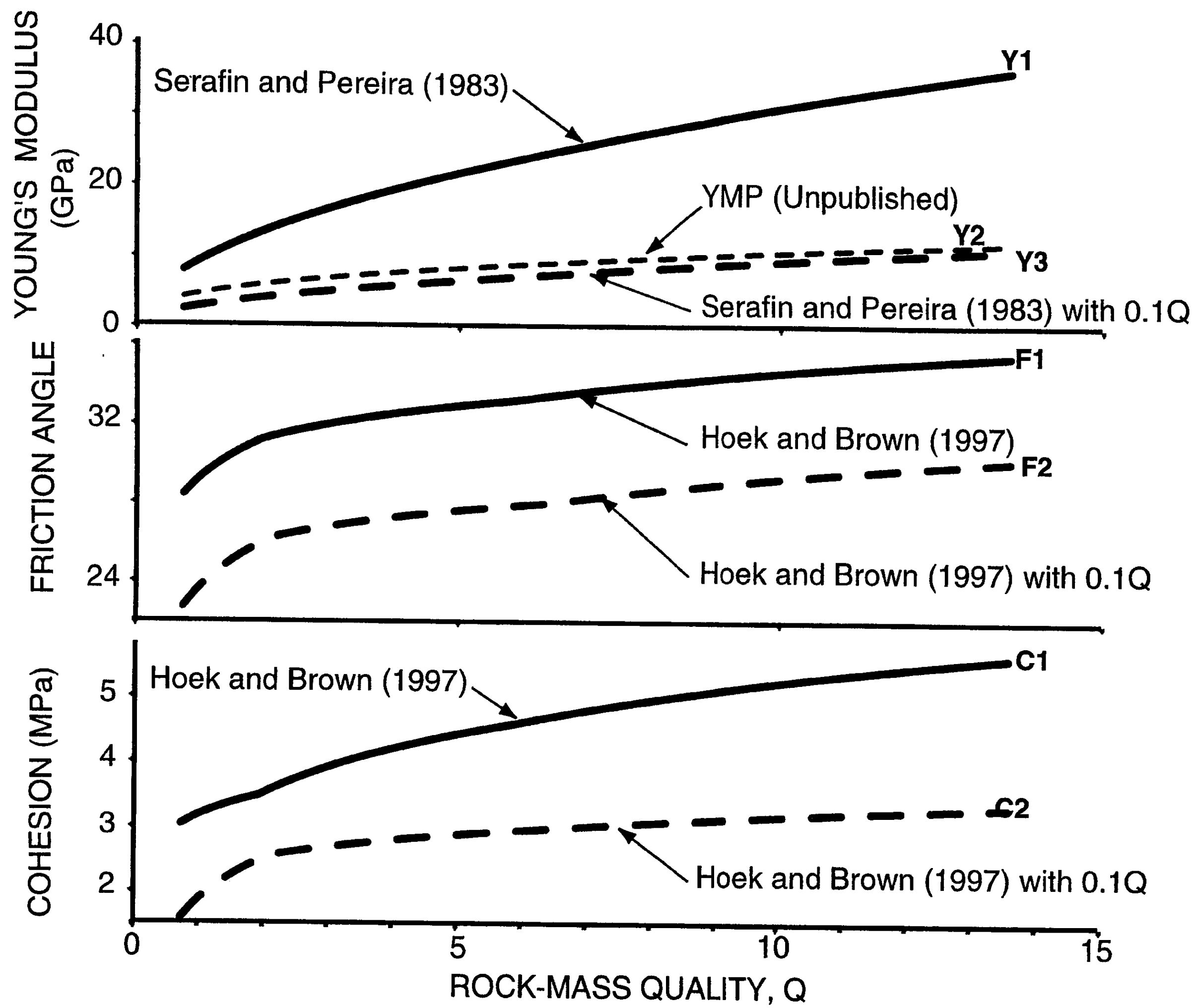

Figure 4. Mechanical parameters estimated from *Q* for the TSw2 stratigraphic unit using empirical relationships (Hoek, 1994; Hoek and Brown, 1997) for: (i) current rock-mass conditions (curves Y1, F1, and C1); and (ii) degraded rock-mass conditions (curves Y3, F2, and C2). The reduction of *Q* to 10 percent of its current value simulates the effects of fracture-wall alterations from extended exposure to heat and moisture. The curve Y2, which is of questionable validity as indicated in Figure 3, is shown here to emphasize its relationship with the other Young's-modulus curves.

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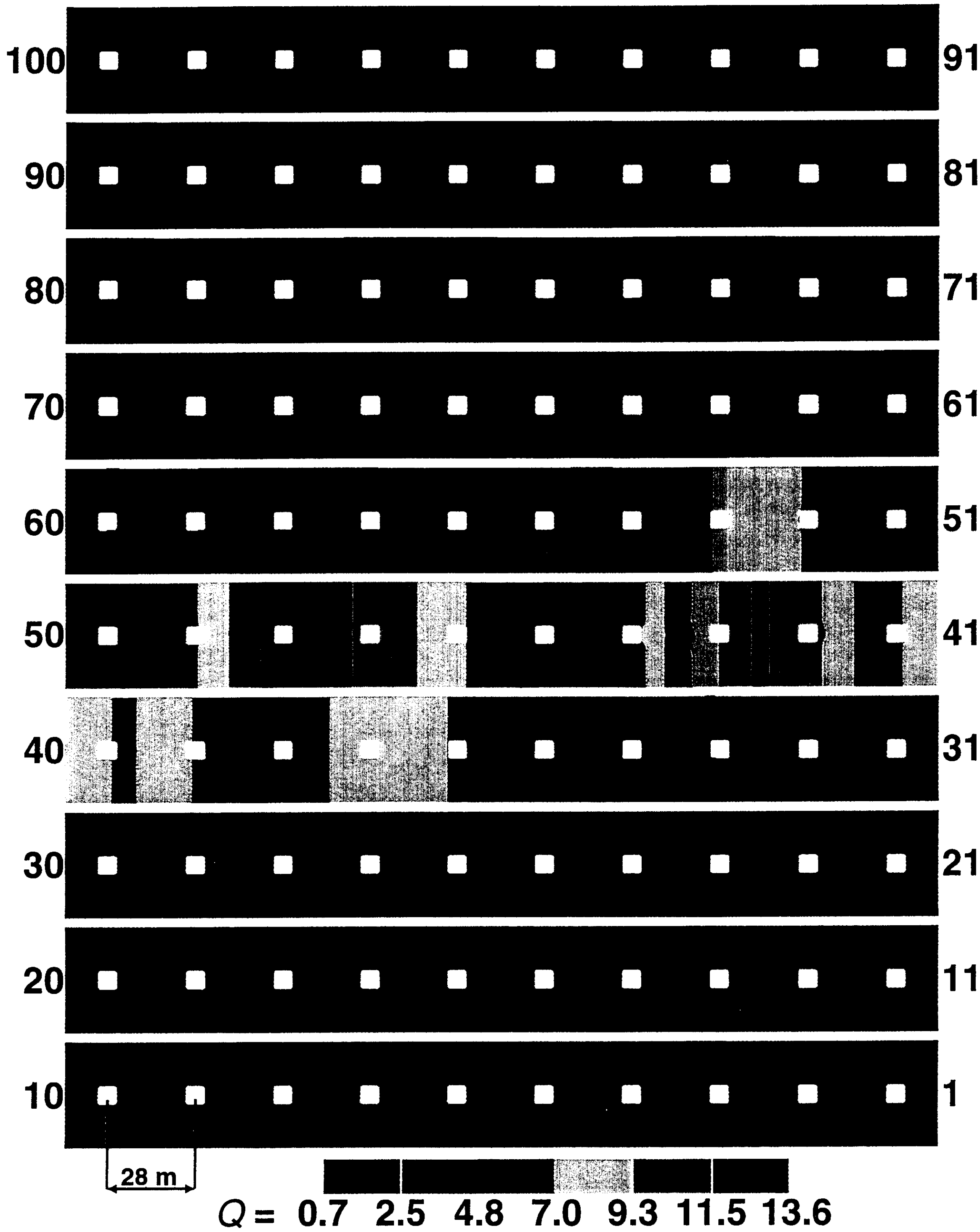

Figure 5. South-to-north profile of rock-mass quality, *Q*, adopted from the ESF main-drift profile. The profile is presented in ten 35-m high and 280-m long sections. Each section includes 10 drifts (end-drift numbers shown). Drifts #1 and #100 are at the north and south ends of the drift array. Areas between drifts #1 and #32, which fall outside of the ESF main-drift alignment, were assigned the *Q* value for #32.

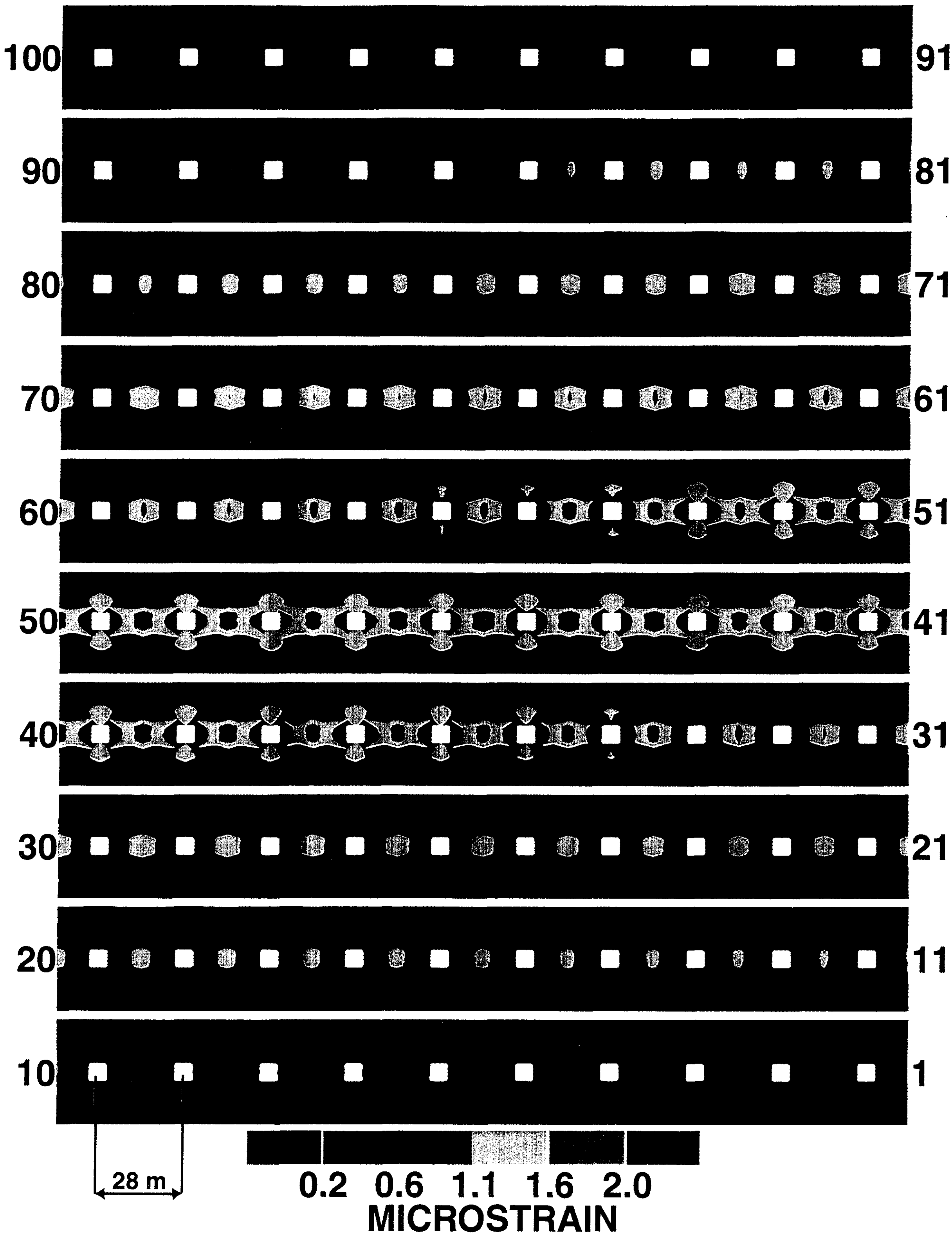

Figure 6. Inelastic strain distribution at 150 years with stiff drift support, shown in 10 sections as explained in Figure 5.

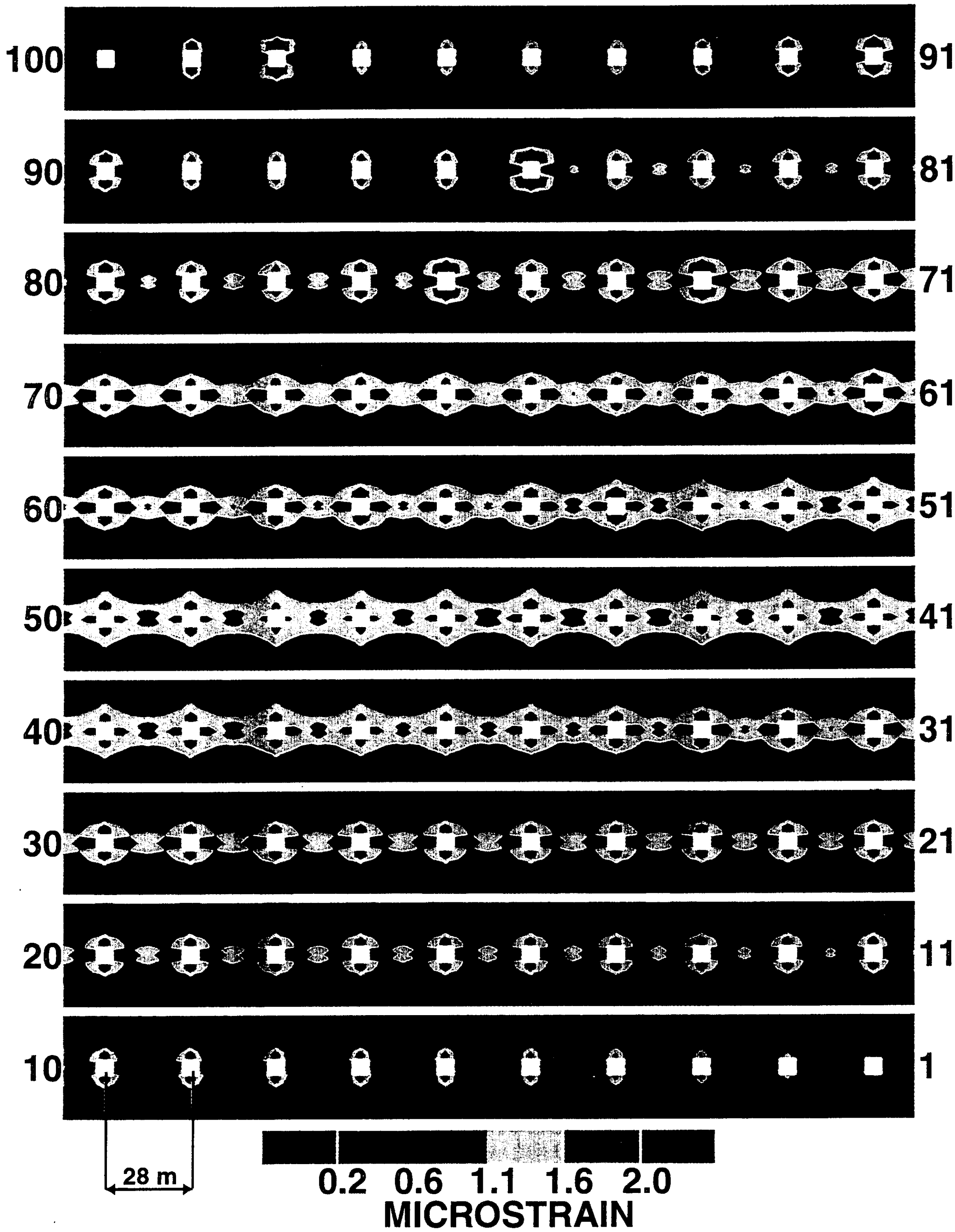

Figure 7. Inelastic strain distribution at 150 years with degraded drift support. Support degradation was simulated by deactivating the support system rapidly (over 1 year) after 150 years.

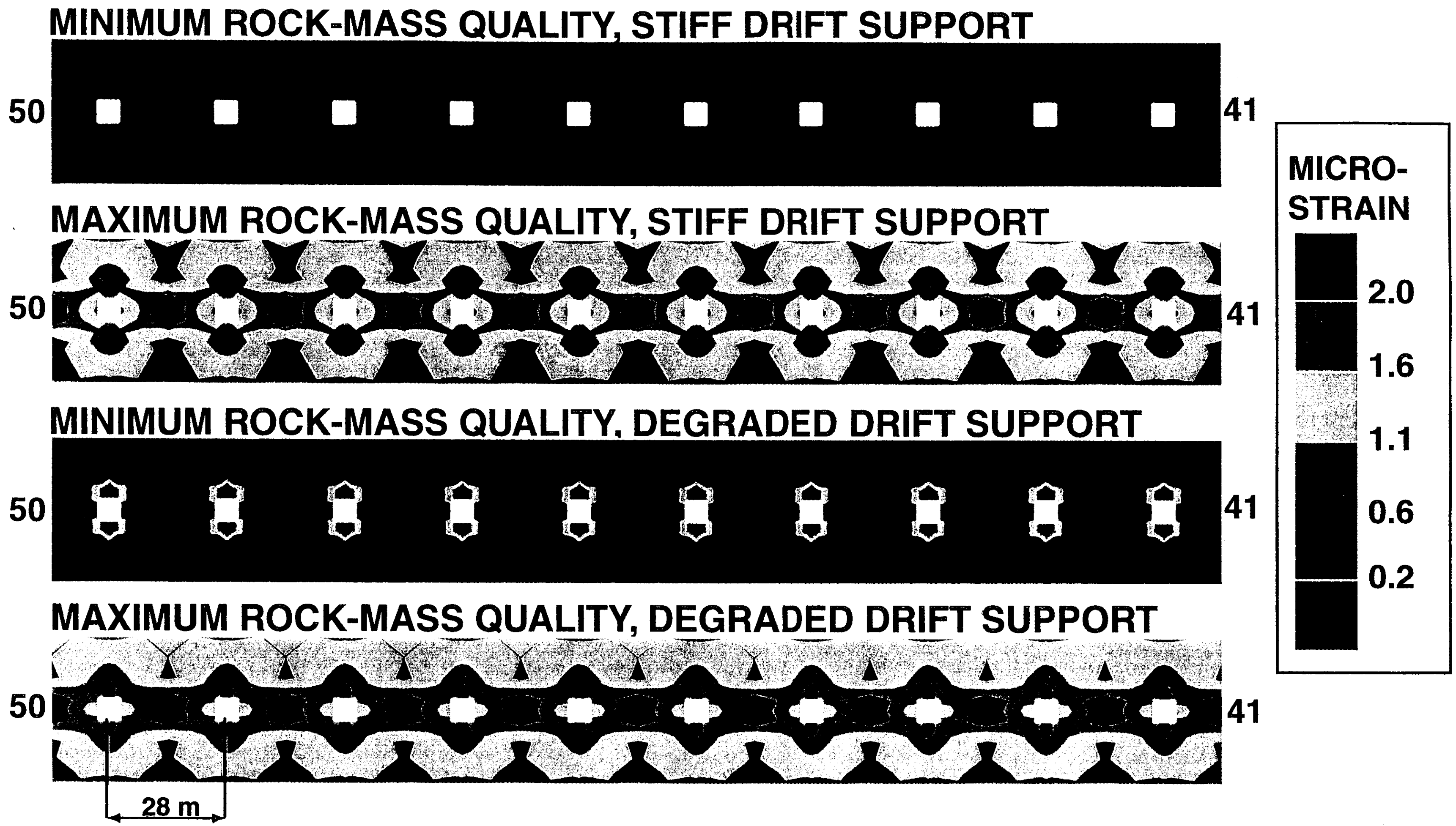

Figure 8. Inelastic strain distributions between drifts #41 and #50 at 150 years, from homogeneous models. Analyses were performed using the parameter values that correspond with the minimum and maximum *Q* values on curves Y1, F2, and C2 in Figure 4.

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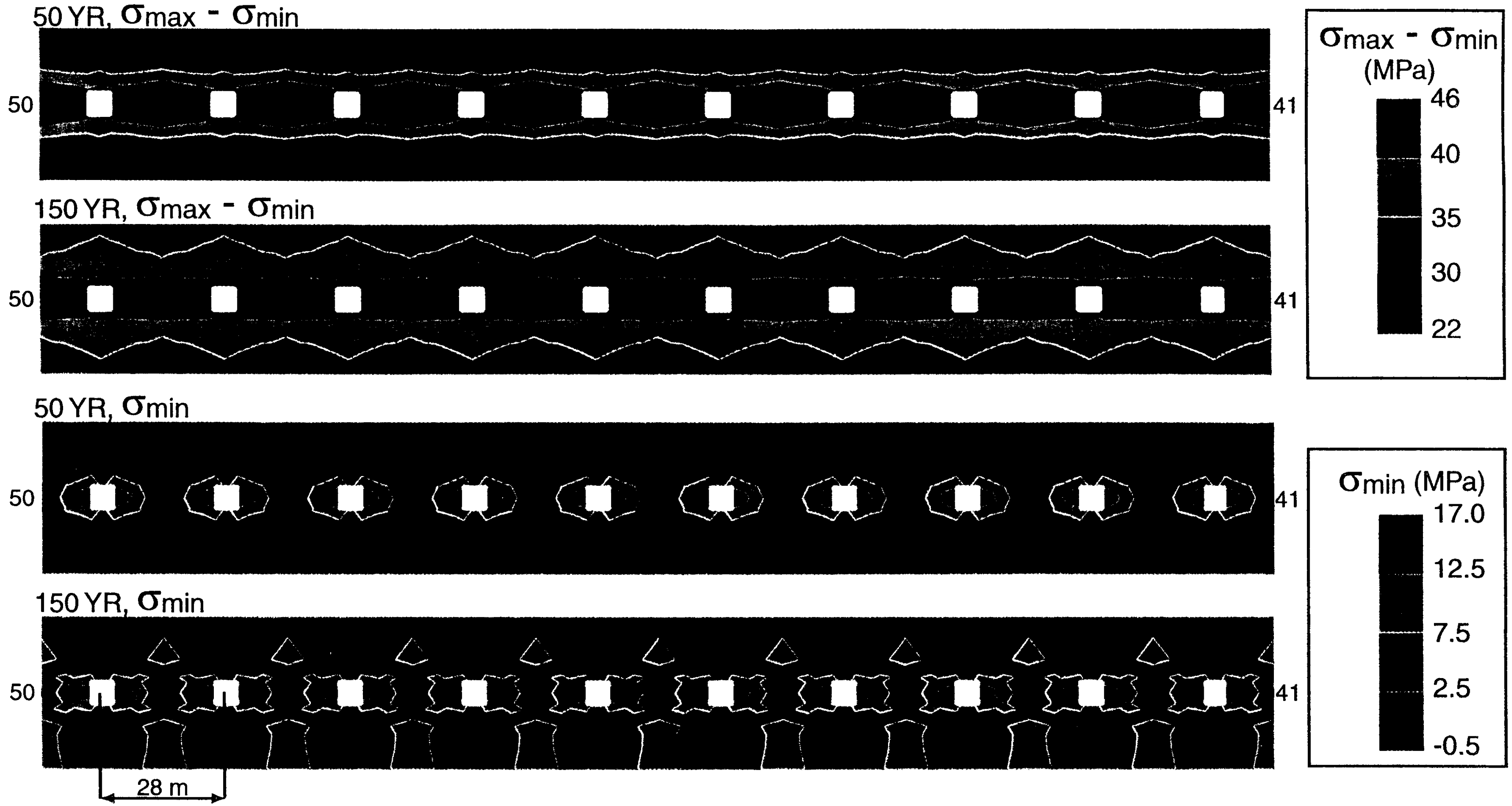

Figure 9. Distribution of principal stress difference ($\sigma_{max} - \sigma_{min}$) and minimum principal stress (σ_{min}) from a homogeneous, linear-elastic model with stiff drift support and Young's modulus corresponding to the maximum *Q* value on curve Y1 of Figure 4.

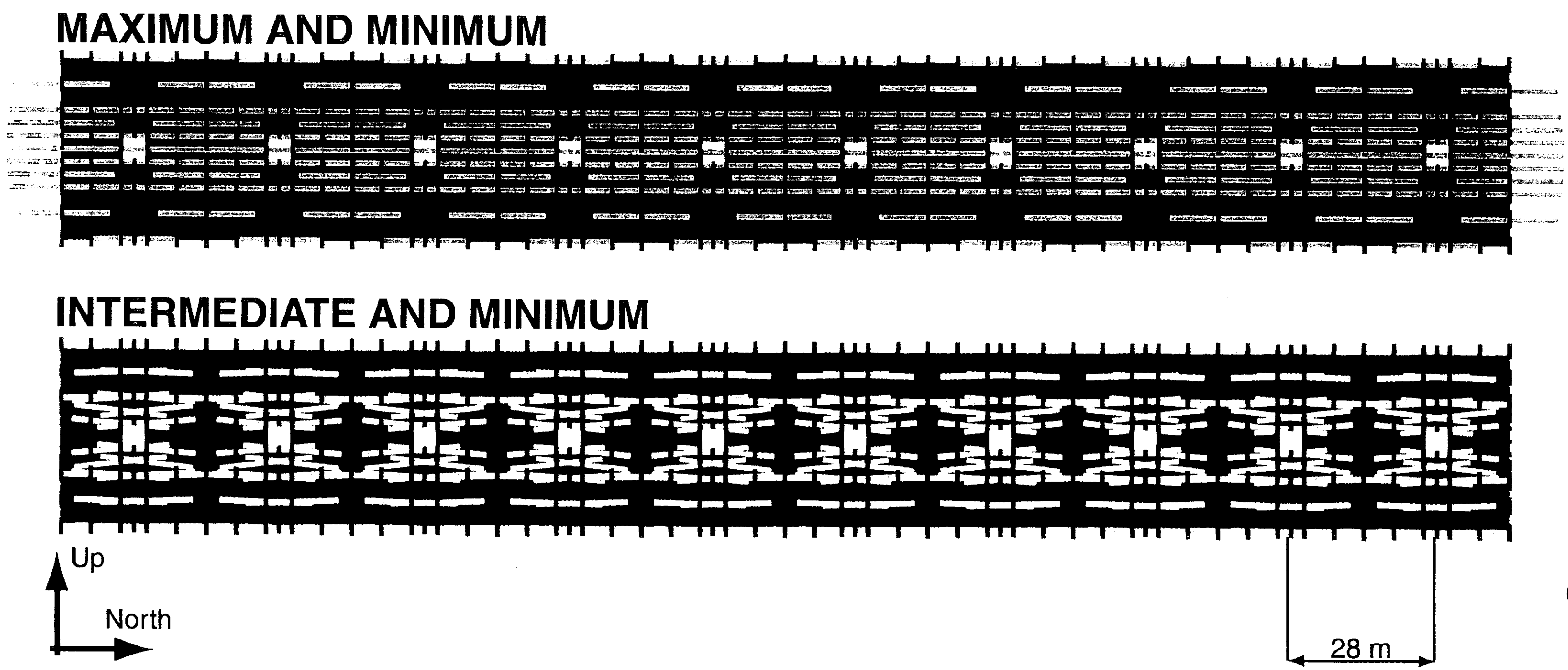

Figure 10. Principal stress orientations from a homogeneous, linear-elastic model with stiff drift support. Each plot shows the orientations of the in-plane principal stress components only, so the plots demonstrate that the maximum principal stress is in-plane (~north-south) in the pillars and out-of-plane (~east-west) in the roof and floor.

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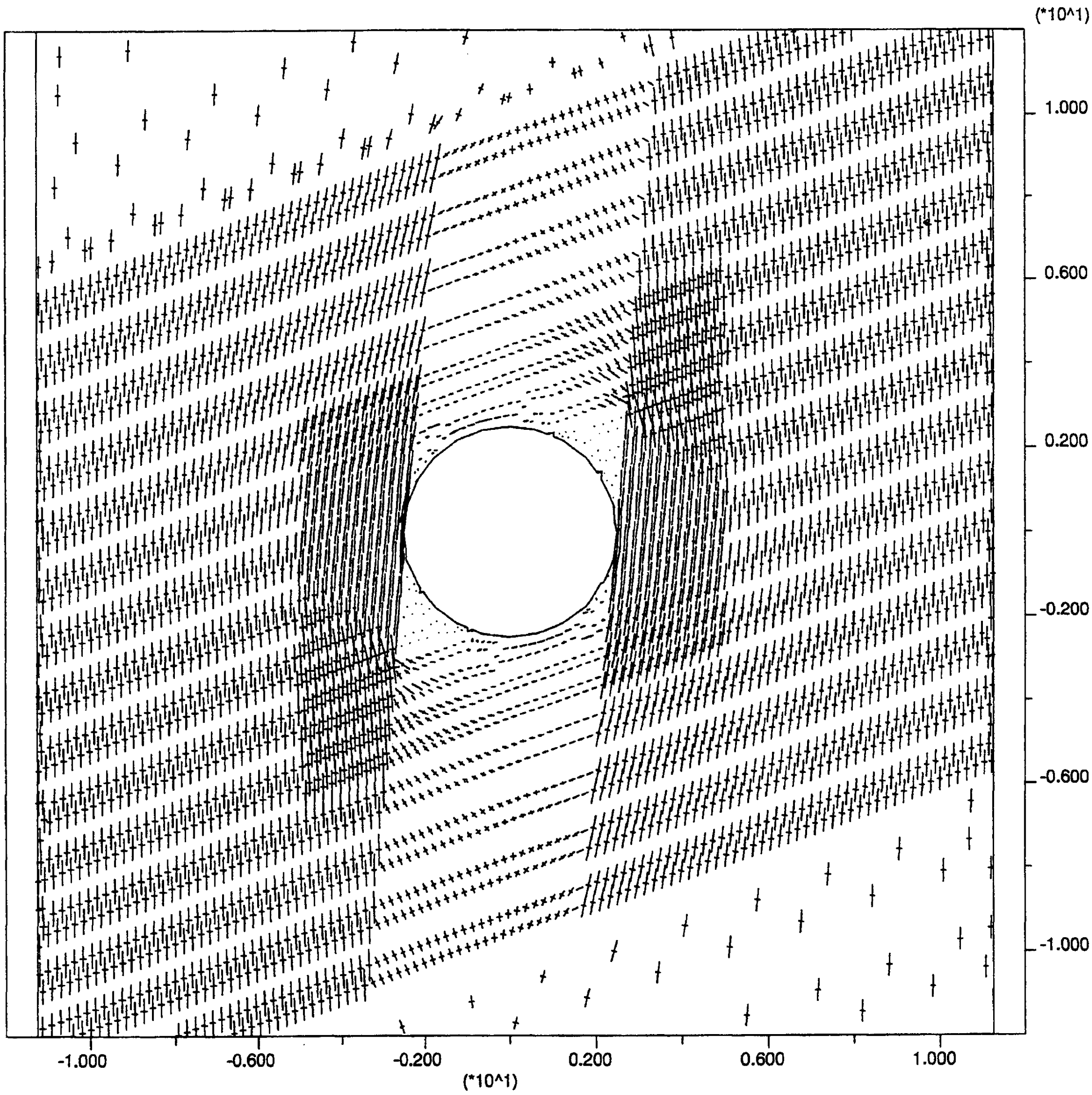

Figure 11. Distribution of principal stresses after drift excavation

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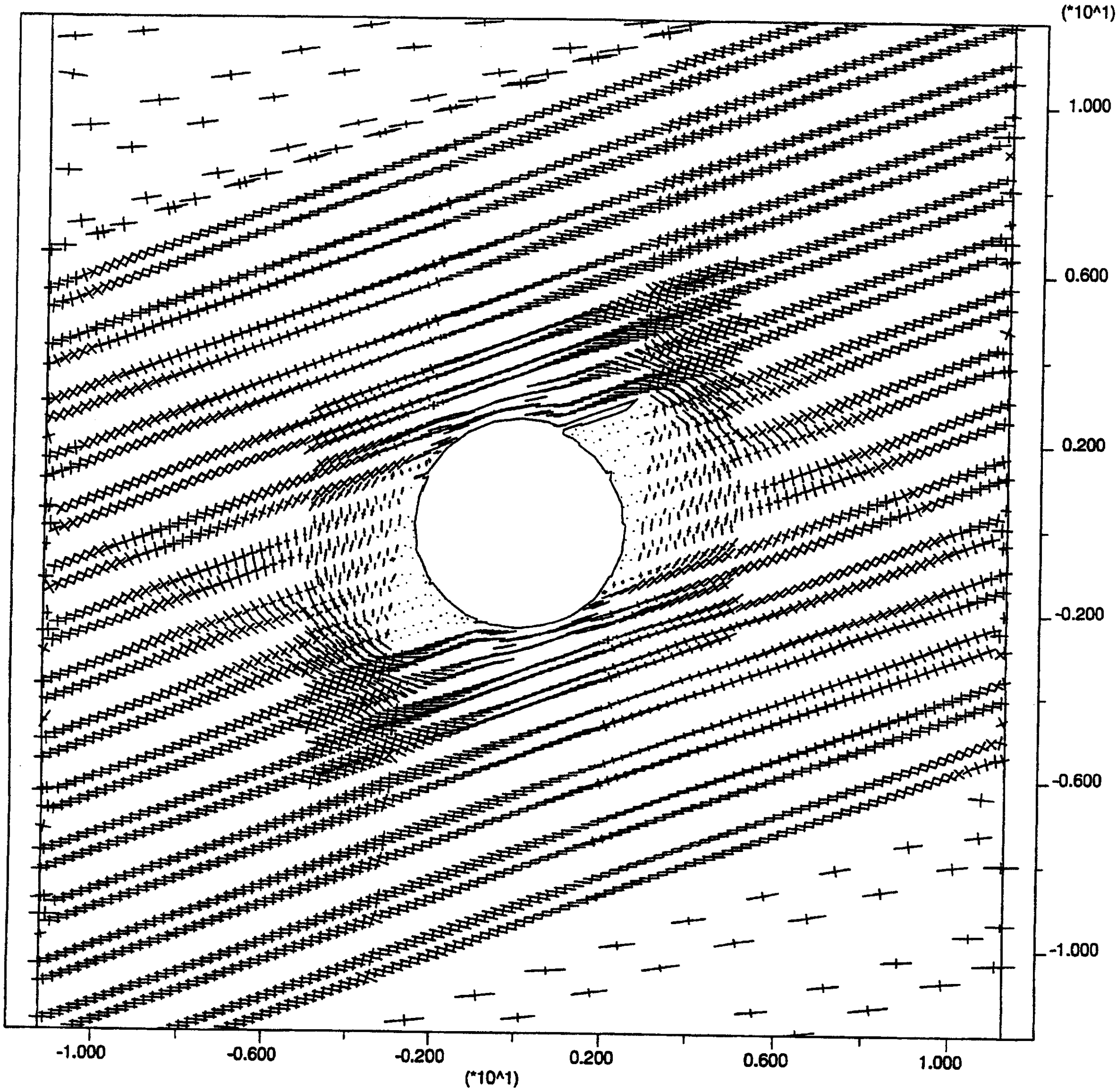
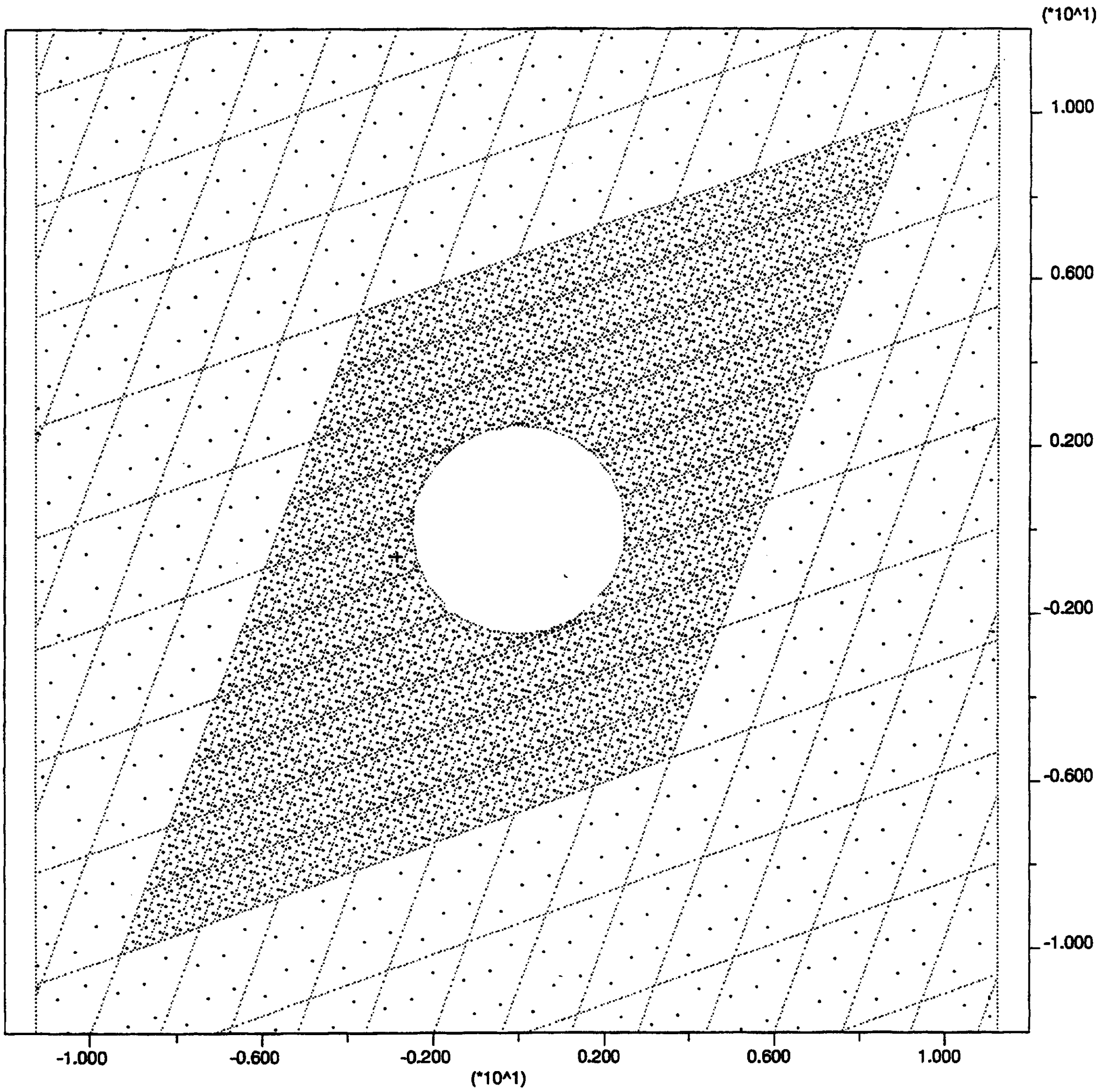


Figure 12. Distribution of principal stresses after 100 years of heating



Note: Dots represent elastic state. Crosses represent yield zones. Dash lines represent joints.

Figure 13. Distribution of yielding after drift excavation

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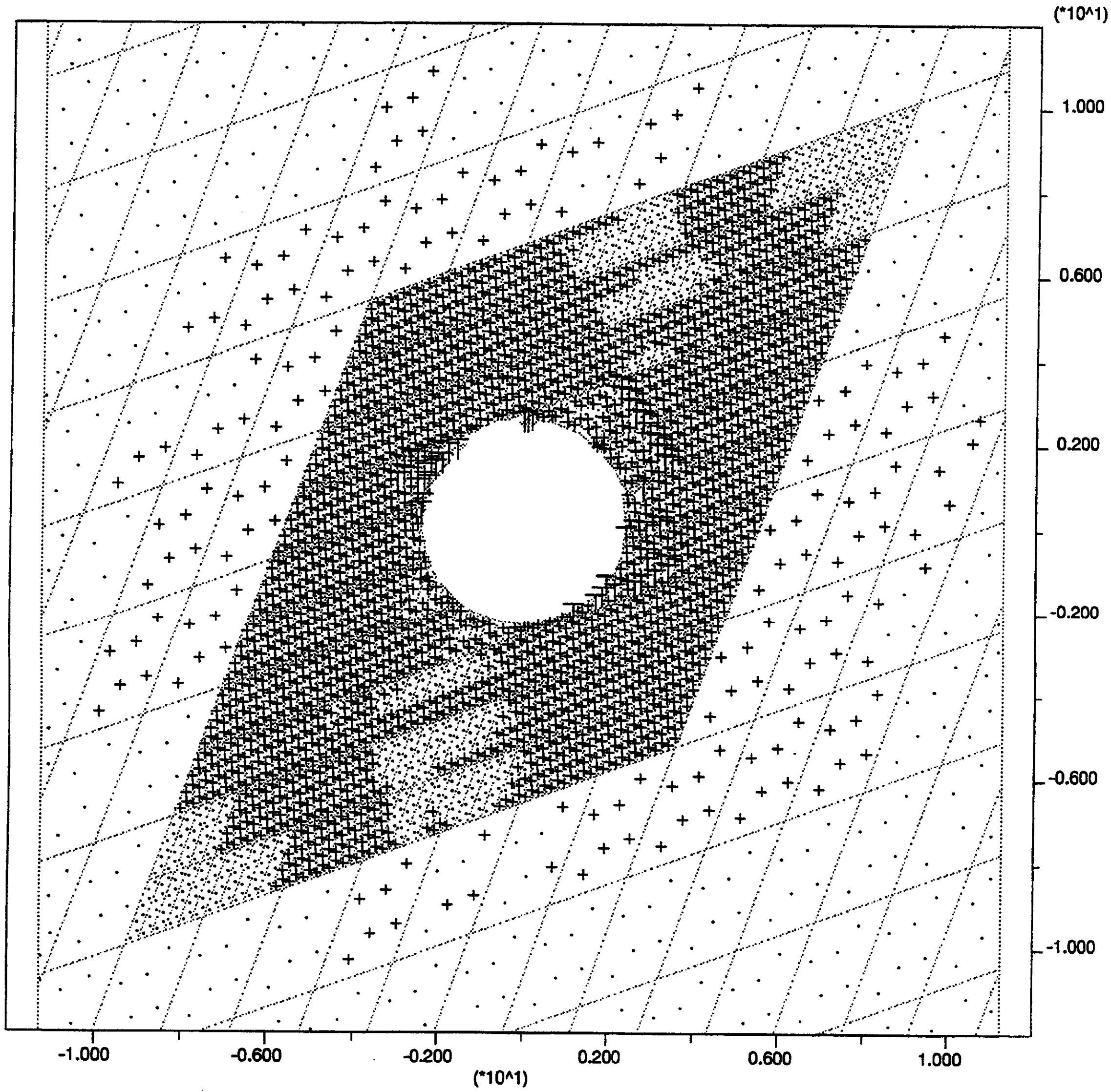
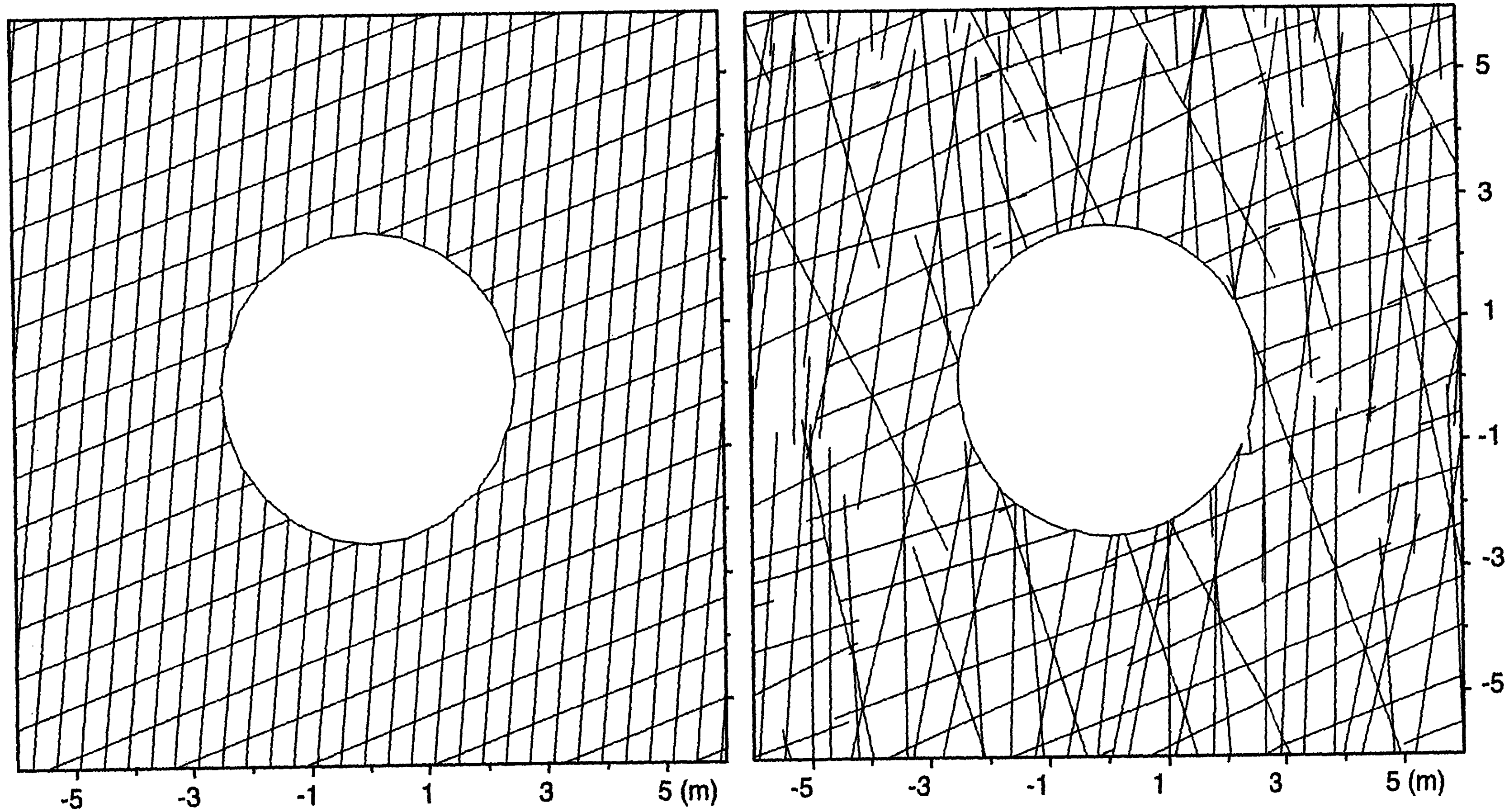


Note: Dots represent elastic state. Crosses represent yield zones. Dash lines represent joints.

Figure 14. Distribution of yielding after 100 years of heating



(a) Regular Fracture Pattern

(b) Irregular Fracture Pattern

Figure 15. Examples of (a) a regular fracture pattern and (b) an irregular fracture pattern

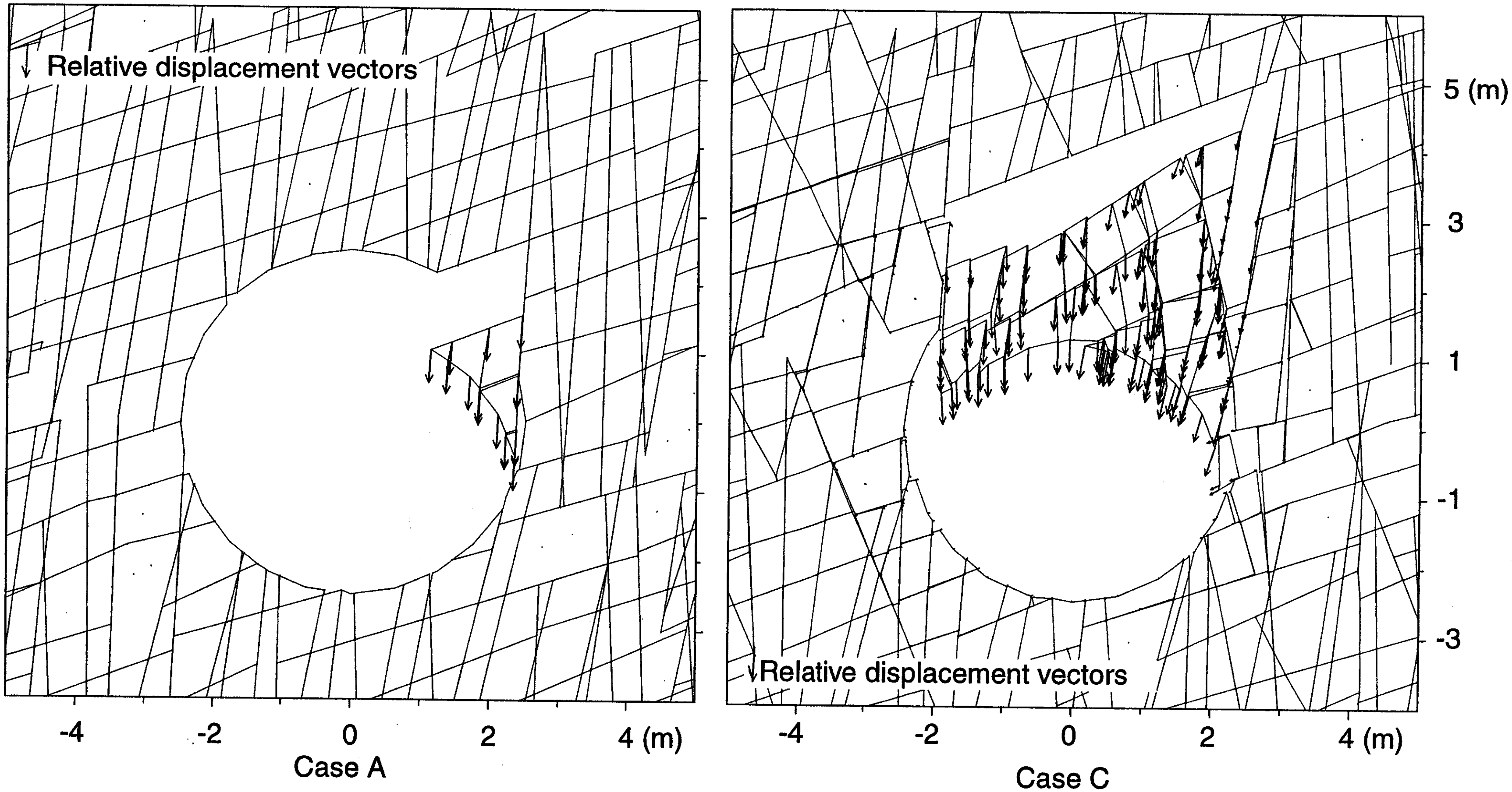


Figure 16. Simulated rockfall after 100 years of thermal loading and one episode of dynamic ground motion for two slightly different fracture patterns

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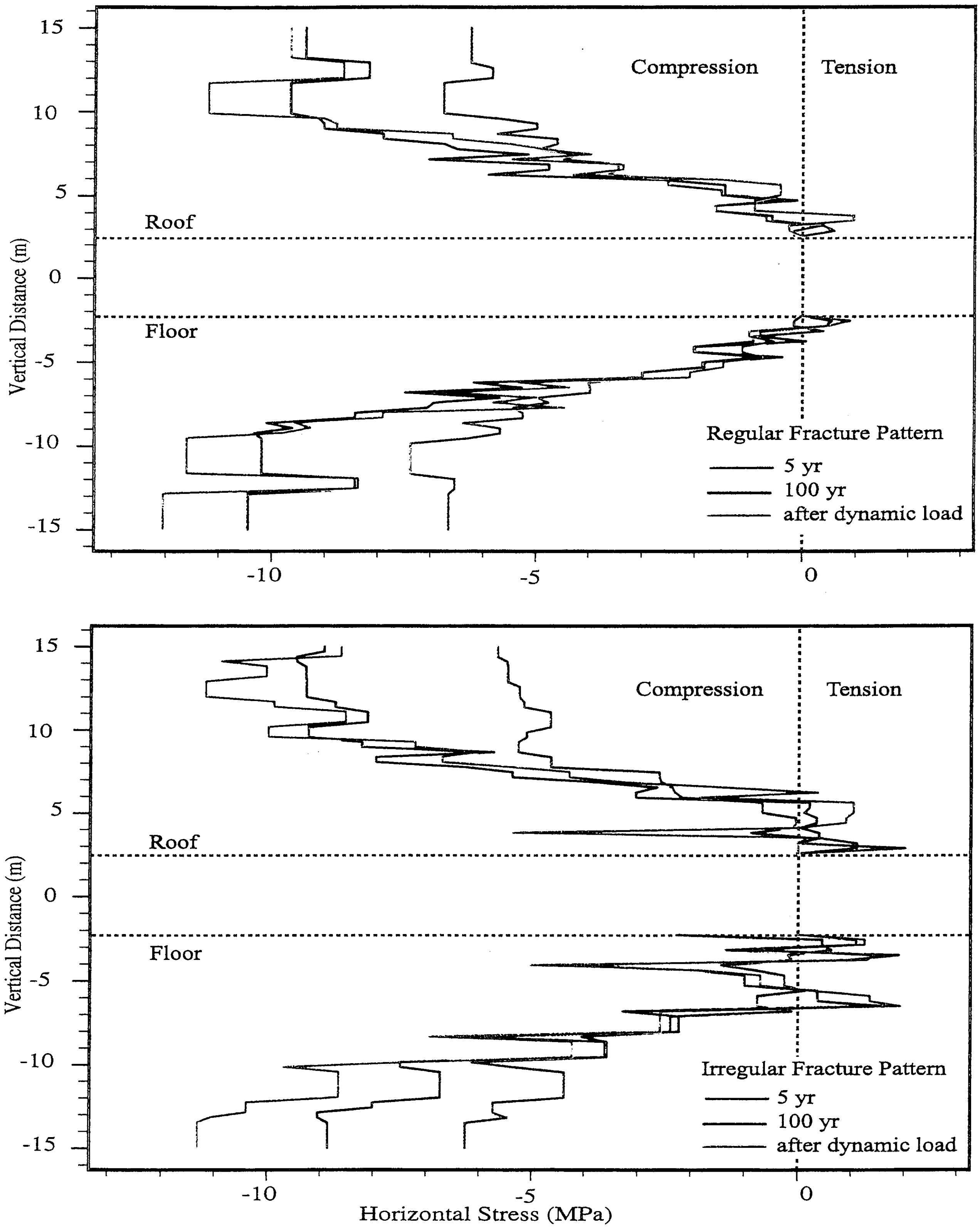

Figure 17. Comparison of vertical profile of minimum principal stresses for irregular and regular fracture patterns after 5 and 100 years of thermal and dynamic load

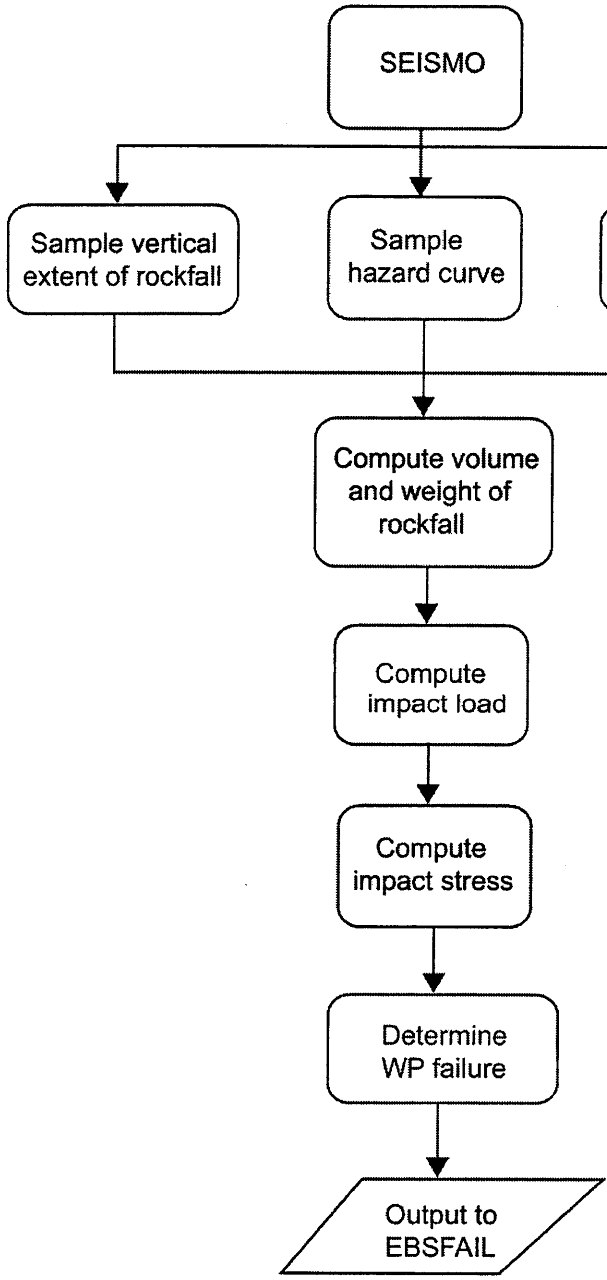

Figure 18. Flowchart highlights SEISMO calculation

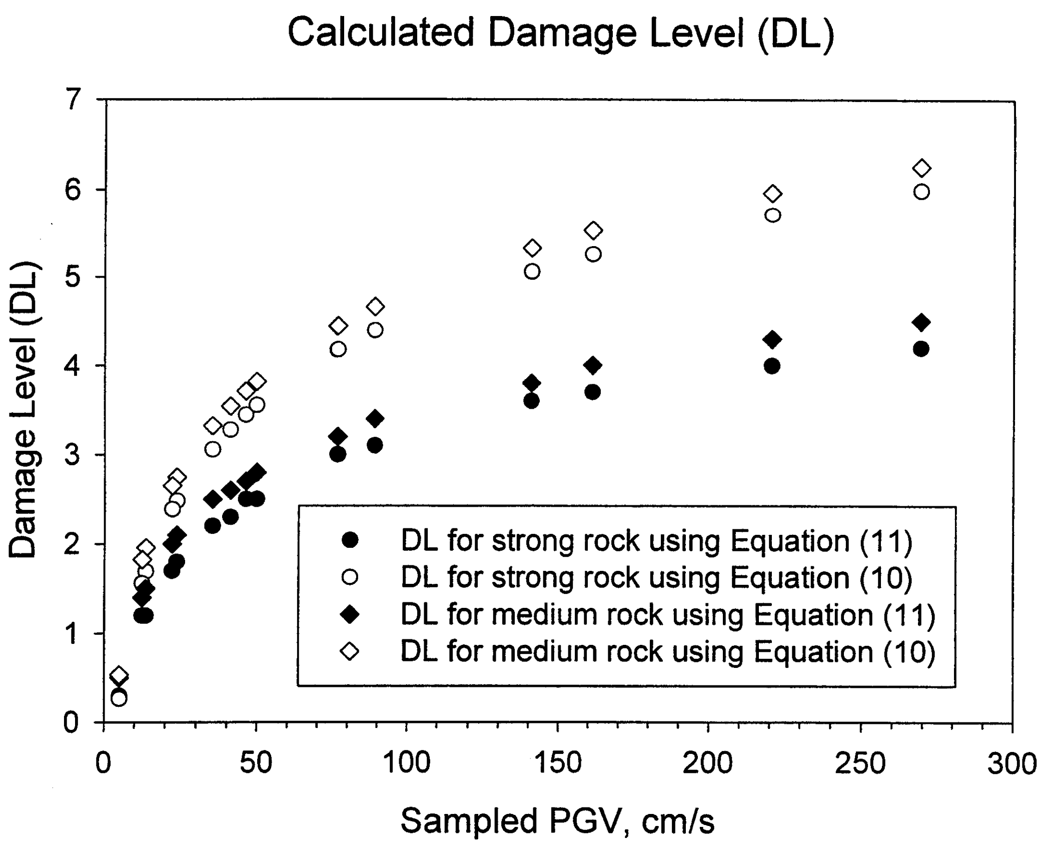

Figure 19. Damage level versus peak ground velocity

5 STATUS OF ISSUE RESOLUTION AT THE STAFF LEVEL

The status of issue resolution reported in this section reflects the current understanding of NRC staff based on the most recent information that is available to the staff. As discussed previously, in this revision, the status of resolution for the RDTME KTI has been divided into preclosure and postclosure aspects. Subissues related to PCSA, design of surface facilities and EBS, retrievability, repository operations, and performance confirmation are added in the preclosure section. The discussion of status of these aspects will be limited in this revision and will be expanded in subsequent revisions. Evaluations with respect to these subissues against the ACs being developed have started and results will be documented in subsequent revisions. The design control process, seismic design, and underground facility design related subissues that were listed under the RDTME KTI in Revision 2 are included in the preclosure section of this revision. The format for documenting the status resolution for the design control process and seismic design subissues is the same as that for Revision 2 of this IRSR and is different from the format used for the rest of the subissues. A summary of the resolution status on RDTME KTI subissues is provided in Table 2 and the status is discussed in detail in the following sections. ~~presented in the VA. Staff is aware of the alternative design concepts that are being considered by DOE. Future revisions of the IRSR will reflect the NRC's evaluation of any design changes.~~

5.1 PRECLOSURE SUBISSUE RESOLUTION STATUS ~~IMPLEMENTATION OF AN EFFECTIVE DESIGN CONTROL PROCESS WITHIN THE OVERALL QUALITY ASSURANCE PROGRAM~~

5.1.1 IMPLEMENTATION OF AN EFFECTIVE DESIGN CONTROL PROCESS WITHIN THE OVERALL QUALITY ASSURANCE PROGRAM

Historically, DOE's implementation of a design control process for design, construction, and operation of the GROA has been one of NRC's major concerns. The staff conducted a series of interactions, reviews, and an in-field verification to evaluate the effectiveness of DOE's design control process. ~~The most recent limited review was conducted in June 1998. The review results are documented in Section 4.1.5 of the RDTME KTI IRSR Revision 1 and summarized in this section. Discussion on compliance at the level of AC will be provided in a future revision of this IRSR when more activities in this area have been conducted.~~

Exploratory Studies Facility

The staff considers DOE's design control process implemented for the ESF to be acceptable. This conclusion is based on the reviews of DOE's responses to staff queries, QA audits, surveillances, review of DOE's RCRR, observation of design reviews, selective reviews of design packages, site visits, meetings, and in-field verification. The staff has no major concerns or questions related to the ESF design or the design control process employed for the ESF design, construction, or operation at this time. ~~However, the following two items will continue to be under focused review by the staff: (i) quality classification for the concrete inverts used for the ESF construction; and (ii) hierarchy of documents that control site characterization, design, construction, and operations activities at the YM site (see Item 24 of the appendix).~~

Table 2. Summary of Subissue Resolution Status

Subissue	Closed	Open	Comment
Preclosure			
Design Control Process	Closed		Design control process hierarchy is simplified.
Seismic Design Methodology	Closed Pending		Awaiting review of Seismic Topical Report No. 3.
Preclosure Safety Analysis		Open	Resolution process for this subissue started during this revision. Limited review indicates that aircraft crash hazard analysis does not use sufficient data and assumptions are not justified.
Design of Geological Repository Operations Area		Open	Resolution process for surface facilities and EBS started during this revision. Concerns on areas such as adequacy of data, data reduction approach, modeling approaches, and assumptions for ventilation model are noted.
Retrievability		Open	Resolution process started during this revision. No review performed.
Design of Engineered Barrier System	Closed Pending		DOE to conduct preclosure performance evaluation for EBS, WP, and WF based on current design. DOE to collect and provide mechanical properties as functions of time.
Performance Confirmation Program		Open	Resolution process started during this revision. No review performed.
Repository Operations		Open	Resolution process started during this revision. No review performed.
Postclosure			
Thermal-Mechanical Effects		Open	Concerns related to modeling rockfall impact on drip shield and WPs are not resolved. Concerns related to thermal-mechanical effect on change in local hydrologic properties remain. Concerns related to screening out drift geometry change from model attractions remain.
Repository Seals	Closed		10 CFR Part 63 does not have specific requirements for repository seals

Geologic Repository Operations Area

During FY1998, the staff conducted a limited evaluation of the effectiveness of DOE's implementation of the design control process as a generic matter for all the SSCs that comprise the GROA. Specifically, the staff selected six systems of the GROA (three surface and three subsurface systems) for a detailed assessment on ~~of DOE's compliance/noncompliance with the 12 AC (in Section 4.1.3 of Revision 2 of this IRSR) that the staff developed to measure~~ the effectiveness of DOE's design control process. While the staff recognizes that the six systems represent only a small part of DOE's design activities for the entire GROA, the staff concludes that, with one exception, DOE

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has an effective design control program for the GROA, based on this limited review. The one area in this program in need of improvement is in relation to control of design changes relative to an original design and proper documentation of such changes (Section 4.1.1.3 ~~4.1.5.2~~). As mentioned previously, the staff will continue to monitor the effectiveness of DOE's design control process, including any identified areas of weakness.

DOE conducted several audits of M&O contractors during 1998 and 1999 with a focus on the implementation of the design control process. Several deficiencies have been found that cover a wide spectrum of the design control process, including data traceability, management, qualification, and software control (e.g., U.S. Department of Energy, 1998a,b,c,d,e; 1999a). To address these deficiencies, the M&O contractor is developing new administrative procedures to replace the existing QAPs. The new administrative procedures will provide a wider coverage to apply to its subcontractors (e.g., National Laboratories). It is understood these new administrative procedures will be in effect in the near future.

U.S. Nuclear Regulatory Commission Staff Evaluation of Design Control Process Subissue For FY2000

STATUS: Closed. Through several interactions with DOE, the staff found that DOE has greatly simplified its document hierarchy flowdown on design control process. As a result, transparency and traceability of the flowdown from the RRs to design bases and criteria are greatly improved. The staff considers this simplified design control process to be acceptable. The implementation of this design control process will continue to be monitored through observation of DOE audits or NRC independent audit/inspection of DOE activities.

5.1.1.1 Status of Open Items from Site Characterization Plan/Site Characterization Analysis, and Study Plans

Item ID: OSC0000001347C121 Comment 121 SCA
Title: Seismic design criteria for ESF
Status: Closed
Basis: Staff review of revised ESFDR submitted by DOE (YMP/CM-0019, Rev. 2), appendix-A. Design input values are subject to verification under TR–3 review.

Item ID: OSC0000001347C130 Comment 130 SCA
Title: Part 60 design criteria applicable to ESF
Status: Closed
Basis: Staff review of RCRR submitted by DOE in response to NRC's letter of October 13, 1994.

Item ID: OSC0000001347Q003 Question 003 SCA
Title: Rationale for selecting the total area for repository development
Status: Closed
Basis: Design concepts for the repository have changed. The question will be re-examined when DOE submits up-to-date design concepts.

Item ID: OSC0000001347Q020 Question 020 SCA
Title: Vertical versus horizontal emplacement orientation decision
Status: Closed
Basis: Vertical emplacement is no longer an option.

Item ID: OSC0000001347Q021 Question 021 SCA
Title: Radiation shielding of host rock
Status: Closed
Basis: Question based on outdated concepts of WP design and vertical emplacement that is no longer an option.

Item ID: OSC0000001347Q042 Question 041 SCA
Title: Regulatory basis for Issue Resolution Strategy 2.4 on waste retrieval
Status: Closed
Basis: Transferred and will be revised under Section 5.1.5 (preservation of retrievability open)

Item ID: OSC0000001347Q042 Question 042 SCA
Title: Stability of vertical emplacement holes
Status: Closed
Basis: Vertical emplacement hole is no longer an option.

Item ID: OSC0000001347Q056 Question 056 SCA
Title: Fault displacement tolerance
Status: Closed
Basis: Question based on outdated vertical emplacement concept. Actual fault displacement design inputs are subject to verification during TR–3 review.

Item ID: OSC0000001347Q057 Question 057 SCA
Title: Borehole drilling and design flexibility
Status: Closed
Basis: Question based on outdated ESF design

Item ID: OSC0000001347Q058 Question 058 SCA
Title: Design to accommodate *in situ* WP testing
Status: Closed
Basis: Question based on two vertical shafts rather than the current ramps

Item ID: OSC0000001347Q062 Question 062 SCA
Title: Separation distance between ESF and waste emplacement panels
Status: Closed
Basis: Question based on SCP conceptual design that is outdated.

5.1.1.2 Status of Open Items from U.S. Department of Energy–U.S. Nuclear Regulatory Commission Correspondence/Interactions

Item ID: OQA013OCT1994C00 Comment 001
Title: The M&O QAP is not being effectively implemented in a manner that will assure acceptability of the ESF (includes flowdown of RRs)
Status: Closed
Basis: See OQA013OCT1994Q00 Question 003

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Item ID: OQA013OCT1994Q00 Question 001
Title: Phases of proposed design and construction of ESF
Status: Closed
Basis: See OQA013OCT1994Q00 Question 003

Item ID: OQA013OCT1994Q00 Question 002
Title: Potential of construction work to impact site characterization or the waste isolation capability of the site
Status: Closed
Basis: See OQA013OCT1994Q00 Question 003

Item ID: OQA013OCT1994Q00 Question 003
Title: Current conceptual design, testing strategy, and control mechanism
Status: Closed
Basis: The previous four items are closed based on staff review of DOE's responses of October 17, 1994; November 14, 1994; January 27, 1995; March 14, 1995; May 1, 1995; staff observation of DOE's QA audit of January 9–13, 1995; and staff in-field verification of April 3–6, 1995 (see appendix for details).

5.1.1.3 Status of Open Items from In-Field Verifications

Item ID: In-field Verification Recommendation-1
Title: Numerical modeling of rock bolts
Status: Closed
Basis: Review of Book #2, "Numerical Modeling of Rock Bolts," during Appendix 7 meeting at M&O office, June 11–12, 1997.

Item ID: In-field Verification Recommendation–2
Title: Reportable geologic condition
Status: Closed
Basis: Staff review of revised procedure, "YAP–30.27" (which superseded administrative procedures–6.14).

Item ID: In-field Verification Recommendation–3
Title: Quality classification of precast concrete inverts
Status: Closed
Basis: Precast convert inverts are no longer a design option in the EDA-II. ~~Staff review of DOE's response of September 25, 1995, and discussions during Appendix 7 meeting at the M&O Office, June 11–12, 1997, including review of Book #5 "Invert Re-evaluation" and final draft of "White Paper on a Functional Reassessment of the ESF Inverts." DOE continues to defend its decision to classify concrete inverts as temporary structures and considers that they can be removed and replaced by temporarily transferring the loads from the steel sets to another load-carrying frame while the "temporary" invert is removed and replaced by another qualified invert. The staff, however, believes that the concrete inverts are part of the roof support system and should be given the same QA classification as the rest of the roof support components, such as the steel sets and roof bolts. The staff also believes that the procedure of temporarily transferring the loads is not only cumbersome and complicated but also could potentially result in stressing the rocks and the steel sets in addition to posing increased worker-safety concerns.~~

Item ID: In-field Verification Open Item
Title: Document Hierarchy
Status: Closed
Basis: DOE has greatly simplified its document hierarchy. Consequently, the transparency and traceability of this document hierarchy have been improved. ~~See Appendix Item 24 (p. A-4). DOE is making progress in this area and NRC staff will continue to monitor this open item during future audits.~~

~~The staff recommends that DOE take appropriate actions necessary to document the quality of concrete used and its characteristics, such as physical, chemical, and mechanical properties, and conduct the necessary analyses to study any long-term adverse impacts.~~

5.1.2 DESIGN OF THE GEOLOGIC REPOSITORY OPERATIONS AREA FOR THE EFFECTS OF SEISMIC EVENTS AND DIRECT FAULT DISRUPTION

To address this subissue, DOE developed three TRs. TR–1 and TR–2 were reviewed and accepted by NRC before the inception of the IRSRs. Consequently, the status of these two TRs is briefly summarized in the following sections without including discussion of compliance with specific AC used for the review. TR–3 will be reviewed during early FY2002. The status of resolution for the report will be documented in future revisions of this IRSR.

5.1.2.1 Status of Topical Report-1

The details of status of open items for TR–1 have been documented in the SDS KTI IRSR.

5.1.2.2 Status of Topical Report-2

Based on the review of Rev. 2 of TR-2, the seismic design methodology presented by DOE is acceptable to the staff. The concerns related to repeated seismic loading for the preclosure design have been closed based on the rationale presented in TR-2. The staff has no further questions on this component of the subissue at the present time.

The staff will continue to be involved in observing DOE's expert elicitation during the preparation of final hazard curves for the YM site along with the identification of design basis accelerations and fault displacements. Although DOE's seismic design methodology is acceptable, it should be noted that the acceptability of DOE's seismic and fault displacement design of the GROA will be made during the LA review. Furthermore, this methodology is intended for a minimal maintenance of the preclosure facilities for a period of 50–125 ~~over a period of 150~~ years. ~~In light of a possible implementation of an extended monitored geological disposition program that could result in continued underground access for up to 300 years (U.S. Department of Energy, 1998a), the applicability of the seismic design methodology may need to be revisited.~~

5.1.2.3 Status of Topical Report-3

Consideration of repeated seismic loading for the (postclosure) design of the WP and TSPAs is expected to be covered during review of TR–3. (As stated earlier, the staff will review TR–3 on seismic and fault displacement inputs for design and PAs and consider the set of three TRs in the context of how the TRs together will help simplify the licensing review.) TR–3 will be reviewed during FY2002 and review results will be documented in a future revision of this IRSR.

STATUS For FY2000: Closed pending further information. Of the three TRs proposed by DOE to address this subissue, two have been accepted by the staff. DOE TR–3 is currently scheduled for completion in early FY2002.

5.1.3 ACCEPTABILITY OF PRECLOSURE SAFETY ANALYSIS FOR THE GEOLOGIC REPOSITORY OPERATIONS AREA

5.1.3.1 U.S. Department of Energy Approach

DOE will perform an ISA of the GROA in two phases[4]. (The term ISA is consistent with the term originally used in the proposed 10 CFR Part 63. This term has been changed to PCSA in the revised proposed 10 CFR Part 63.) In the first phase, the PCSA will be based on preliminary design information (primarily in the form of system descriptions) available at the time of LA for CA. In the second phase, the PCSA will be updated to incorporate more detailed design information in support of LA to receive and possess waste (R&PW). Since the CA will precede the license to R&PW, the level of detail in the PCSA at the time of LA for CA will be less than the PCSA of LA for license to R&PW.

The DOE's methodology for ISA is schematically represented in Figure 20. The chart explains the process of implementation of ISA to meet the preclosure safety objectives through internal and external hazard analyses. The objective is to identify the DBE from internal (human-induced and equipment failures) and external (manmade and natural phenomena) events for consideration in the design of the GROA and identification and classification of the SSCs that are important to safety.

The internal hazards are identified based on credible event sequences that result in bounding radiological release. DOE has developed a safety analysis process utilizing standard hazard analysis methodologies (CRWMS M&O, 1999b,c). The safety analysis will be updated with the evolving design details and operational concepts of GROA. In its methodology, the DOE has generated a generic preliminary hazard list that could potentially lead to radiological release based on the design configuration and facility operation in a functional area. DOE has divided the GROA into functional areas by specific function or physical boundaries. The process and design information consists of system description, process flow diagram, mechanical flow diagrams, and a conceptual description of MGR operations. DOE has developed a list of preliminary internal hazards or initiating events in each of the functional areas based on qualitative energy analysis (System Safety Analysis Handbook, 1997). Internal event scenarios are analyzed for sequence probabilities, using event tree and fault tree techniques. The event frequencies are used to bin the event sequences into either Category 1 or Category 2 events. Internal events with an annual frequency less than 10^{-6} were screened out from

[4] White Paper: Strategy for Performing Integrated Safety Analysis in LA, 1999

further consideration. The radiological dose consequence from the event sequences has been analyzed and, based on the bounding dose limits, the bounding event sequences or DBEs have been determined for Category 1 and Category 2. Identification of SSCs required to prevent or mitigate DBEs and SSC safety classification is achieved by further screening the internal event sequences into the following three groups based on their frequency of occurrence and potential to result in a radiological release: Internal Events with Potential Releases, Internal Events with No Releases, and Beyond Design Basis Events.

In the preliminary external hazards analysis, DOE has generated a potential external hazards list from a generic checklist of 53 manmade and natural phenomena (CRWMS M&O, 1999c,d). The events from a generic checklist were screened as a potential DBE for 100-year preclosure period on the basis of their applicability to the following considerations: (i) the potential of the event exists and is applicable to the YM site, (ii) the rate of process is sufficient to affect the 100-year operational period, (iii) the consequence of the process is significant enough to affect the 100-year operational period, (iv) the event frequency is greater than or equal to 10^{-6} events per year, and (v) the event is not included in another analysis or is not a subset of other DBE analyses. From the above screening process, DOE has selected 12 potential external and natural phenomena. These selected events were further screened through additional analysis that identified nine bounding initiating external events that could lead to potential radiological release. DOE has stated that the SSCs important-to-safety will be designed to withstand the DBEs.

5.1.3.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Sufficiency of Site and Structures, System, and Components Descriptions for Conducting Preclosure Safety Analysis

Site Description

AC1 The LA contains a description of the site geography adequate to permit evaluation of the PCSA and the GROA design.

- The site location is adequately defined. The site location is specified relative to prominent natural and man-made features such as mountains, streams, military bases, civilian and military airports, population centers, and potentially hazardous commercial operations and manufacturing centers that may be significant for the review of the PCSA and GROA design.

- The characteristics of natural and man-made features within the restricted area of the site that may be significant for evaluation of the PCSA and GROA design are adequately defined.

- Maps of the site and nearby facilities are included and are of sufficient detail and of appropriate scale to provide information needed to review the PCSA and GROA design. A site map clearly indicates the site boundary and the restricted area, restricted area access points, and distances from the boundary to significant features of the installation. Maps describe the site topography and surface drainage patterns, as well as roads, railroads, transmission lines, wetlands, and surface water bodies.

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STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC2 The LA contains a description of the regional demography adequate to permit evaluation of the PCSA and the GROA design.

- Regional demographic information is based on current census data and presents the population distribution as a function of distance from the GROA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and documented in subsequent revisions.

AC3 The LA contains a description of the local meteorology and regional climatology adequate to permit evaluation of the PCSA and the GROA design.

- The LA data on local meteorology and regional climatology, that may be significant for the review of the PCSA and GROA design, are adequate.
- The data collection techniques are based on accepted methods, and the technical bases for data summaries are provided.
- Adequate information is provided on the annual amount and forms of precipitation, and the probable maximum precipitation at the site. Acceptable methods are used to develop this information.
- The LA adequately defines the type, frequency, magnitude, and duration of severe weather. Valid design bases/criteria are provided for the severe weather assessment.
- Trending analyses are appropriately conducted and supported by sufficient historical data presented in the LA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented the subsequent revisions.

AC4 The LA contains sufficient local and regional hydrological information to support evaluation of the PCSA and the GROA design.

- The description of the YM surface and groundwater hydrology adequately identifies hydrologic features relevant to the PCSA and GROA design.
- The analyses of the effects of any proposed changes to natural drainage features on GROA design are acceptable.
- The calculation of probable maximum flood is supported by sufficient data, including actual storm data in the region of the drainage basin.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented subsequent revisions.

AC5 The LA contains descriptions of the site geology, and seismology adequate to permit evaluation of the PCSA and the GROA design.

- The LA provides sufficient data on the geology of the site to support the PCSA and GROA design, including the stratigraphy and lithology over the entire surface and subsurface construction area.

- Site characterization data adequately include rock mechanics properties based on *in situ* and laboratory test results for the rock formations where major construction activities will take place. Collection and processing of these data are based on accepted industry techniques.

- Rock mechanics testing data adequately support the LA analyses of the stability of subsurface materials.

- The engineering properties provided for soils in the areas where surface facilities will be constructed are based on laboratory and *in situ* test results. These data are collected and processed using accepted industry techniques.

- Detailed soil testing data support the LA analyses of the stability of surface materials, considering surface subsidence, previous loading histories, and liquefaction potential.

- The vibratory ground-motion and surface and subsurface fault displacements of the site are adequately characterized, taking into account the assessment in Section 4.2.1.3.2.3 (Mechanical Disruption of Engineered Barriers) of the YMRP and considering a list of capable faults, areal seismic source zones, earthquake parameters such as maximum magnitude and recurrence for each source, historical earthquake data, paleoseismic data, and ground-motion attenuation models.

- Acceptable methods are used to develop seismic design data using the characterized vibratory ground-motion and surface and subsurface fault displacement.

- The LA provides adequate analyses of the stability of the facility foundations, subsurface emplacement drifts, and natural and manmade slopes (both cut and fill), the failure of which could result in radiological release. Appropriate methods are used for the analyses, data used are appropriate for the methods, and results are properly interpreted.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC6 The LA contains descriptions of the historical regional igneous activity adequate to permit evaluation of the PCSA and the GROA design.

- The LA adequately considers igneous activity at the site including volcanic eruption, subsurface magmatic activity/flow, and volcanic ash flow/ash fall.

STATUS: Staff will consult with the Igneous Activity KTI regarding this matter and document the results in subsequent revisions.

AC7 The LA provides analysis of site geomorphology adequate to permit evaluation of the PCSA and GROA design.

- The LA adequately considers the extent of erosion of the land surface and the likelihood that extreme erosion such as landslides, rock avalanches, other mass wasting; and rapid fluvial degradation in channels or interfluves might affect site structures or operations.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and documented in subsequent revisions.

AC8 The LA contains sufficient geochemical information to support evaluation of the PCSA and the GROA design.

- Information on the geochemical composition of subsurface water held within the rock matrix, perched water zone, or from episodic flows through fractures is sufficient to determine corrosivity.

- The geochemical composition of the rock strata within which and above the repository horizon is adequately defined to identify minerals that might add to the corrosivity of water flowing through the strata.

- Potential geochemical alterations to the rock fractures and the rock matrix through heating or other processes that might significantly alter geomechanical rock mass properties are adequately characterized.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Structures, System, and Components Descriptions

AC1 The LA contains a description of the location of the surface facilities and their designated functions sufficient to permit evaluation of the PCSA and the GROA design.

- The LA has a description of surface facilities that includes their location and arrangement at the site and their distance from the site boundary. This description includes drawings of sufficient detail and appropriate scale.

- The discussion of the design of the surface facilities is adequate to permit an evaluation of the PCSA.

- The descriptions of the functional requirements for the facilities are adequate to provide an understanding of GROA operational activities, sequences, and locations sufficient for evaluation of the PCSA and GROA design.

- The descriptions of the capabilities of the equipment, training, level of the operators, and testing/maintenance plan are sufficient for evaluation of the PCSA.

STATUS: Open. The draft Environmental Impact Statement and other reports (U.S. Department of Energy, 1999b; CRWMS M&O, 1999e) explain the main features and functions of the surface facilities along with location and arrangement at the site. The description of some areas, including drawings, e.g., Canister Transfer System (CRWMS M&O, 1997j) is sufficient for evaluation of PCSA, however, information available for other areas, (e.g., carrier preparation building, assembly transfer system, carrier bay, and disposal container handling areas are very limited and are not sufficient for evaluation of PCSA. DOE should provide current design diagrams. A comparison between the various documents on arrangement and elevation drawings shows differences in details. DOE indicated that the current safety analysis is based on VA design. The impact on the safety analysis due to the adoption of EDA-II design is not currently addressed.

The descriptions of the functional requirements for each of the facilities at the current level of design provide some level of understanding of the operational activities, sequences, and locations. However, information on operating procedures has not been provided. In addition, there is not a sufficient description given to provide a clear understanding of the sequence of operations and simultaneous operations involved in the entire surface and underground facilities. DOE should provide descriptions of the capabilities of the equipment, training, operation, and testing/maintenance plan.

AC2 The LA contains descriptions and design details for SSCs and equipment of the surface facilities sufficient to permit evaluation of the PCSA and the GROA design.

- The LA provides adequate descriptions and design information for the SSCs and equipment of the surface facilities.
- The LA provides adequate descriptions of the location and functional arrangement of the SSCs within each facility.
- The LA provides adequate discussion of design information regarding the capability of the surface facilities to withstand the effects of natural phenomena.

STATUS: Open. The descriptions and design details for SSCs and the equipment are not sufficient to permit evaluation of PCSA. DOE has not provided a detailed list of SSCs, their locations, and functional arrangements. While detailed information has been provided for the canister transfer area (e.g., plan and elevation sketches including critical dimensions, lifting equipment details including lift heights, and the dimensions of the cask and canisters) (CRWMS M&O, 1997j), process and procedures such as crane operating routes have not been specified. Such information is needed to determine frequency of canister damage due to a drop of a canister during crane lifting operations. Similar descriptions have not been provided for other facilities and equipment. Performance confirmations (testing, maintenance, interlock, alarms, emergency procedures) have not been provided for SSCs.

Design information regarding capability of surface facilities to withstand the effects of natural phenomena was not reviewed at this time. The sufficiency of description will be evaluated and documented in subsequent revisions.

AC3 The dose to workers and members of the public from normal operations and Category 1 event sequences is within the limits specified in 10 CFR 63.111(a).

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- Normal operations and Category 1 event sequences that could adversely affect radiological exposures are adequately considered.

- An appropriate method is used to aggregate the doses from normal operations and Category 1 event sequences.

- Doses to workers and members of the public will be ALARA.

STATUS: DOE has provided adequate descriptions for SSCs and equipment of the subsurface facility (CRWMS M&O, 1998g; 1999f); however, the description is based on VA design. DOE needs to make sure that necessary changes from the EDA-II design are accommodated in the safety analysis.

AC4 The LA characterizes the HLW sufficiently to permit evaluation of the PCSA and the WP design.

- The LA adequately characterizes the ranges of parameters that characterize the HLW.

- The LA adequately characterizes the properties of the HLW.

STATUS: Not reviewed at this time. Material related to this AC will be evaluated and results documented in subsequent revisions.

AC5 The LA provides a general description of the EBS and its components sufficient to support evaluation of the PCSA and the EBS design.

- The principal characteristics of the WP, including dimensions, weights, materials, fabrications, and weldings, are defined.

- Adequate characterization of functional features of the WP, such as criticality control, shielding, and confinement, is provided.

- The discussions of analyses and characterization of EBS components, such as drip shields, backfill, support/inverts, and sorption barrier, are sufficient to support evaluations in the PCSA and GROA design reviews.

STATUS: Not reviewed at this time. Material related to this AC will be evaluated and results documented in subsequent revisions.

AC6 The description of the operational processes to be used at the GROA is sufficient for review of the PCSA.

- Descriptions of GROA operational processes provide an adequate understanding of the component and facility functions and sequences of activities.

- Information provided on operational process design, equipment design and specifications, and instrumentation and control systems is sufficient to assess the PCSA.

STATUS: Open. The descriptions of the operational processes for each of the facilities provide some level of understanding of the component and facility functions and sequences of activities to be used at the GROA. However, information on operating procedures, equipment design and specifications, and instrumentation and control systems has not been provided. In addition, there is insufficient description given to provide a clear understanding of the sequence of operations and parallel operations involving the entire surface and underground facilities.

Identification of Hazards (Natural and Manmade)

Methods for Identifying Hazards

AC1 Technical basis and assumptions for methods used for identification of hazards and initiating events are adequate.

- Methods used for hazard and initiating event identification are consistent with standard industry practices.

- If standard industry practices are not used, the DOE basis and justification for choosing a particular hazard and initiating event identification method(s) are defensible.

- Methods selected for hazard and initiating event identification are appropriate for the available data on the site and GROA.

- Assumptions used to identify naturally occurring and human-induced hazards and initiating events are well-defined, have adequate technical basis, and are supported by information on the site and its SSCs and operational processes.

STATUS: Open. While the methods selected by DOE for identification of hazards and initiating events based on energy analyses are consistent with standard industry practice, the justifications for considering and eliminating hazards in each process step after due consideration have not been provided in a systematic manner. Consequently, the possibility exists of overlooking hazards during safety analysis. Methods such as Failure Modes and Effects Analysis are available to minimize this possibility.

DOE has developed a list of preliminary hazards for internal events for subsurface and surface facilities based on generic lists provided in the following safety analyses methodologies: Energy Analysis, Energy Trace, and Barrier Analysis and Energy Trace Checklist (System Safety Analysis Handbook, 1997). These techniques are applicable to the systems that contain, make use of, or store energy in any form and use a checklist type of evaluation to identify and evaluate hazards. The completeness of the list will be reviewed and the results documented at a later time.

DOE has conducted several hazard analyses on various potential hazards. Among them, the MGR Aircraft Crash Frequency Analysis (Morissette, 1999) has been briefly reviewed by the staff to examine the applicability of the methodology and appropriateness of data used in the analysis. The findings for the former are presented in the paragraphs below and the findings for the latter are presented under the status of **AC2**.

Morissette (1999) has used the suggested methodology given in NUREG–0800, Section 3.5.1.6, Aircraft Hazards (U.S. Nuclear Regulatory Commission, 1981), to estimate the probability of crash of an aircraft onto the proposed high-level nuclear waste repository. Additionally, Morissette (1999) has used the methodology suggested in the DOE Standard DOE–STD–3014–96 to estimate the effective area of a particular structure and crash rate data for different aircraft developed by Kimura et al. (1996). All these documents are used in standard engineering practices, for estimating the aircraft crash hazard, and are acceptable.

The NRC staff disagrees with the conclusion that Criterion (b) of NUREG–0800, Section 3.5.1.6 Aircraft Hazards, has been met for the proposed repository. Criterion (b) states that the probability is considered below the threshold for further evaluation if "the plant is at least 5 statute miles from the edge of military training routes, including low-level training routes, except for those associated with a usage greater than 1000 flights per year, or where activities (such as practice bombing) may create an unusual stress situation." Additionally, the site has to satisfy two other criteria. The number of flights per year exceeds 1,000 by a significant margin (at least 12 to 15 times) and these flights create unusual stress situations due to practice bombing or simulated dogfights etc. Criterion (b) has not been satisfied and, consequently, a detailed analysis is necessary, as per NUREG–0800, Section 3.5.1.6.

Additionally, Morissette (1999) has used erroneous formulas to calculate the effective area of a structure to estimate the aircraft crash hazard probability. Although the document refers to the DOE Standard (U.S. Department of Energy, 1996b, Appendix B) for the source of these formulas, the formulas used are different from those given in the DOE Standard (U.S. Department of Energy, 1996b). As a consequence of these erroneous formulas, the estimated effective area is less than actual and, hence, nonconservative. The difference is more pronounced for structures which are more square in shape, such as WHB. Preliminary calculations carried out by the staff showed that the total effective area of five facilities, assuming only F-16 aircraft and using the formulas given in the DOE Standard, is 0.091 mi^2, instead of the 0.0812 mi^2 in Morissette (1999). DOE should either justify the formulas used or use correct formulas given in DOE (1996b).

The staff does not agree with the assumption that considering the WHB alone will be the "best estimate" case. The site plan shows that both the WHB and the WTB are adjacent. Therefore, for estimating the effective area of the buildings, these two structures should be considered as one, as suggested in the DOE Standard (U.S. Department of Energy, 1996b). DOE should carry out a detailed analysis as the site has failed in Criterion (b) of NUREG–0800, Section 3.5.1.6. Additionally, DOE should either justifies the formulas used in estimating the effective area or uses the correct formulas given in the DOE Standard. DOE should also justify why considering only the WHB is the "best estimate" when the site plan clearly shows that this structure is adjacent to the WTB.

Data Consistency and Technical Basis for Inclusion and Exclusion

AC2 Site data and system information are appropriately used in identification of hazards and initiating events.

- Appropriate site-specific data are used to identify naturally occurring hazards and initiating events.

- In determining the adequacy of the hazard and initiating event identification, the appropriate properties and factors are considered.

- The identification of human-induced hazards encompasses relevant aspects of the GROA radiological systems. The identification of hazards encompasses all GROA modes of operation.

STATUS: Open. Human-induced hazards and initiating events should be consistent with operational processes and the equipment. Since the design and processes are changing, DOE will need to assure that all changes are reflected in the safety analysis.

The identification of hazards should encompass all GROA modes of operation. However, this has not been done in all instances. For example, hazards from onsite storage of flammable and hazardous material have not been addressed in the preliminary hazard analysis.

Sufficiency of assumptions used to identify human-induced hazards and initiating events will be evaluated and documented in subsequent revisions. The staff will need information such as descriptions, design details, and performance requirements for SSCs and the equipment, along with scaled diagrams, to evaluate the assumptions on potential drop heights for casks, canisters, and WPs.

AC3 Determination of frequency or probability of occurrence of hazards and initiating events is acceptable.

- Methods selected for determining probability or frequency of occurrence for hazards and initiating events are appropriate, and uncertainties are adequately quantified.

- An appropriate basis and justification is provided for any use of nonstandard practices for determining frequency or probability estimates.

- Methods selected for determination of probability or frequency of occurrence for hazards and initiating events are appropriate. If relevant data are not sufficient or not available, appropriate bounding values are used. The associated bounding calculations are adequate. The expert elicitation process is adequate.

- The frequencies and/or probabilities established for naturally occurring events and human-induced hazards, and initiating events are valid.

- Human errors that may lead to radiological consequences are adequately identified, and adequate human reliability analyses are performed.

STATUS: Open. DOE has indicated that estimation (quantification) of initiating frequencies and event probabilities for human-induced hazards are based on actuarial data for similar operations. DOE needs to provide the source of these data for staff to review DOE estimates. Safety analysis presented by DOE does not include consideration of human errors. Since human errors can impact the frequency of occurrence for hazards, human reliability needs to be included in the analysis.

The frequencies and/or probabilities established for hazards and initiating events were not reviewed at this time. However, the review of the DOE MGR Aircraft Crash Frequency Analysis report (Morissette, 1999) has raised some concerns about the data used to estimate the crash potential and technical bases for different assumptions made in the analysis. As the probability of aircraft crash to the proposed facility is directly proportional to the number of aircraft flying nearby, it is necessary to get a better estimate of the number of aircraft overflights than that given in the report. In this report, only 6 months of flight data [only the number of flights through the R-4808N restricted area, not R-4308N, as stated in several places in Morissette (1999)] have been presented. The number of flights per year, N, has been estimated by fitting a normal distribution to the 6 months (also to 5 months of data as data for September 1996, were determined to be suspicious) data using the Bestfit program of Palisade Corporation. Both 90-and 95-percent confidence levels were estimated from the fitted distribution. It was concluded that the fitted distribution is conservative. The staff disagrees with this approach. Fitting a normal distribution to five or six data points leaves too few degrees of freedom to carry out any meaningful statistical analysis. As discussed in the manual of the Bestfit program, the Goodness-of-Fit tests are very sensitive to the number of data points. For a small number of data points, the tests will only measure a large difference between the input data and the distribution function. Consequently, the null hypothesis that the data were generated by a process that follows a particular distribution (in this case, normal distribution) will be accepted more often than in reality. Standard textbooks in statistics (e.g., Scheaffer and McClave, 1982) suggest that a sample size of less than 20 does not discriminate among different distributions. Many different distributions may apparently fit equally well to the data. This can be seen in the results for the Bestfit program as no single distribution produced the best fit using all three Goodness-of-Fit tests. Therefore, the DOE should obtain more data on the number of flights to carry out a defensible analysis, since the probability of crash is directly related to the number of flights.

Kimura, et al. (1998) discussed the considerable uncertainty in the estimated number of overflights on the restricted airspace R-4808N. A previous study, carried out on The YM repository system, estimated the number of military overflights over the Nevada Test Site (NTS) and the restricted airspace R-4808N to be approximately 73,000 per year (Kimura, et al., 1998). Estimates over the years vary as the mission of Nellis Air Force Base Range evolves. Therefore, it is apparent that the estimated number of flights, especially over the preclosure period, is highly uncertain. Additional follow-on work should be carried out to monitor the level of flights and re-estimate the aircraft crash probability at the proposed repository site when better estimates of the number of flights are obtained.

Restricted airspace R-4808N is controlled by DOE for activities in the NTS. R-4808S is jointly used by the NTS, Nellis Air Force Base, and Federal Aviation Administration, Los Angeles Air Traffic Route Traffic Control Center (ARTCC) for overflight of civilian aircraft. Southwestern and western parts of these restricted airspaces are used by military aircraft transiting to and from R-4807A and R-4807B. R-4808B is also used by DOE for flights to Pahut Mesa area as an extension of the NTS. Additionally, there are 21 Military Training Routes within the Nellis Range Complex (U.S. Air Force, 1999). Information about potential aircraft traffic in these restricted airspaces and military training routes should be presented along with analysis of associated potential hazards to the proposed facility.

No justification has been provided for classifying the inflight mode flights by all military aircraft in the vicinity of the potential repository surface facilities as "normal" inflight mode. Normal inflight mode, as defined by Kimura et al. (1996), includes "climb to cruise, cruise between an originating airfield and an operations area, if applicable, and cruise descent portions." "Special" inflight mode includes "low level and maneuvering operations in restricted area." Both Operations Red Flag and Green Flag provide realistic combat training to new fighter pilots (U.S. Air Force, 1999). This indicates that these flights will be in special inflight mode rather than in normal inflight mode. Justification is required why all aircraft flying in restricted area R-4809N will not be in special inflight mode. Using special inflight crash rates for F-16, F-15, and A-10, and assuming the total number of flights equals 12,714 with the same fractions of aircraft flights, among the types of aircraft as assumed by Morissette (1999), the estimated crash probability will be 3.7×10^{-6}/year. The estimated crash probability increases to 5.5×10^{-6} if the number of flights is assumed to be 18,910.

No justification has been provided why particular fractions of F-16, F-15, and A-10 aircraft were assumed in the analysis. Morissette (1999) has assumed 29 percent of all aircraft will be F-16s, 63 percent will be F-15s, and 7 percent will be A-10s. Data from Nellis Air Force Base, presented in Table 7.2-3, do not indicate that the assumed distribution of these aircraft into these three types is reasonable. As a consequence of the assumed distribution, F-15s with lower crash probability comprises a large fraction of the total aircraft (63 percent). It is prudent to use the bounding case scenario for safety analysis unless defensible data presented show otherwise. In this case, the bounding case would be assuming all aircraft are F-16s. Moreover, a reasonable change in this distribution of the aircraft types, even with 12,716 flights in a year and normal inflight crash rates, may raise the crash probability over 10^{-6} /year. For example, assuming 50 percent of the aircraft are F-16s, 40 percent are F-15s, and 10 percent are A-10s will give a crash probability of 10^{-6} /year. Assuming the number of flights to be 18,910 and normal inflight crash rates, the crash probability will be 1.3×10^{-6}/year if it is assumed that F-16s will comprise 40 percent of the total aircraft, 50 percent will be F-15s, and A-10 will be10 percent. Moreover, it is quite confusing why bounding case estimates in Tables III-3 and IV-3 use the crash rate of all small aircraft (all fighter, trainer, and attack aircraft), instead of F-16 which has the highest crash rate in a normal inflight mode. Trainer aircraft have much lower crash rates than fighters and attack aircraft (Kimura, et al., 1996). Therefore, use of this crash rate (1.84×10^{-8}/mi) biases the crash probability calculations toward unrealistically lower values and, hence, is not conservative.

No justification has been provided why the analysis assumed only F-16, F-15, and A-10 for the type of aircraft flying near the proposed site when Tullman (1997) stated that "any aircraft in the Department of Defense inventory, or other NATO country, could fly these routes." A typical red flag exercise includes attack, fighter, bomber, air superiority, and reconnaissance aircraft, electric countermeasures suppression aircraft, aerial refueling aircraft, and search and rescue aircraft (U.S. Air Force, 1999). It is not clear why no large bombers or cargo aircraft or any other aircraft were included in the analysis.

Morissette (1999) does not provide any information on the ordnance carried on these aircraft. The pilot of an aircraft about to crash will attempt to jettison the ordnance first to gain altitude so that more time is available to take any corrective measures. The jettison ordnance could pose significant hazards to the proposed repository. Additionally, "live" ordnance could pose additional hazards from flying fragments and air overpressure. Therefore, jettisoning of ordnance is also a concern for the site and should be investigated.

DOE should provide the following information with aircraft crash probability analysis:

- A map showing different airports and their approach paths, different commercial and general aviation airways, and military training routes with respect to the surface facilities at the proposed repository at YM. A National Oceanographic and Atmospheric

Administration chart with all of the above-mentioned information plotted would be necessary.

- Information of number and type of aircraft that use the military training routes including information on all "live" or "dummy" ordnance.

- A map showing the land boundaries of different Military Operations Areas (MOAs) and restricted airspace with respect to the proposed facility.

- Anticipated increase in civilian and military aircraft traffic in the future near the proposed facility.

Additionally, the 57th Wing uses the land on the Nellis Air Force Range Complex to conduct several training and simulated combat exercises for the United States and allied forces including: (i) Operation Red Flag and Green Flag to provide realistic training in a combat air, ground, and electronic threat environment; (ii) training for several different aircraft; (iii) Operation Air Warrior for close air support mission to support the U.S. Army; (iv) the Thunderbird air demonstration team; and (v) operation of the unmanned reconnaissance aircraft Predator (U.S. Air Force, 1999). Sandia National Laboratory launches rockets from Wahmonie in Area 26 to the Tonopah Test Range. Moreover, Kistler Aerospace may begin testing a fully reusable orbital launch vehicle in Area 18 of the NTS (U.S. Department of Energy, 2000b). Additionally, Nellis Air Force Range is used for air-to-air training (e.g., aircraft and missile targets testing, air-to-air gunnery range for aircraft), air-to-ground testing (e.g., cruise missile flight tests, ballistic flight test weapons evaluation, bomb testing for separation and accuracy, aircraft and missile targets use), and ground-to-ground testing (surface-launched missiles, ground shooting for large weapons) (U.S. Air Force, 1999). Any of these operations or other similar operations may have a potential effect on estimating the aircraft crash hazard probability. DOE should analyze any potential hazards from these activities or justify exclusions of them from analysis.

DOE should also obtain sufficient data to arrive at a defensible value for number of flights per year. Aircraft traffic in different restricted airspaces and military training routes should be analyzed for potential hazard to the proposed facility. DOE should also properly justify the assumptions of normal inflight mode for estimating the crash rate. DOE should also demonstrate that the assumption of small aircraft is bounding and conservative with proper analysis. Information on ordnance carried by the aircraft and potential for impacting or affecting any SSCs important to safety should be analyzed. The analysis for estimating the aircraft crash hazard should at least have the information suggested. Additionally, potential impact of other activities in the vicinity should be analyzed.

AC4 Adequate technical bases for the inclusion and exclusion of hazards and initiating events are provided.

- The technical bases are technical defensible and consistent with site and system information.

- The technical bases include adequate consideration of uncertainties associated with frequency or probability of the hazards and initiating events.

STATUS: Open. See discussion in AC2 and AC3.

AC5 The list of hazards and initiating events that may result in radiological releases is acceptable.

- The DOE list of hazards and initiating events contains the credible natural and human-induced events.

- Independent assessment confirms that the list of hazards and initiating events that may result in radiological releases is acceptable.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Identification of Event Sequences

Methods and Data for Identifying Event Sequences

AC1 Adequate technical basis and justification are provided for methodology used to identify PCSA event sequences.

- Methods selected for event sequence identification are appropriate and are consistent with standard practices.

- The methods selected are consistent with and supported by site-specific data.

STATUS: Not reviewed at this time. The methodology used for identification of event sequences based on event tree and fault tree analysis, for example, appear to be consistent with standard practices (CRWMS M&O, 1997; 1998g). However, since the system design is still evolving, DOE will need to assure that all changes are adequately reflected in the event sequence analyses.

Technical Basis for Inclusion and Exclusion

AC2 Category 1 and 2 event sequences are adequately identified.

- DOE properly applies methods for identification of event sequences.

- Adequate technical bases are provided for assumptions used in identification of event sequences.

- The potentially relevant human factors reviewed in Section 4.1.1.3 of the YMRP are adequately considered in the event sequence identification.

- DOE considers reasonable combinations of initiating events and the associated event sequences that could lead to exposure of individuals to radiation.

- Category 1 event sequences are identified based on the probability of occurrence of the event sequence being greater than or equal to 1 during the preclosure period, and the technical methods or approaches used to determine the probabilities of occurrence are acceptable.

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- Category 2 event sequences include all those event sequences with probabilities less than 1 and greater than one chance in 10,000 of occurring during the preclosure period, and are adequately justified based on sound technical methods or approaches used to determine the probabilities of occurrence are acceptable.

- Possible event sequences that may cause radiological releases are adequately identified, and related DOE analyses and calculations are performed properly.

STATUS: Not reviewed at this time. Material related to this AC will be evaluated and results documented in subsequent revisions.

Identification of SSCs Important to Safety

Meeting 10 CFR 63.111(a) and 63.112(b)(1)

AC1 Consequence analyses include normal operations and Category 1 event sequences as well as factors that allow an event sequence to propagate within the GROA.

- DOE conducts consequence analyses for normal operations and Category 1 event sequences that adequately consider hazard event sequences that could result in radiological consequences, interactions of identified hazards and proposed controls, and all modes of GROA operation. Analyses assume that operations are carried out at the maximum capacity and rate of receipt of radioactive waste stated in the LA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC2 Consequence calculations adequately assess the consequences to workers and members of the public from normal operations and Category 1 event sequences.

- Adequate methods are used to perform the consequence calculations, and adequate technical bases are provided for selecting these methods. Adequate technical bases are also provided for assumptions used for the calculations and methods. The selected methods are consistent with site-specific data and system design and process information.

- The identification of the member of the public likely to receive the highest dose from GROA normal operations or Category 1 event sequences is adequate, and the rationale for this identification is adequate. The dose to this individual bounds the annual dose to any real member of the public located beyond the site boundary.

- Input data and information used for the consequence analysis are identified and are consistent with site-specific data and system design and process information. Adequate technical bases are provided for their selection.

- The calculation of the source term is based on the following:

— Characteristics of the SNF and HLW used in the source term calculation reasonably represent or bound the range of characteristics of waste that will be handled at the GROA; and

— The type, quantity, and concentration of airborne radionuclides released during normal operations and Category 1 event sequences are supported by appropriate data or are in accordance with NRC guidance documents.

- The calculations of onsite and offsite direct exposures during normal operations and Category 1 event sequences are based on the following:

— The analyses are consistent with commonly acceptable shielding calculations and are provided in sufficient detail to allow independent confirmatory calculations,

— Credit taken for shielding materials that reduce direct exposure dose rates is appropriate and accounts for any degradation that may occur as a result of the event sequences,

— Methodologies used in any shielding analyses are appropriate for the radiation types and geometries and materials modeled and are validated using dose rate measurements from similar facilities, and

— Flux-to-dose conversion factors, atmospheric dispersion data, and cross-sectional data used in the analyses are consistent with accepted practice.

- The calculations of dose to workers and members of the public from airborne radionuclides during normal operations and following Category 1 event sequences are based on the following:

— Credit taken for the use of ventilation and filtration systems in mitigating the release of airborne radioactive materials is appropriate.

— For the calculation of dose to the public from airborne radionuclides, airborne transport modeling is conducted using acceptable methods, and DOE considers appropriate exposure pathways.

— For the calculation of dose to workers from airborne radionuclides, the calculation of airborne radioactivity concentrations within the GROA utilizes times and levels of elevated airborne radioactivity concentrations that are reasonable or conservative based on technically defensible data, and the times that workers are assumed to be exposed to elevated radiation fields and airborne concentrations of radioactivity are reasonable or conservative based on technically defensible data.

— The inhalation dose conversion factors used in the analyses are standard for dose assessments.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results

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documented in subsequent revisions.

AC3 The dose to workers and members of the public from normal operations and Category 1 event sequences is within the limits specified in 10 CFR 63.111(a).

- Normal operations and Category 1 event sequences that could adversely affect radiological exposures are adequately considered.

- An appropriate method is used to aggregate the doses from normal operations and Category 1 event sequences.

- Doses to workers and members of the public will be ALARA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Meeting 10 CFR 63.112(b)(2)

AC1 Consequence analyses include Category 2 event sequences as well as factors that allow an event sequence to propagate within the GROA.

- DOE conducts consequence analyses for Category 2 event sequences that adequately consider hazard event sequences that could lead to radiological consequences, interactions of identified hazards and proposed controls, and the maximum capacity and rate of receipt of radioactive waste. The consequence analyses provide details on the SSCs and controls that are relied on to prevent or mitigate event sequences.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC2 Consequence calculations adequately assess the consequences to members of the public from Category 2 event sequences.

- Adequate methods are used to perform the consequence calculations, and adequate technical bases are provided for selecting these methods. Adequate technical bases are also provided for assumptions used for the calculations and methods. The selected methods are consistent with site-specific data and system design and process information.

- The identification of the hypothetical member of the public, located on or beyond the site boundary, likely to receive the highest dose from the GROA during a Category 2 event sequence is adequate, and the rationale for this identification is adequate.

- Input data and information used for the consequence analysis are identified and are consistent with site-specific data and system design and process information. Adequate technical bases are provided for their selection.

- The calculation of the source term is based on the following:

- Characteristics of the HLW used in the source term calculation reasonably represent or bound the range of characteristics of waste that will be handled at the GROA; and
- The type, quantity, and concentration of airborne radionuclides that could be released during Category 2 event sequences are supported by appropriate data and analyses or are estimated in accordance with NRC guidance documents.

• The calculations of offsite dose from direct exposure following Category 2 event sequences are adequate and are based on the following:

- The analyses are consistent with commonly acceptable shielding calculations and are provided in sufficient detail to allow independent confirmatory calculations;
- Credit taken for shielding materials that reduce direct exposure dose rates is appropriate and accounts for any degradation that may occur as a result of the event sequence;
- Methodologies used in any shielding analyses are appropriate for the radiation types and geometries and materials modeled and are validated using dose rate measurements from similar facilities;
- The time that a member of the public is assumed to be exposed to elevated levels of radiation from Category 2 event sequences is reasonable. The time is based on the amount of time required for the facility to recover from the event sequence; and
- Flux-to-dose conversion factors, and cross-sectional data used in the analyses are consistent with accepted practice.

• The calculation of dose to members of the public from airborne radionuclides following Category 2 event sequences is adequate and is based on the following:

- Credit taken for the use of ventilation and filtration systems in mitigating the release of airborne radioactive materials is appropriate. The analyses consider credible damage to the ventilation system that may result from event sequences,
- Airborne transport modeling uses an acceptable method,
- DOE considers appropriate exposure pathways,
- The time that a member of the public is assumed to be exposed to airborne radioactive materials from Category 2 event sequences is reasonable and is based on the time that radioactive effluents are released from the facility, and
- The inhalation dose conversion factors used in the analyses are standard for dose assessments.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

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AC3 The dose to hypothetical members of the public from Category 2 event sequences is within the limits specified in 10 CFR 63.111(b)(2).

- Category 2 event sequences that could adversely affect radiological exposures are adequately considered.

- No identified Category 2 event sequence will lead to a dose to a member of the public that exceeds the dose limit in 10 CFR 63.111(b)(2).

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Meeting 10 CFR Part 20 As Low As Reasonably Achievable Criteria

AC1 An adequate statement of management commitment to maintain exposures to workers and the public ALARA is provided.

The management commitment includes provisions for ensuring that:

- No practice involving radiation exposure will be undertaken unless its use produces a net benefit;

- Supervisors will integrate appropriate radiation protection controls into work activities;

- Personnel are aware of the management commitment to ALARA principles;

- Workers will receive sufficient and appropriate initial and periodic training related to ALARA principles; and

- An operations program to control radiation exposure will be implemented. This program will ensure that individual and collective doses are ALARA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC2 ALARA principles are adequately considered in GROA design.

The design of the GROA adequately considers the ALARA philosophy.

ALARA principles are adopted in the design considerations, to the extent possible, to ensure the following:

- Engineered design features minimize the time workers must stay in radiation areas;

- Remotely operated or robotic equipment such as welders, wrenches, or radiation monitors is used to minimize worker dose;

- Suitable methods are used to monitor for possible blockage of air cooling passages or to perform inspection of materials;

- Design permits placement of equipment and temporary shielding by remote control to reduce doses where possible;

- Materials and design features minimize the potential for accumulation of radioactive materials or surface contamination to facilitate decontamination or decontamination and dismantlement of surface facilities;

- Offices, security areas, and laboratory facilities are located away from radiation sources;

- Radioactive material handling and storage facilities are located sufficiently far from the site boundary and from other onsite work stations. The controlled area of the facility is sufficient to maintain doses at locations accessible to members of the public at acceptable levels;

- Transfer routes for HLW will maintain the desired distance from the site perimeter; and

- Multiple restricted areas within the controlled area provide control of access to areas with radiation levels that would pose unacceptable risk to workers within those areas.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC3 Proposed operations at the GROA adequately incorporate ALARA principles.

Operational procedures follow the ALARA philosophy.

GROA operational procedures will ensure that the doses to workers and members of the public will be ALARA, including the consideration of items such as:

- An operations program designed to control radiation exposure will be implemented to ensure both individual and collective doses are ALARA;

Tradeoffs between requirements for increased monitoring or maintenance activities (and the increased exposures that would result) and the potential hazards associated with reduced frequency of these activities;

- Placement sequence of HLW in a manner that maximizes shielding by casks or structures;

- Dry runs to develop proficiency in procedures involving radiation exposures, to determine exposures likely to be associated with specific procedures, and to consider alternative procedures to minimize exposures;

- Development of tested contingency procedures for potential off-normal occurrences; and

- ALARA operational alternatives based on experience with independent SNF storage installations, pool facilities, and waste management facilities.

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Modifications to proposed operations of the GROA to maintain doses ALARA have been incorporated in the PCSA to ensure that they do not adversely influence other aspects of GROA operations.

Verify that operational procedures are follow the ALARA philosophy in Regulatory Guides 8.8 and 8.10. Plans for conduct of normal activities including maintenance, surveillance, and testing should be reviewed using Section 4.3.6 (Plans for Conduct of Normal Activities Including Maintenance, Surveillance, and Periodic Testing) of the YMRP.

Confirm that GROA operational procedures will ensure that the doses to workers and members of the public will be ALARA, including the consideration of items such as:

- An operations program designed to control radiation exposure will be implemented to ensure both individual and collective doses are ALARA (plans for conduct of normal operations are reviewed using Section 4.3.6 of the YMRP);

Tradeoffs between requirements for increased monitoring or maintenance activities (and the increased exposures that would result) and the potential hazards associated with reduced frequency of these activities;

- Placement sequence of SNF in a manner that maximizes shielding by casks or structures;
- Dry runs to develop proficiency in procedures involving radiation exposures, to determine exposures likely to be associated with specific procedures, and to consider alternative procedures to minimize exposures;
- Development of tested contingency procedures for potential off-normal occurrences; and
- ALARA operational alternatives based on experience with independent SNF storage installations, pool facilities, and waste management facilities.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Technical Bases for and Completeness of SSCs Important to Safety

AC1 A list of SSCs identified as being important to preclosure radiological safety, the technical bases for the approaches used to identify SSCs important to safety and safety controls based on analysis of their performance, and a list and analysis of the measures to be taken to ensure the availability of the safety systems are provided.

- The analysis and classification of SSCs for the GROA uses results of the consequence analyses as a basis to identify those SSCs that are important to safety.
- The analyses used to identify SSCs important to safety, safety controls, and measures to ensure the availability of the safety systems include adequate consideration of:

— Means to limit concentration of radioactive material in air;

- Means to limit time required to perform work in the vicinity of radioactive materials;
- Suitable shielding;
- Means to monitor and control dispersal of radioactive contamination;
- Means to control access to high radiation areas, very high radiation areas, or airborne radioactivity areas;
- Means to prevent or control criticality;
- A radiation alarm system designed to warn of significant increases in radiation levels, concentrations of radionuclides in air, and increased radioactivity in effluents;
- Ability of SSCs to perform their intended safety functions, assuming the occurrence of event sequences;
- Explosion and fire detection systems and appropriate suppression systems;
- Means to control radioactive waste and radioactive effluents and to permit prompt termination of operations and evacuation of personnel during an emergency;
- Means to provide reliable and timely emergency power to instruments, utility service systems, and operating systems important to safety if there is a loss of primary electric power;
- Means to provide redundant systems necessary to maintain, with adequate capacity, the capability of utility services important to safety; and
- Means to inspect, test, and maintain SSCs important to safety, as necessary, to ensure their continued function and readiness.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC2 Administrative or procedural safety controls needed to prevent event sequences or mitigate their effects are adequate.

- Management systems and procedures are sufficient to ensure that administrative or procedural safety controls will function properly.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Risk Basis for the Categorization of SSCs Important to Safety

To be developed.

STATUS: Not reviewed at this time. Pertinent ACs need to be developed.

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5.1.4 ACCEPTABILITY OF GROA DESIGN TO MEET THE PRECLOSURE PERFORMANCE OBJECTIVES

5.1.4.1 U.S. Department of Energy Approach

Design Criteria and Design Bases

To be developed.

GROA Design Methodologies

To be developed. DOE seismic design methodology was reviewed and accepted by the staff. The relevant discussion is provided in Section 5.1.2.

Design of Surface Facilities

To be developed.

Design of Subsurface Facilities

DOE load considerations for subsurface facilities include *in situ*, thermal, and seismic load (U.S. Department of Energy, 1997). Characterization of the *in situ* stress is rather straightforward. The vertical component of the in situ stress is calculated using overburden rock-mass density. The horizontal stress component is estimated from the vertical component. In most of the earlier DOE analyses (i.e., CRWMS M&O, 1998d; 1996b), the horizontal component of the *in situ* stress was calculated from the vertical component and rock mass Poisson's ratio. During the DOE/NRC Appendix 7 Meeting on Ground Control[5], however, it was proposed that horizontal stress be calculated from vertical stress and an assumed horizontal to vertical stress ratio of 0.3–1.0, with 1.0 being the upper bound stress ratio.

Thermal load depends on repository design, and DOE repository design is still an evolving process. The EDA II (CRWMS M&O, 1999a) appears to be the most recent design concept. EDA-II is also most likely to be submitted by DOE in its SR and, eventually, in LA (Barrett, 1999). In EDA-II, thermal load is designed to be an initial areal mass loading of 60 MTU/acre. This initial heat load will decay with time. The specific decay characteristics of thermal load are discussed in a CRWMS M&O report (CRWMS M&O, 1997c). No thermal load calculations (modeling) documented in the form of Analysis and Model Report (AMR); Process Model Report (PMR); or Features, Events, and Processes (FEPs) are available for staff review. If designed appropriately, ventilation could reduce temperature around the emplacement drift significantly. DOE Ventilation Model AMR (CRWMS M&O, 1999g) documented numerical analyses conducted to predict the fraction of heat that would be removed from the repository during the preclosure period. The analyses used a combination of 2D models for heat transfer in drift-normal planes and spread-sheet calculation for along-drift heat transfer. The numerical stability of the explicit stepping algorithm applied in the analyses to advance the solution along the drifts was not investigated.

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[5]DOE/NRC Appendix 7 Meeting on Ground Control, 1999.

Design ground-motion parameters for the proposed repository are still to be finalized by DOE in its Seismic TR–3 to be submitted for staff review in FY2002. The design ground-motion parameters will be developed based on site-specific probabilistic seismic hazard analyses (PSHA) (CRWMS M&O, 1998e). Details of the DOE approaches in its site-specific PSHA and staff evaluation can be found in SDS IRSR (U.S. Nuclear Regulatory Commission, 1999; 2000). In a preliminary report in development of seismic design basis inputs for YM (CRWMS M&O, 1998h), DOE documented some preliminary design ground-motion inputs at the repository interface. These results include: (i) 1–2 Hz and 5–10 Hz design earthquake spectra at annual exceedence probability of 10^{-3} and 10^{-4}; (ii) representative vertical and horizontal time histories at an annual exceedence probability of 10^{-4} and 1–2 Hz; and (iii) vibratory motions, dynamic strains, and dynamic curvatures throughout the tuff overburden for the seismic design of inclined and vertical shafts, ventilation shafts, and associated structures. These input parameters, however, are still to be finalized by DOE.

No details of ground support design or drift stability and ground support design analyses have been documented by the DOE in the form of AMRs, PMRs, FEPs, or any other forms that are available for staff review. The following summary of DOE approaches, therefore, is based mainly on information obtained during the Appendix 7 meeting on ground control. Previous DOE analyses used design configuration and thermal load that are very different from the recent design concept. These include ground support design analyses for ESF (CRWMS M&O, 1996b) and for VA (CRWMS M&O, 1998d). Although the results of these analyses will not be applicable to the final design, it is very likely that the same analysis approaches will be used by DOE in its drift stability and ground support design analyses for LA.

During the Appendix 7 meeting on ground control, it was proposed that ground support design analyses be conducted using continuum and discontinuum approaches using numerical codes FLAC and UDEC, respectively. Ground support modeling will include fully grouted rock bolts and steel sets. In case steel sets are over-stressed due to thermal loads, stress-relief elements or additional contact gaps may be used. Rock-mass and fracture property values for lithophysal and nonlithophysal rock units were proposed. However, no bases for the selection of such property values were given and these property values are not consistent with previous values given by DOE (CRWMS M&O, 1997a,h; 1998d). No actual modeling results were presented during the Appendix 7 meeting.

5.1.4.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Design Criteria and Design Bases

AC1 The relationship between the principal design criteria and the requirements specified in 10 CFR 63.111(a) and (b), the relationship between the design bases and the principal design criteria, and the design criteria and design bases for all SSCs important to safety are adequately defined.

- Principal design criteria and bases for SSCs important to safety and for those SSCs that affect the proper functioning of SSCs important to safety are identified, and these criteria and bases are derived from the specific site characteristics and consequence analyses. The design criteria and bases are consistent with the analyses used in the identification of the SSCs.

- Structural design criteria and bases for SSCs important to safety meet relevant guidance.

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- Thermal design criteria and bases are consistent with relevant regulatory guidance.

- Ventilation design criteria and bases are consistent with relevant regulatory guidance.

- Design criteria and bases for shielding and confinement systems utilize appropriate guidance.

- Design criteria for normal operating conditions are adequately developed so that designs do not result in any degradation of the capabilities of the GROA to protect radiological health and safety. Design criteria for Category 1 event sequences do not permit degradation of the performance of GROA SSCs important to safety.

- Designs for fixed-area radiation monitors and continuous airborne monitoring instrumentation are consistent with relevant regulatory guidance.

- Design criteria for Category 1 and 2 event sequences are sufficiently developed and adequately consider PCSA results to ensure that SSCs important to safety will continue to prevent unacceptable consequences.

- Criticality design criteria are developed based on consequence analysis results from the PCSA and are consistent with relevant regulatory guidance. Design criteria are adequately factored into the models and assumptions used for criticality analysis.

- Design bases and criteria are clearly identified for thermal, structural, shielding, criticality, and other operating limits for the GROA facilities.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

GROA Design Methodologies

AC1 GROA design methodologies are adequate.

- Proposed design methodologies are supported by adequate technical bases.

- Proposed design methodologies are consistent with established industry practice.

- Uncertainties associated with the proposed methodologies are adequately addressed.

- If the design methodologies depend on site-specific test data, such data are available.

- Any analytical or numerical models used to support the design methodologies are verified, calibrated, and validated.

- Any assumptions or limitations relating to the proposed methodologies are identified and their implications for the design are adequately analyzed and documented.

- Seismic design methodologies use ground-motion information that is consistent with proposed DOE methodologies for hazard assessment and, taken together, they provide adequate input for seismic design and for PA.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions. Seismic design methodology was reviewed and accepted at the staff level in a separate subissue (in Section 5.1.2 of this revision of the IRSR).

Design of Surface Facilities

AC1 Design codes and standards used for the design of surface facility SSCs important to safety are identified and are appropriate for the design methodologies selected.

- Applicable design codes and standards are specified for structural, thermal, shielding and confinement, criticality, and decommissioning designs.

- If other methods are used for design, the LA provides adequate technical bases for those methods.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in the subsequent revisions.

AC2 The materials to be used for SSCs important to safety related to surface facility design are consistent with the design methodologies.

- Materials used for SSCs important to safety related to surface facility design are consistent with either the accepted design criteria, codes, standards, and specifications or with those specifically developed by DOE.

- Materials are adequate, considering the material properties and allowable stresses and strains associated with the design.

- Materials and their properties are appropriate for the expected design loading conditions. In addition, anticipated stress limits for each material are based on maximum temperatures as established in the thermal analysis evaluation presented in the LA.

- The potential for creep or brittle fracture of materials is adequately assessed to ensure that SSCs important to safety will perform their safety functions.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC3 Design analyses use appropriate load combinations for normal and Category 1 and 2 event sequence conditions.

- The loads used in the DOE design analyses are consistent with those normal and Category 1 and 2 event sequence loadings of radiological importance.

- The load combinations used in the design analyses are consistent with those used and accepted by the NRC for the design of similar types of nuclear facilities and for steel and reinforced concrete structures.

- The design analyses use appropriate techniques that are correctly applied to provide established design temperatures, mechanical loads, and pressures for the SSCs important to safety.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

AC4 Design analyses are properly performed and documented.

- The design analyses include relevant structural, thermal, shielding, criticality, confinement, and decommissioning factors.

- Values of material properties used for the design analyses have adequate technical bases and are consistent with site-specific data.

- Loads and load combinations used in the design analyses are consistent with defined normal operations and Category 1 and 2 event sequences.

- Analytical methods, models, and codes used for the design analyses are appropriate for the conditions analyzed and are properly benchmarked.

- Technical bases for the assumptions used in the design analyses are conservatively defined and based on accepted engineering practice.

- The designs and design analyses for those SSCs defined as important to safety are performed correctly. These SSCs have sufficient capability to withstand normal and Category 1 and 2 event sequence loadings.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated and results documented in subsequent revisions.

Design of Subsurface Facilities

AC1 Design assumptions, codes, and standards used for the design of subsurface facility SSCs important to safety are acceptable.

- Applicable design codes, standards, or other detailed criteria used for the design of the subsurface facility are specified. Codes and standards are equivalent to and consistent with those accepted by the NRC for design of nuclear facilities with similar hazards and functions. If nonstandard approaches are used, the LA provides adequate technical bases to justify why they are used.

- Assumptions made for the design of the subsurface facility are technically defensible.

- Designs for steel and concrete structures and components, air controlled systems, electrical power systems, and ventilation systems use applicable standards.

STATUS: Open. At the time of preparing this revision (Rev. 3) of the RDTME KTI IRSR, the design codes, standards, and other applicable detailed criteria identified or determined by DOE for the design of the subsurface facility are not available for staff review. Neither are the assumptions made for the design of the subsurface facility. Consequently, the staff is unable to determine if codes and standards used for subsurface design are equivalent to and consistent with those accepted by the NRC for design of nuclear facilities with similar hazards and functions, if assumptions in subsurface design are technical defensible, and if design of other components uses applicable standards.

AC2 The design of subsurface operating systems is adequate.

- Methods, assumptions, and input data used in the ventilation design are consistent with proposed thermal loading performance goals.

- Considering the design analyses of control system functions, equipment, instrumentation, control links, and communication systems, the subsurface monitoring and control systems are appropriate for the safety functions of the SSCs during waste transportation, emplacement, and monitoring.

- The design of the waste transport and emplacement system is compatible with proposed waste transport and emplacement procedures. Interfaces with other systems are identified and assessed, and continuity of operations and safety can be achieved.

- Considering the layout of the subsurface portion of the repository, emplacement drifts are located away from major faults, consistent with the seismic design, and the subsurface layout is appropriate for the quantity of waste to be emplaced and the design thermal load.

- Standards and codes used for design of subsurface operating systems are properly applied.

STATUS: Not reviewed at this time. Information related to this AC, if available, will be evaluated and results documented in subsequent revisions.

AC3 Materials and material properties used for the subsurface facility design are appropriate.

- The selection of materials and the properties of these materials are appropriate for the anticipated subsurface environment.

- Materials and material properties are consistent with applicable design criteria, codes, standards, and specifications. If no standards are used, the technical bases provided are acceptable.

- Applicable American Society for Testing and Materials (ASTM) standard specifications are used.

- The selection of ground support materials accounts for degradation of such materials under elevated temperature and thermal loading. Plausible mechanisms for material degradation are identified and properly incorporated in assessments of subsystem SSC performance.

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- Fire resistant materials are incorporated into the design of the subsurface ventilation systems (e.g., fire resistant filters) to protect against fires occurring inside or outside the systems. Ventilation equipment/components are designed to withstand prolonged high temperature conditions, effects of potential sudden blast cooling, and potentially wet and corrosive environments.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and results documented in subsequent revisions.

AC4 Design analyses use appropriate load combinations for normal and Category 1 and 2 event sequence conditions.

- The arrangement of WPs within the subsurface facility satisfies the thermal load design criteria.

- The magnitude and temporal history of the applied thermal loading are consistent with the anticipated characteristics of the proposed nuclear waste, repository design configurations, and design areal mass loading.

- Thermal analyses have an appropriate technical basis, use site-specific thermal property data, consider temperature dependency and uncertainties of thermal property data, and use thermal models and analyses that are properly documented. If credit is taken for use of ventilation, assessments of the effects of ventilation are adequate.

- Design analyses consider appropriate *in situ* stresses and potential running ground conditions.

- The dynamic loads used in design analyses are consistent with seismic design ground-motion parameters including any repeated seismic effects, consider faulting effects, and are consistent with accepted methodologies for assessing faulting hazards.

STATUS: Open. No design analysis reports based on the current design concept (EDA-II) are available for staff review and evaluation, except information obtained from an Appendix 7 meeting on ground control held in November 1999. In considering *in situ* stresses, DOE proposed modeling horizontal to vertical stress with a ratio of 0.3 to 1.0 and considers the stress ratio of 1.0 as "bounding cases."[6] This range of stress ratio adequately covers the possible *in situ* stress ratio; however, they may not necessarily represent bounding cases after superimposing thermal load. A more realistic stress ratio should be used.

Thermal load calculation depends on details of repository design. As the repository design evolves, thermal load calculation needs to be updated and the updated calculation needs to be considered in ground support design and drift stability analyses. In the cases where such analyses take credit of ventilation, the model acceptance also depends on whether the ventilation model is acceptable.

Design values for seismic ground-motion are still to be developed. The evaluation of design seismic

[6]U.S. Department of Energy/Nuclear Regulatory Commission Appendix 7 Meeting on Ground Control, November, 1999.

loads on the acceptance of the third seismic TR. The modeling approach, however, can be established in advance. Recent analyses conducted at the CNWRA indicate that it may be necessary to consider both velocity and acceleration as input ground-motion in seismic design analyses (Chen, 2000). It is also desirable to perform analyses in both the time domain and frequency domain, because the effect of frequency may be affected by the input wave form. These analyses also show that incorporating input ground-motion parameters into ground support design and drift stability analyses can be very difficult, depending on available software. The preliminary representative design ground-motion time histories developed by DOE (CRWMS M&O, 1998h) have over 60 s of strong motion. Using these time histories as input for ground support design and drift stability analyses using numerical modeling could be a challenging task. DOE should ensure that selected numerical design analyses tools are capable of handling these time histories. Design spectra should also be developed so that the engineers and designers can take them for frequency-domain analyses. In the final Seismic TR–3, design ground-motion time histories should be developed for all the frequency ranges of interest [instead of only 1–2 Hz presented in CRWMS M&O (1998h)].

The design seismic load proposed during the NRC/DOE Appendix 7 meeting on ground control held in November 1999 includes only PGV and peak ground acceleration. These may not be sufficient. The analyses conducted at the CNWRA (Chen, 2000) show that seismic wave form and other input ground-motion parameters affect load acting on ground support. Such effects need to be analyzed using time domain and frequency domain analyses. Further evaluation will be conducted once the documents related to DOE methodologies for considering load and load combinations for design analyses become available to the staff.

AC5 Design analyses use appropriate models and site-specific properties of the host rock and consider spatial and temporal variation and uncertainties in such properties.

- Appropriate combinations of continuum and discontinuum modeling as well as 2D and 3D modeling are conducted to assess the behavior of a fractured rock mass under prolonged heated conditions and identified Category 1 and 2 event sequences. The bases for the choice of specific models and model combinations are adequate. Appropriate bases for the assumptions and limitations of the modeling approach are provided.

- Principles formulating the design analyses, the underlying assumptions, and the anticipated limitations are documented, are consistent with modeling objectives, and are technically sound.

- Values for the rock mass thermal expansion coefficient are consistent with properly interpreted site-specific data, and such interpretation accounts for likely scale effects and temperature dependency. The uncertainty in the thermal expansion coefficient is adequately assessed and considered in the thermal stress calculation.

- For continuum rock-mass modeling, the values for rock-mass elastic parameters (Young's modulus and Poisson's ratio) and strength parameters (friction angle and cohesion) are consistent with properly interpreted site-specific data. If the parameter values are obtained through empirical correlations with a rock-quality index, the empirical equations used are appropriate for the site and are applied correctly and the values of the index are consistent with site-specific data. If intact-rock-scale values are used, the bases for application of the values to the rock-mass scale are adequate.

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- For discontinuum rock mass modeling, the selection of fracture patterns for numerical modeling is appropriate for the objectives of the design and analyses and the interpretation of modeling results adequately considers effects of simplification of the characteristics of the modeled fracture network compared to those of the *in situ* fracture network.

- For discontinuum modeling, the selection of stiffness and strength parameters for rock blocks between any fractures that are explicitly represented in the model are appropriate and account for fractures that are not explicitly represented.

- For discontinuum modeling, the values for fracture stiffness and strength parameters are consistent with properly interpreted site-specific data.

- For both continuum and discontinuum modeling, time-dependent mechanical degradation of the rock mass, fractures, and ground support that may occur following the emplacement of nuclear waste is adequately accounted for in thermal-mechanical analyses. The bases for the magnitude and rate of mechanical degradation applied in the analyses are appropriately established and are technically defensible.

- Uncertainties in rock mass and fracture mechanical properties are adequately estimated and considered in both continuum and discontinuum modeling.

STATUS: Open. No design analyses based on the current design concept (EDA-II) are available for staff review and evaluation, except information obtained from an Appendix 7 meeting on ground control held in November 1999. Therefore, staff evaluation of design analyses is based on information from the Appendix 7 meeting, and ground support design analyses for VA (CRWMS M&O. 1998d). During the Appendix 7 meeting, it was announced that both continuum and discontinuum model analyses will be performed. It was proposed that such calculations will use FLAC and UDEC. No actual analyses or results, however, were presented to the staff knowledge.

Section 4.1.3.1 of this IRSR summarizes data needs and characterization for a continuum approach and demonstrates a 2D site-scale continuum analysis model. The analysis illustrated methodologies for considering spatial and temporal variations in rock mass properties and the effects of fractures on rock-mass properties for continuum analyses. Section 4.1.3.1 also summarizes rock mass and fracture property data required in discontinuum analyses. Chen, et al. (2000) and Chen (2000) further illustrated important factors, parameters, and modeling limitations that affect drift stability and ground support design analyses, using a discontinuum approach. Similar and more complete analyses should be performed and documented by DOE using well justified site-specific properties and models. In evaluation of DOE approaches in drift stability and ground support design analyses, the staff has the following concerns:

- Input rock mass and fracture mechanical properties have not been consistent and may not be conservative (also see Section 4.1.3.1). Specifically, rock-mass friction angle ranging from 56 degrees for a RMQ1 rock mass to 58 degrees for a RMQ5 rock mass (as proposed for the TM analyses during the November, 1999 Appendix 7 meeting) is too high and not realistic. These values are even higher than DOE laboratory testing results on intact TSw2 rock (48 degrees, CRWMS M&O 1997a). Rock mass Young's moduli ranging from 9.22 MPa for a RMQ1 rock mass to 24.90 MPa for a RMQ5 rock mass, proposed at the Appendix 7 meeting, are not consistent with the previously used range of 7.76 for a RMQ1 rock mass to 32.61 for RMQ5 rock mass (CRWMS M&O 1998d). No bases for selecting these parameters were provided. DOE rock mass friction angles and Young's moduli deviate significantly from those obtained from CNWRA independent implementation of the same empirical procedure based on rock mass quality (Ofoegbu, 1999, 2000; Ofoegbu, et al., 2000). Also, a fracture friction angle of 41 degrees proposed at the Appendix 7 meeting is too high and not consistent with available laboratory testing data (e.g., Hsiung, et al., 1993).

- Rock-mass properties for the lithophysal zone were proposed at the November 1999 Appendix 7 meeting. However, no bases for these parameter values are available for staff review. These parameter values need to be justified, particularly because a large portion of the repository will be in the lithophysal unit.

- DOE has based its design analyses largely on approaches developed from mining and tunneling. Such design analyses may be appropriate for ambient conditions but they may not be appropriate for emplacement drifts in heated conditions. Recent analyses performed at the CNWRA show that rock mass responses in heated conditions expected at the proposed YM repository are different from their responses in ambient conditions (Chen, et al., 2000; Chen, 2000). Under thermal load, rock mass deformation and load acting on ground support may be much greater in a strong (RMQ5) rock mass than in a weak (RMQ1) rock mass. This phenomenon contradicts observations from conventional underground mining and tunneling in ambient conditions. These observations show that a weaker rock mass would experience greater deformation than a stronger rock mass under the same loading conditions. Consequently, design approaches, particularly empirical design approaches using rock mass classification, that have been developed from underground mining and tunneling in ambient conditions may not apply to the design of emplacement drifts and ground support in YM.

- Analyses at the CNWRA also show that rock mass deformation under thermal load may be controlled by different mechanisms in different quality rock masses (Chen, et al., 2000; Chen, 2000). In a strong (RMQ5) rock mass, deformation is controlled mainly by high thermal stresses and failure occurs along subhorizontal fractures in roof and floor areas. In a weak (RMQ1) rock mass, deformation is controlled mainly by preexisting structures and failure occurs along subvertical fractures in sidewall areas.

- Rock mass thermal properties have been shown to have varying degrees of effect on the magnitude and distribution of thermal stresses and, consequently, drift stability. The effect of thermal expansivity is direct and significant because thermal stresses are directly proportional to rock mass thermal expansivity. Such an effect was illustrated by a simple numerical experiment (Chen, 2000). Future DOE drift stability and ground support design analyses need to use realistic and well based thermal expansivity values. Temperature-dependent thermal conductivity and specific heat capacity also affect thermal stresses (Ofoegbu, 2000). Inconsistent values have been reported and used in previous DOE analyses.

- Previous DOE analyses often used very simplified fracture patterns consisting of two sets of through going fractures with constant orientation and spacing. The effect of *in situ* fracture network characteristics has not been addressed. CNWRA analyses show that fracture pattern has a controlling effect on drift stability, particularly in terms of rockfall and drift collapse (Chen, 1999). Fracture pattern also affects load acting on ground support.

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Whereas it is acknowledged that no currently exiting discontinuum tools could incorporate fracture network characteristics to the level of complexity observed at YM, the potential effect of fracture pattern on drift stability and ground support design analyses should be evaluated.

With regard to seismic design, the analyses conducted at the CNWRA (Chen, 2000) show that dynamic modeling using UDEC is difficult and, in some cases, impractical because it is time consuming. Modeling results show that dynamic load has various degrees of impact on drift stability and ground support performance. The extent of such effects depends on many factors, including fracture pattern, input ground-motion parameters (particularly frequency), and, to a lesser degree, rock mass properties. Such effects need to be evaluated in drift stability and ground support design analyses for preclosure design. DOE has proposed using UDEC and FLAC to conduct its seismic design analyses. UDEC and FLAC treat dynamic input in a similar fashion. The staff is skeptical of the capability of these numerical tools. There are problems with UDEC dynamic modeling which must be resolved before it could be used for ground support design.

- The form of input ground-motion that UDEC accepts is limited to stress history converted from velocity history based on rock-mass properties. A stress time history may not be appropriate for a highly prestressed model. If input acceleration is to be used rather than velocity, the acceleration needs to be converted to velocity, and frequency has a huge effect on such conversion. A factor of 10 difference is introduced in input stress amplitudes in the frequency range of 1 and 10 Hz ground-motions. These conversions make it difficult to interpret modeling results and distinguish true frequency effects from modeling artifacts.

- Drift stability under dynamic load depends largely on simulated fracture pattern. When the fracture patterns are simplified, almost no response can be observed. For a more complicated fracture pattern, however, there are numerical problems such as numerical instability. A complicated fracture pattern also increases the size of the problem and often makes it impractical to do sensitivity analyses or to use a time history that is longer than a few seconds.

- A time history is only a particular case in a spectrum of ground-motions. It may be necessary in ground support design to conduct frequency-domain analyses. UDEC is not capable of such analyses.

- A geological model may respond differently to different forms of dynamic input. The differences in model responses to velocity, stress, or acceleration inputs need to be examined and UDEC is not capable of such examinations.

AC6 The design of ground support systems is based on appropriate design methodologies and interpretations of modeling results.

- Design methodologies or combinations of design methodologies are properly applied to the design of ground support systems. When used, the empirical design approach is consistent with accepted technology in the underground tunneling and mining industry. The evaluation and selection of ground support systems are supported by analyses that satisfy the previous two AC and that provide mechanical evaluation of ground support systems under thermal and dynamic loads.

- The ground support system responses are adequately evaluated, based on the results of model analyses. If the ground support system is explicitly modeled, the ground support responses include an adequate assessment of deformation and potential failure of the ground support systems. The interaction between the ground support system and the host rock units is adequately considered in the analysis. If the ground support system is not explicitly modeled, the anticipated ground support system responses from the modeling results are reasonably estimated and the technical bases for these estimates are adequate.

- The geometrical, thermal, and mechanical characteristics of the support system used in the TM analyses are consistent with design and construction specifications. The time-dependent mechanical degradation of the support system under heated conditions is adequately accounted for in the analyses.

- Stability of drifts, shafts, and ventilation tunnel is adequately assessed both with and without ground support. Such assessment includes identification of rock blocks that have potential to fall in the drift; the potential for cave-in, collapse, or closure of the emplacement drifts; and the extent and severity of rock-mass disturbance in the vicinity of the drift. The selection of a ground support system is consistent with the anticipated rock-mass responses and potential failure mechanisms of the rock mass in the vicinity of the drifts.

STATUS: Open. DOE has proposed to use both empirical and numerical approaches for the design of ground support. However, it appears that the emphasis has been on empirical approaches based on rock mass classifications. Numerical approaches have been used for confirmation purposes. Empirical design approaches have been developed mainly from experiences gained from conventional underground mining and tunneling in ambient conditions. As mentioned in the evaluation of the previous acceptance criterion, rock mass response in a heated environment is very different from that in a ambient thermal environment. Ground support analyses conducted at the CNWRA, using rock bolt and steel sets as examples, show that load acting on ground support is much greater in a strong (RMQ5) rock mass than in a weak (RMQ1) rock mass (Chen, 2000). This phenomenon contradicts observations on rock mass deformation from conventional underground mining and tunneling in ambient conditions. It implies that a stronger rock mass in heated conditions needs more ground support than a weaker rock mass. The empirical design approach, on the other hand, states that a weaker rock mass needs more ground support. Therefore, design of ground support for the emplacement drifts at YM may need to rely more on numerical approaches using appropriate models, combinations of models, and input parameters and uncertainties.

Also, as indicated in the evaluation in previous acceptance criterion, the deformation and failure of different quality rock masses under thermal load may be controlled by different mechanisms. Consequently, different strategies in ground support design may need to be applied in different quality rock masses. Specifically, ground support design may need to concentrate on stabilizing the roof and floor areas in a RMQ5 rock mass and sidewall areas in a RMQ1 rock mass.

AC7 The subsurface ventilation systems are adequately designed.

- The design of subsurface ventilation system is consistent with accepted design criteria, codes, standards, and specifications or with those specifically developed by DOE.

- The subsurface ventilation systems including their power sources identified as important to radiological safety (reviewed using section 4.1.1.6 of the YMRP) are designed to continue functioning under normal subsurface operating conditions, as well as under Category 1 and 2 event sequences.

- Applicable ventilation design guidance is met for the subsurface ventilation design.

- Subsurface ventilation equipment important to safety has backup or standby equivalents and fail safe mechanisms, where required, or DOE's ventilation design and analysis adequately shows that such equipment is not required.

- There is an adequate periodic inspection, testing, and maintenance program to assure that concentrations of radioactive materials meet the limits specified in 10 CFR Part 20 and 10 CFR Part 63 as practicable.

- The subsurface ventilation design is adequate to seal off or isolate airborne radiation within areas that could have a potential release.

- The ventilation design analysis is based on accepted industry codes or methods, incorporates site specific data, and is based on an accurate representation of the subsurface drift structure. The ventilation design analysis shows that subsurface ventilation flows from the least contaminated areas to the most contaminated areas and meets all other specified design criteria.

STATUS: Open. As described previously, the staff has questions on the methodology and, consequently, results of the DOE ventilation analyses model. The main concern is that the numerical stability of the explicit stepping algorithm applied in the analyses to advance the solution along the drifts was not investigated and, consequently, calculated air and drift-wall temperatures and the predicted amount of heat removal by ventilation may not be correct. Staff independent confirmatory analyses found inconsistency in DOE calculated drift-wall temperature and air temperature. The assumptions and methodology of the DOE ventilation model need to be further assessed and modeling results need to be validated. Also, the model needs to be reanalyzed as the repository design changes.

AC8 The design of subsurface power and power distribution systems for SSCs and operations important to safety is adequate.

- The design of subsurface electric power supplies and power distribution systems for operation of SSCs important to safety is consistent with accepted design criteria, codes, standards, and specifications for underground usage and is suitable for the normal operating environment and Category 1 and 2 event sequences.

- The design incorporates proper grounding of electrical power sources/equipment.

- The design has sufficient emergency backup power capability for SSCs important to safety.

- The design of electric power systems important to safety permits appropriate periodic inspection and testing.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

AC9 An adequate maintenance plan exists for subsurface facility SSCs, equipment, and controls important to safety.

- The maintenance plan developed to maintain drift stability prior to permanent closure of the repository is adequate. This maintenance plan considers the likely effects of uncertainties due to high temperature and high radiation levels and is based on an appropriate interpretation of modeling results that assess the possibility of degradation of both the rock mass and the ground support system under sustained thermal load.

- Adequate maintenance plans for other subsurface facility SSCs, equipment, and controls important to safety are in place, and they account for drift stability and accessibility during the period prior to permanent closure. The consideration of drift stability effects in the maintenance plan is based on an appropriate interpretation of modeling results.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

5.1.5 PRESERVATION OF RETRIEVABILITY OPTION

5.1.5.1 U.S. Department of Energy Approach

To be developed.

5.1.5.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Stability of Underground Openings and Maintainability

The resolution of this subissue will be assessed using the ACs listed under Section 5.1.4 (Acceptability of GROA Design to Meet the Preclosure Performance Objectives—Design of Subsurface Facilities).

Feasibility and Acceptability of Retrieval Plan

AC1 Plans for retrieval of WP, based on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, are provided and can be implemented, if necessary.

- Waste retrieval plans include a discussion of: (i) retrieval operations processes, (ii) equipment to be used, and (iii) compliance with 10 CFR 63.111(a) and (b) preclosure performance objectives during retrieval of waste.

- DOE has prepared reasonable scenarios under which retrieval operations will take place. The scenarios consider the 50-year requirement for retrievability option and the projected duration required to complete retrieval operations.

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- Adequate methodologies are established for identifying and analyzing potential problems for the various retrieval operations scenarios. The solutions proposed for the problems identified are feasible and are based on sound engineering principles. The extent of degradation of emplacement drifts during the period of retrieval operations is appropriately considered in the retrieval plans. The retrieval plans contain acceptable maintenance plans to support the completion of retrieval within the projected duration.

- Should the backfilling option be used in emplacement drifts before the end of the period of design for retrievability, the retrieval plans adequately address the requirements of 10 CFR 63.111(e).

- DOE provides a discussion of the potential effect of the duration of the planned performance confirmation program on the time frame required to maintain the option of waste retrieval. If there is a need for a different time frame for the period of design for retrievability, the time frame is consistent with the duration proposed by DOE for conducting the performance confirmation program.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

AC2 The proposed retrieval operations comply with the requirements of 10 CFR 63.111(a) and (b) preclosure performance objectives.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

AC4 A reasonable schedule for potential retrieval operations is provided.

- Plans for retrieval meet the 10 CFR 63.111(e)(3) requirement that retrieval can be completed within a time frame consistent with that required to construct the GROA and emplace waste.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

Temporary/Permanent Storage Considerations

AC4 The proposed alternate storage of retrieved radioactive wastes is reasonable.

- The physical location and boundary of the proposed alternate storage area are adequately defined.

- The proposed alternate storage area is sufficient to accommodate the amount of waste to be retrieved.

- Plans are adequate for protection of workers and the public while transporting the retrieved wastes to the alternate storage area.

STATUS: Not reviewed at this time. Information related to this AC will be evaluated once it becomes available and documented in subsequent revisions.

5.1.6 ACCEPTABILITY OF ENGINEERED BARRIER SYSTEM DESIGN TO MEET THE PRECLOSURE PERFORMANCE OBJECTIVES

5.1.6.1 U.S. Department of Energy Approach

While the EBS, as defined in 10 CFR Part 63, includes the WP and WF, DOE has chosen to address only the issues related to drift components other than WP and WF in the PMRs and AMRs pertaining to EBS. The issues related to WP and WF are addressed by DOE in separate PMRs and AMRs focused on these components (CRWMS M&O, 2000a,b). For evaluating the DOE approach, this distinction is maintained in this IRSR section.

The DOE VA (U.S. Department of Energy, 1998h) outlined the process for the nuclear safety analysis (i.e., preclosure PA) of the SSCs during the preclosure period in terms of classifying the DBEs according to their frequency of occurrence and identifying the status of determination of the consequences of these event sequences. It also identified some mitigating measures for these event sequences. It concluded that the potential bounding DBE for the repository preclosure period is a drop of the SNF fuel basket in the surface waste handling facility, and the consequence of this event can meet the off-site dose limits beyond a 5 km controlled area boundary through the use of high-efficiency particulate air filters. However, the VA analysis of the preclosure performance of EBS did not have sufficient discussion on the technical bases and methodologies used in this analysis. Additionally, many of the design features have changed since the VA was published. These changes include: (i) the pedestal for holding up the WP will now be made out of stainless steel instead of carbon steel, (ii) the drift will be lined with steel sets and wire mesh instead of concrete, (iii) the floor support of the drift will consist of steel plate over crushed tuff instead of concrete invert, (iv) backfill may or may not be placed over the drip shield, and (v) the drip shield may or may not be included in the LA design.

The PMRs and AMRs related to analyses of EBS design in the SR mostly pertain to postclosure performance (CRWMS M&O, 2000c,d). In most of these models, the preclosure period is assumed to be about 50 years during which the repository is completely ventilated, leading to dry out and removal of heat (assumed to be in the range of 70 to 100 percent during that period). However, these calculations are used mainly as input to postclosure performance calculations (CRWMS M&O, 2000c). The AMR on FEPs relevant to EBS performance (CRWMS M&O, 2000d) used an event-tree approach to identify the FEPs and a fault-tree approach to examine common mode failures, which are failures of multiple subsystems through the initiation of a single event such as seismic activity. While the methods used to identify FEPs and common mode failures are focused on postclosure performance, some of these events and processes will also be relevant to preclosure performance.

5.1.6.2 U.S. Nuclear Regulatory Commission Staff Evaluation

AC1 WP and EBS SSCs and their controls are adequately designed.

- The WP/EBS design adequately incorporates containment, criticality control, shielding, structural strength of WPs, thermal control, WF degradation, drip shield, backfill, and sorption barrier, as appropriate.

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- The description and assessment of the components for the various types of WPs include containers and internal structures such as structural guides, baskets, fuel baskets, fuel basket plates with neutron absorbers, neutron absorbers rods, canisters, fillers, and the fill gas, in addition to specific components of the EBS such as drip shield, backfill, and sorption barrier. The design analyses for these components are adequate.

- The materials, methods, and processes used in the fabrication of containers, internal WP components, and EBS components are consistent with accepted design criteria, codes, standards, and specifications. Processes specified for fabrication, assembly, closure, and inspection are based on accepted industry technology, and the LA documents any significant discrepancies or uncertainties related to the corrosion and mechanical resistance of container materials and relevant EBS components such as the drip shield. If DOE chooses to use different design criteria, codes, standards, specifications, and industry technology than that mentioned above, the technical bases provided are adequate.

- The specifications for container and internal WP materials are in agreement with those established in the final design. The specifications for closure welding, preparation for welding, materials to be used in welds, and inspection of welding comply with applicable American Society of Mechanical Engineers (ASME) codes. Any documented deficiencies or variations with respect to the specifications of the code are adequately supported.

- Appropriate methods for nondestructive examination of fabricated containers and other structural components of WP are identified to detect and evaluate fabrication defects and any other defects that may lead to premature failure.

- Criticality design criteria are consistent with those used in model calculations that support the design, waste is properly characterized in terms of isotopic enrichment, model configurations are appropriate for the various postulated repository environments, and appropriate computer models are used in design calculations.

- The assessment of shielding provided by the containers is sufficient, including estimates of dose rates, a description of the source of data for the evaluation, and the methods for estimating dose rate, including the use of computational codes.

- The components of the WP and internals are designed to sustain loads from normal operation and Category 1 and 2 event sequences.

- Thermal control is such that the fuel cladding temperature is sufficiently low to prevent cladding failure. Appropriate models are used for the calculation of decay heat, taking into consideration fuel age and fuel blending inside WP.

- The materials used in construction of the internal components of the WP are compatible with the WF, and interactions among these materials will not be detrimental to the stability of the WF. No pyrophoric, explosive, or chemically reactive materials are introduced in the WP.

- The design of any drip shield, including materials of construction, configuration, and method of emplacement, is sufficiently complete. The safety aspects of the EBS design and WP handling are not impaired by the drip shield.

- The design of any backfill, including materials and physical characteristics, configuration, and methods of emplacement and compaction, is adequate to reduce the relative humidity in the proximity of the WP, divert the flow of water away from the drip shield and WP, and avoid direct impact of rockfall on the drip shield without impairing the safety aspects of the EBS design and WP handling.

- The design of any sorption barrier is adequate to control the migration of radionuclides and materials and sorption properties, depth of placement, mixing with other materials, and degree of compaction provide adequate sorption barrier performance.

STATUS: This component is considered to be closed pending additional information. As mentioned previously, much of the DOE analyses focus on postclosure performance of the EBS, WP, and WF. Therefore, evaluation of DOE preclosure performance is incomplete.

The WP and EBS PMRs provide a detailed description of the EDA-II design of the EBS. However, the mechanical properties of all these components as functions of temperature have not been established to enable an accurate evaluation of event consequences. Specifically, the fracture toughness values for WP overpack materials, the tensile strength of drip shield material as a function of temperature, and the mechanical properties of borated stainless steel are only partially known. The fracture properties of WP overpack materials, especially weldments, are important in assessing the effect of rockfall or container drop on crack initiation. The mechanical properties of Ti-Pd drip shield alloy at temperatures anticipated in the drift during preclosure are important in assessing whether the drip shield will crack under loading from rockfall. Depending on the Ti alloy, the tensile properties of the drip shield can decrease significantly as the temperature increases. While DOE has performed preliminary calculations of the structural adequacy of pier and supports of WP under static and seismic loading (CRWMS M&O, 1997k), such an analysis is based on the VA design (e.g., carbon steel pier) and the use of room temperature mechanical properties.

The VA describes the waste transfer operations, which involves removal of SNF assemblies in a pool, drying them, and then transferring them to the WP outside the pool. It is not clear whether this will be the final design of the transfer process. It is mentioned in the VA that the drop height of WP in the surface handling facilities has been reduced through design. The WP drop analyses do not explicitly consider the effect of the drop on internal reconfiguration of the SNF due to basket cracking or on the potential for denting of the WP which may deteriorate its eventual stress corrosion cracking (SCC) resistance. Reconfiguration internal components may increase the risk of criticality.

The WP PMR (CRWMS M&O, 2000a) describes the closure welding process to be used in the EDA II design. The approach used for estimating the initial failure rate of the container is also detailed (CRWMS M&O, 2000a). This approach assumes a certain probability of initial failures and the ability to detect initially defective WP. The radiological consequences during the preclosure period to workers and the public due to initial defects needs to be examined.

The postclosure PA of the EBS (CRWMS M&O, 2000c) includes the effect of microbiological colonies and water seepage on steel components (rock bolts, steel sets, and WP support system). The assumption is that, during the preclosure period, ventilation will dry out the system and therefore aqueous corrosion processes are insignificant. However, the effectiveness of ventilation system in drying out a significant portion of the drift wall and the effect of an accidental malfunction, of the ventilation system during the preclosure period needs to be examined. Degradation of the steel support system may adversely affect waste retrieval.

The methodologies used by DOE for identifying the FEPs and the consequences are similar to those methods used in the PCSA required in 10 CFR 63.112. However, this analysis has not been performed by DOE for the current design of the EBS, WP, and WF. The mechanical property data for these components as functions of temperature is lacking. During the preclosure period, corrosion of support structures in the drift, on waste retrievability, and its effect needs to be examined.

5.1.7 ACCEPTABILITY OF THE PERFORMANCE CONFIRMATION PROGRAM

5.1.7.1 U.S. Department of Energy Approach

To be developed.

5.1.7.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Feasibility of the Performance Confirmation Program

To be developed. Some ACs in Section 5.1.4 may be applicable.

Design and Performance Verification During Construction and Operation

To be developed.

5.1.8 REPOSITORY OPERATIONS

5.1.8.1 U.S. Department of Energy Approach

To be developed.

5.1.8.2 U.S. Nuclear Regulatory Commission Staff Evaluation

To be developed.

5.1.9 Permanent Closure, Decontamination, and Decommissioning

5.1.9.1 U.S. Department of Energy Approach

To be developed.

5.1.9.2 U.S. Nuclear Regulatory Commission Staff Evaluation

To be developed.

5.2 POSTCLOSURE ISSUES RESOLUTION STATUS

5.2.1 THERMAL-MECHANICAL EFFECTS ON UNDERGROUND FACILITY ~~DESIGN AND~~ PERFORMANCE

Consideration of repeated seismic loading for the (postclosure) design of the WP and TSPAs is as discussed previously, this subissue includes two components: ~~(i) TM effects on design of the underground facility;~~ (ii) effects of seismically induced rockfall on WP performance and (iii) TM effects on flow into emplacement drifts. The status of resolution for each component is presented in separate subsections.

~~**5.2.2 Status of Thermal-Mechanical Effects on Design of Underground Facility**~~
~~This component of the Subissue on TM Effects on Repository Design and Performance relates to the sufficiency of DOE's underground facility design program. Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.3.1 of this IRSR.~~

~~**5.2.2.1 Acceptance Criterion 1**~~

~~**Approved QA control procedures and standards were applied to collection and documentation of data, methods, models, and codes.**~~ ~~The DOE and M&O Contractor periodically conducts performance-based audits and surveillances on the activities related to data collection and repository design. NRC staff participates as observers in these audits and surveillance. In the future, NRC staff will continue to participate in these audit activities to ensure that proper QA procedures have been implemented in the area of TM aspect of repository design.~~

~~Recent DOE audits identified deficiencies in data traceability, management, and qualification (e.g., U.S. Department of Energy, 1998e,f,g,h,i). Corrective actions are being taken to address these deficiencies. NRC staff will monitor the progress of the corrective actions.~~

~~**5.2.1.2 Acceptance Criterion 2**~~

~~**If used, expert elicitations are conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable guidelines.**~~ ~~Expert elicitations have been used in developing probabilistic seismic hazard data and, perhaps, the seismic and fault displacement input data for repository design and PA. The report for the former is currently available, and the latter will be available in FY2000. The RDTME KTI will review the process of the expert elicitations implemented in FY2000, in conjunction with the Structural Deformation and Seismicity KTI, to determine if acceptable guidelines have been followed.~~

~~**5.2.1.3 Acceptance Criterion 3**~~

~~**TM analyses of the repository design are based on site-specific thermal and mechanical properties, the spatial variation of such properties, and temporal variations caused by post-emplacement TMHC processes, as appropriate, including the consideration of seismic effects relevant to the YM site within the rock mass.**~~ ~~Appropriate data, including variations in the spatial and temporal domains, are important to support underground facility design analyses. In its VA report (U.S. Department of Energy, 1998j), DOE commits to continue characterization of the rock mass in the lower lithophysal zone of TSw2 unit where about 75 percent of the WPs will be emplaced. The VA report also discusses plans for testing TM properties of the proposed host rock at YM~~

~~(U.S. Department of Energy, 1998j, Section 3.1.1.8), convergence monitoring at the ESF and the cross drift to characterize the rock-mass support intersection (U.S. Department of Energy, 1998j, Section 3.1.1.7), TM deformation and associated permeability changes in the cross drift thermal test (U.S. Department of Energy, 1998j, Section 3.1.4.4), and evaluation of long-term mechanical stability of the host rock and candidate ground support materials based on laboratory test results and natural or manmade analogs (U.S. Department of Energy, 1998j, Section 3.1.5.3). However, details of the proposed testing plans are sketchy. Furthermore, review of a number of DOE design-related reports (see discussion in Section 4.3.3.2) indicates a need for an Appendix 7 meeting for NRC staff to better understand DOE's approach to data collection and utilization in design. An Appendix 7 meeting is proposed for FY2000. As a part of the meeting, Acceptance Criterion 3 is expected to be discussed in detail.~~

~~In its Repository Ground Support Analysis for Viability Assessment (CRWMS M&O, 1998e), DOE evaluated effects of seismic loads on rock-mass behavior surrounding emplacement drifts and ground support systems. The ground support systems under consideration include concrete lining and steel set lining. DOE is reevaluating concrete lining ground support because of a number of concerns (e.g., effectiveness of concrete lining under prolonged heated conditions and potentially adverse effects on postclosure performance). A combination of rock bolts and steel sets may be used in the emplacement drifts. Accordingly, the effect of seismic loads on rock bolts needs to be evaluated. The relevancy of the seismic signal used in the analyses will be determined once the DOE seismic design TR–3 is reviewed.~~

~~5.2.1.4 Acceptance Criterion 4~~

~~**The process to develop inputs to TM design includes consideration of associated uncertainties and documents the potential impacts on design.**~~ ~~The data reduction methods proposed in the DOE seismic design methodology to develop input for TM design analyses are empirical equations proposed by the industry. The equations for both mechanical and strength properties have considerable uncertainties. In its seismic design methodology, DOE also recognizes this fact and has committed to update these empirical equations. Although plans are included in the VA report for updating these empirical equations (U.S. Department of Energy, 1998j, Section 3.1.1.8), no specifics regarding how these empirical relationships will be validated have been provided. Validation of the empirical equations will be a subject of the proposed Appendix 7 meeting discussed in Section 5.3.1.3.~~

~~5.2.1.5 Acceptance Criterion 5~~

~~**The seismic and fault-displacement data inputs for design are consistent with those established in seismic design TR–3.**~~ ~~This acceptance criterion will be adequately addressed when the seismic design TR–3 is reviewed and found to be acceptable, and the seismic and fault-displacement data proposed in TR–3 are used in the design and analyses. Review of seismic design TR–3 is currently scheduled for FY2000, pending its issuance by DOE.~~

~~5.2.1.6 Acceptance Criterion 6~~

~~**The methodologies used for the TM design and analyses are consistent with those established in DOE Seismic TR–2.**~~ ~~The resolution of this acceptance criterion will await design details to be provided in the SR and LA.~~

~~5.2.1.7 Acceptance Criterion 7~~

~~**The TM design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. The models are tested as appropriate (verified, validated, and calibrated) before the submittal of the LA.**~~ ~~The current approach adopted by DOE for the TM design and analyses calls for the use of both continuum and discontinuum analyses to investigate the rock mass behavior and stability of the emplacement drifts under thermal and seismic loads. This approach is found to be acceptable. However, appropriate constitutive models representing reduction of mechanical and strength properties with time as a result of degradation of the rock mass induced by appropriate TMHC processes [e.g., progressive fracturing caused by sustained TM loading, alteration of fracture-wall rock from extended exposure to heat and moisture, and longevity (long-term effectiveness under high-temperature and thermally induced stress) or degradation of ground support systems] should be used in the design analyses for both continuum and discontinuum approaches. Alternatively, these two aspects can be properly bounded in the analyses. To the staff's understanding, long-term deterioration of rock material properties and ground support effectiveness is not currently factored into DOE's repository design and analyses. The staff will begin review of relevant documents and engage in discussions with DOE to resolve concerns regarding this acceptance criterion during FY2000. For those aspects of the models for which long-term experimental data are needed, continued verification and validation during performance confirmation may be acceptable as long as detailed plans and procedures for such continued activities are presented in the LA or supporting documentation. This acceptance criterion will be addressed at the proposed Appendix 7 meeting.~~

~~5.2.1.8 Acceptance Criterion 8~~

~~**Both drift- and repository-scale models of the underground facility are used in TM analyses to establish the intensity and distribution of ground movement (rock deformations, collapse, and other changes that may affect the integrity or geometrical configuration of openings within the underground facility). The number and variety of models permit the examination of conditions along drift-parallel and drift-normal directions.**~~ ~~DOE has not conducted repository-scale design calculations to establish the intensity and distribution of ground movement and synergistic effect on stability of the emplacement drifts in the area of high to low rock quality transition. Nor have bounding calculations been performed to account for the potential effects. This acceptance criterion may be discussed at the proposed Appendix 7 meeting. The staff will continue to follow DOE's progress in this area.~~

~~5.2.1.9 Acceptance Criterion 9~~

~~**The principles formulating the TM analytical methodology, underlying assumptions, resulting limitations, and various steps involved in the design procedures are clearly explained and justified.**~~ ~~The staff will review DOE's design and analyses related documents during FY2000 to determine progress on this acceptance criterion.~~

~~5.2.1.10 Acceptance Criterion 10~~

~~**Time sequences of thermal loading used in TM design and analyses are clearly defined.**~~ ~~The DOE is currently considering adoption of Enhanced Design Alterative No. 2, which was proposed by~~

~~the M&O Contractor as a design baseline for the LA (CRWMS M&O, 1999). The new design alternative features a 60-MTU/acre thermal load and a 0.1-m gap between adjacent WPs as compared with an 85-MTU/acre thermal load and an average 5.75-m gap for the VA design. Consequently, the thermal loading used for the TM design and analyses will need to be redefined if a decision is made in favor of the new design. The staff will continue to follow the developments in this area.~~

~~5.2.1.11 Acceptance Criterion 11~~

~~**The TM design and analyses consider the presence of roof supports (bolts, shotcrete, concrete, and steel liners, as applicable), consider the interaction between rock and roof supports, and address the degradation of supports with time under high temperature and moisture conditions as they affect the maintainability of stable openings during the extended preclosure period.**~~ ~~DOE repository designs and analyses (e.g., CRWMS M&O, 1998e) considered the presence of ground supports. However, as stated in Section 5.3.1.11, the ground support systems included only concrete lining and steel set lining. Given that rock bolts may eventually become the major support system in the underground facility, their effectiveness will need to be evaluated in DOE's design and analyses. Furthermore, potential deterioration of ground support effectiveness over the period of preclosure performance needs to be factored into the repository design and analyses. This acceptance criterion will be addressed at the proposed Appendix 7 meeting.~~

~~5.2.1.12 Acceptance Criterion 12~~

~~**Results of the TM analyses, including the consideration of ground support (e.g., liners), are accounted in the determination of maintenance requirements for the underground facility.**~~ ~~The staff will review DOE's maintenance requirements for the underground facility when they become available to determine if the TM analysis results are used to develop the requirements.~~

~~5.2.1.13 Acceptance Criterion 13~~

~~**The design discusses maintenance plans for keeping the underground openings stable, with particular attention to maintaining the option for retrieval. (If the details of retrieval operations/plans are found in other sections of the LA, a reference to such sections would be acceptable.)**~~ ~~The staff will review pertinent sections of the LA to evaluate how this acceptance criterion is addressed.~~

5.2.1.1 Status of Effects of Seismically Induced Rockfall on the Engineered Barrier System ~~Waste Package~~ Performance

This component of the Subissue on TM Effects on Repository Design and Performance relates to the assessment of rockfall effect on WP integrity. ~~Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.4.1 of this IRSR.~~ Two aspects of the rockfall event that are addressed are: (i) the status of the DOE efforts to establish the probability of this event and (ii) the subsequent consequences to the EB components.

The following model abstraction applies to this subissue:

- Mechanical Disruption of EBS

U.S. Department of Energy Approach

DOE disruptive events FEPs screening analysis (CRWMS M&O, 2000e) has concluded that mechanical disruption of the WP due to rockfall will not be considered in the TSPA because of the presence of the drip shield and/or backfill. According to the *Engineered Barrier System Degradation, Flow, and Transport Process Model Report* (CRWMS M&O, 2000c), Table 3-47, however,

> "...a design change prompted by thermal considerations, was initiated to remove backfill and change the drift orientation to minimize the size of key blocks. Revision or ICN of the AMR and the EBS PMR will assess consequences of this change."

DOE used key block analysis to assess drift degradation due to seismicity, thermal load, and long-term rock mass degradation for the 10,000-year performance period (CRWMS&O, 2000n). DOE has concluded in its analysis (CRWMS M&O, 1999h) that about 1 percent of the total length of emplacement drifts to be located in the Topopah Spring Tuff (TSw2) Lower Lithophysal unit is expected to experience rockfall during the 10,000-year performance period and about 16 percent of the TSw2 nonlithophysal unit. About 75 percent to 80 percent of the WP will be emplaced in the TSw2 lower lithophysal unit.

The consequences of rockfall on various components of the EBS continue to be considered by DOE. Specifically, DOE is using FE based numerical analysis methods to assess the structural response of the drip shield and WP to rock block impacts. For example, a recent report pertaining to rockfall describes the current drip shield design and the FE modeling methodology used to perform the rock block impact simulation. Areas of interest addressed in this report include: (i) the assumed sizes and shapes of the impacting rock blocks, (ii) modeling of the drip shield and rock block material behavior, (iii) the individual FE types used to model the drip shield and rock block, (iv) the load and displacement boundary conditions employed within the analysis, and (v) the failure criterion used to assess the ability of the drip shield to withstand rock block impacts.

The rock block sizes and shapes used to impact the drip shield in the FE analysis were derived from fracture geometry data obtained from tunnel mapping in the ESF located at YM (CRWMS M&O, 2000f). Using the software program entitled UNWEDGE (Version 2.3), the rock block geometry is calculated using input data representing three fracture sets. The fracture set data were defined in the context of an assumed repository tunnel azimuth of 75 degrees.

Only a 3-m length section of the drip shield was modeled in the FE analysis. The justification given for modeling the drip shield in this manner was that the largest partial volume of the rock block occurs over a 3-m length. The report further states that:

> "For sizes of rock up to 4 MT, entire rock volume is located above the 3-m partial length of the drip shield. ... the increase in rock mass is by increase in length of the rock geometry along the emplacement drift rather than any increase in the rock block apex height. For approximately the same apex height (1.3 m) ... a 4 MT rock" will have "a total length of 4 m along the emplacement drift whereas ... a 52 MT rock mass" will have "a length of 40 m. ... Using the concept of effective rock mass over a 3-m partial-

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length of drip shield, maximum rock mass is determined to be 10 MT per 3-m partial length of drip shield. In other words, an estimated maximum rock of 52 MT will load a 3-m partial-length of drip shield the same as a 10-MT rock, and for any rock mass over 52 MT a 3-m partial-length of drip shield will experience the same load as 10 MT."

The following table delineates the relationship of the actual rock mass with the effective partial-volume rock mass for the different rock sizes addressed in the DOE analysis of rockfall on the drip shield.

Table 3. Relationship between actual rock mass and effective rock mass

Actual Rock Mass (MT)	Effective Rock Mass Over a 3-m Length of Drip Shield (MT)
2.0	2.0
4.0	4.0
6.0	5.7
8.0	6.7
52.0	10.0

In expectation of the drip shield experiencing loads from the rock block impact that would cause plastic deformations, the drip shield materials (i.e., Titanium Grades 7 and 24) were modeled using bi-linear stress-strain curves. The material properties required to construct a bi-linear stress-strain curve are the yield stress, ultimate strength, Young's modulus, and minimum elongation. The actual material properties used for the two materials to construct these curves were derived from empirical data obtained at room temperature (i.e., approximately 20 °C).

The rock block material was assumed to respond to the impact load in a purely elastic manner. The rationale for this assumption was that the stresses experienced by the drip shield would be bounded if potential energy dissipation mechanisms of the rock block were not accounted for.

Shell and solid element formulations were used to model the drip shield and rock block, respectively.

Even though the drip shield is intended to be a free-standing structure (i.e., the base of the drip shield is not mechanically attached to the invert), the FE model employed boundary conditions that fixed the base of the drip shield to the invert. In other words, the base of the drip shield was not allowed to translate in any direction. No definitive information was provided regarding the constraints, if any, that were applied to the rotational degrees-of-freedom of the nodes at the base of the drip shield. The justification given for fixing the translational degrees-of-freedom was that the stresses experienced by the drip shield as a result of the rock block impact would be larger than the case of no constraints at all. No information was provided concerning the displacement boundary conditions applied at the ends of the 3-m section of the drip shield model.

The fall height of the rock block was estimated to be 2.3 m. Assuming no initial downward velocity for the rock block at the time it becomes dislodged, the velocity of the rock block at the time of impact with the drip shield was calculated to be 6.72 m/second.

A strain-based criterion was used to establish the structural failure of the drip shield. Specifically, "The failure of the drip shield is defined as the condition when the strain in the drip shield exceeds the failure strain (ductility), which results in rupturing of the material." No further information on the implementation of this failure criterion was provided.

Two different rock block and drip shield impact scenarios were investigated. In the first scenario, the rock block was centrally positioned above the drip shield such that impact would occur at the crest of the drip shield crown. The second scenario addressed the rock block impacting the side of the drip shield. Additional analyses considered the effects of increasing the drip shield side wall height by 0.2 m.

It was reported that:

> "The results of the finite element solutions indicate that no crack develops in the drip shield due to the dynamic impact of a rock on the drip shield for any of the rock sizes .... This is based on the steady-state drip shield configuration after the impact. The failure of drip shield structural components were specified by failure strain values equal to the material elongation values .... When the failure strain value is reached during the simulation, the corresponding elements are automatically removed from the FER. Since none of the elements were removed throughout the simulation, the failure strain is not exceeded in any of the components, and the drip shield is deemed to remain intact after the rockfall event."

No discussion was provided in the report detailing which components or types of strain measure were used in making this assessment.

The FE analysis results were also used to assess the potential for the initiation of SCC arising from the residual stresses developed as a consequence of the rock block impact. The results indicated that the drip shield may be susceptible to SCC. No discussion was provided in the report detailing which components or types of stress were used in making this assessment.

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AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of mechanical disruption of EB components (MDEB) and other related abstractions in the TSPA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of MDEB that are important to waste isolation and includes the technical bases for these descriptions.

- DOE identifies the EB components (e.g., backfill, drip shield) that may: (i) mitigate the effects of mechanically disruptive events on WP performance or (ii) adversely affect WP performance. DOE sufficiently describes these influences and the technical bases provided for their inclusion or exclusion in the MDEB abstraction.

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- DOE identifies the materials used in the construction of the WP and other relevant EB components. DOE defends the technical basis for including or excluding various behavioral characteristics and properties (e.g., corrosion, SCC, hydrogen embrittlement, fracture toughness, ultimate strength, etc.) of these materials in the MDEB abstraction in the DOE LA.

- DOE justifies the environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) included or excluded in the MDEB abstraction.

- DOE identifies pertinent design features and dimensions of the relevant EB components accounted for in the MDEB abstraction.

- DOE justifies the mechanically disruptive events considered in the development of the MDEB. DOE considers, at a minimum, seismicity, seismically induced rock fall, faulting, transient criticality, and igneous intrusion.

- DOE identifies the mechanical failure processes and concomitant failure criteria used for the individual EB components included in the MDEB abstraction. DOE defends the technical bases used to demonstrate that the failure processes and criteria are consistent with the material behavioral characteristics and anticipated loading conditions derived from the disruptive events.

- DOE justifies the TSPA models of seismicity, seismically induced rock fall, faulting, and igneous intrusion relies on consistent and appropriate assumptions throughout the TSPA abstraction process.

- DOE demonstrates the impact of internal pressure and temperature build-up on the integrity of the WP.

- DOE justifies the earthquake vibration effect on the EB and in particular the WP and its support (the invert).

- DOE considers appropriate components such as WP internal structures and WF (i.e., SNF matrix, cladding, structural support) that effect mechanical integrity under disruptive events.

STATUS: Open. DOE disruptive events FEPs screening analysis (CRWMS M&O, 2000e) has concluded that mechanical disruption of the WP due to rockfall will not be considered in the TSPA because of the presence of the drip shield and/or backfill. According to the *Engineered Barrier System Degradation, Flow, and Transport* PMR (CRWMS M&O, 2000c), Table 3-47, however, "...a design change prompted by thermal considerations, was initiated to remove backfill ...." Consequently, backfill needs to be removed from the screening arguments used by DOE as an EB component that will mitigate the effects of rockfall on the WP. In addition, backfill should no longer be used as justification for excluding rockfall effects as they pertain to the drip shield. The NRC staff does recognize that the presence of the drip shield will play a significant role in protecting the WP from rockfall. In the absence of backfill, however, the drip shield will be susceptible to extensive damage potential because of rock block impacts. Of particular concern is the continued ability of the drip shield to act as a water infiltration barrier once it has been damaged by falling rock blocks.

The NRC staff is also concerned that the use of the *Drift Degradation Analysis* (CRWMS M&O, 1999h) as a screening argument for excluding seismically induced rockfall from the TSPA code is premature and misrepresents the significance of the analysis results presented. For example, the areal coverage and sizes of the key blocks are reportedly quite small when the emplacements drifts are oriented at an azimuth of 75 degrees. This result is being independently verified by the NRC staff. The preliminary results indicated that the key block trace area (projected on the emplacement drift wall) to the emplacement drift surface area is about 1.4 to 2.2 percent for the TSw2 lower lithophysal unit. Although the drift length affected by rockfall was not specifically calculated, the trace plots of the key blocks show a much higher percentage than the 1.0 percent reported in the DOE *Drift Degradation Analysis* report (e.g., Figure 21). Consequently, the 1.0 percent value does not appear to be appropriate or conservative. Furthermore, in determining block sizes, the *Drift Degradation Analysis* report assumes that a joint surface is represented by a circular disc with a radius equal to twice the mapped trace length. This assumption may potentially underestimate the block size. Shorter joint length indicates less persistency; thus, the rock blocks will be bigger and their shapes will become more irregular, as shown in Goodman and Shi (1985). Consequently, the pyramid shape will be much less dominant as suggested in the DOE *Possible Rock Block Geometry, Dimension, Orientation, Probability, and Masses* report (CRWMS M&O, 2000f). A preliminary analysis indicates that a reduction of joint length to half could cause the maximum rock block size to increase by as much as 30 to 40 percent. In the *Drift Degradation Analysis* report, Monte Carlo simulations were used to model a 24.4-m-long tunnel in 3D space to generate rock blocks for conducting key block analysis. The use of a 24.4-m-long tunnel for analysis is not justified in the report. The complete dimension of the model domain is not given. The potential "boundary effect" is not discussed, either.

The effects of thermal load and long-term degradation of rock-mass was considered in the *Drift Degradation Analysis* report by reducing joint cohesion. The report indicates that time-dependent and thermal effects have a minor impact on rockfall. This finding is intuitive since the value used to represent joint cohesion is very small to start with. The report neglected the potential effects of reduction in joint friction angle.

Furthermore, the thermal stress induced in the rock-mass surrounding the emplacements drift could potentially fracture the intact rock and consequently cause additional rockfalls due to rock fracturing and subsequently increase the possibility for other rock blocks to fall. The *Drift Degradation Analysis* report does not take this aspect into consideration. The rock block size and potential emplacement drift affected by rockfall could increase if mapped trace length is used, and long-term and thermal effects on joint friction angle and intact rocks are factored into consideration. The concern regarding use of a pseudostatic approach to address seismic effect on rockfall using the key block analysis is discussed in Section 5.2.1.2 (*Change in Emplacement-Drift Geometry*, U.S. Department of Energy Approach subsection).

It does not appear that the *Drift Degradation Analysis* report considered potential joint sampling biases. Accurate characterization of fracture networks at YM requires that several important sampling biases common to fracture analyses be accounted for. If left uncorrected, these sampling biases could potentially lead to under-representation of fracture intensity, porosity, permeability, and connectivity and an incorrect statistical determination of dominant and subordinate fracture distributions. A detailed examination of sampling biases in the YM fracture data sets is given in the SDS IRSR Revision 2.0 (U.S. Nuclear Regulatory Commission, 1999). Some of the pertinent points are summarized in the following paragraph.

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First, the lengths of the longest fractures in a population are often unconstrained because the ends of the fracture are obscured (blind). This bias can lead to underestimation of fracture connectivity. Second, the orientation of a one-dimensional sampling line (e.g., borehole or detailed line survey scan line) or two-dimensional sampling surface (e.g., pavement or road cut) inherently biases sampling against discontinuities parallel to the sampling line or surface, and in favor of sampling discontinuities at a high angle to the sampling line or surface. Mathematical corrections (e.g., Terzaghi, 1965) can partially compensate for this sampling bias. Third, because measuring every fracture from microscale to megascale is impractical or impossible for large sample areas, fracture studies usually have a size (e.g., length) cutoff. Fractures smaller than a given dimension are not counted. Consequently, small fractures are under-represented in fracture characterization. Exclusion of fractures less than 1-m from the ESF data set may lead to an incorrect interpretation of fracture intensity. For example, interpretations near faults such as the Ghost Dance fault in the ESF, where the1-m cutoff for trace length was used, leads to extremely variable fracture intensity estimates over a wide zone (Sweetkind, et al., 1997a,b).

DOE has indicated that the drip shield will be fabricated using Titanium Grades 7 and 24. The WP, according to the EDA-II design, will employ Alloy 22 for the outer barrier and stainless steel 316NG for the inner barrier of the WP.

In anticipation of loads that would cause the drip shield materials to exceed their respective yield stress limits, the drip shield materials were modeled using bi-linear stress-strain curves in the preliminary DOE analysis of rockfall on the drip shield (CRWMS M&O, 2000n). The material properties required to construct a bi-linear stress-strain curve are the yield stress, ultimate strength, Young's modulus, and minimum elongation. The actual material properties used for the two materials to construct these curves were derived from empirical data obtained at room temperature (i.e., approximately 20 °C). As tables 4 and 5 indicate, however, the mechanical material properties for Titanium Grade 7 are strongly dependent on temperature. In addition, note that the yield stress values for Titanium Grade 7 published in the 1995 and 1998 versions of the ASME Boiler and Pressure Vessel (B&PV) Code, Section II, Part D– Properties (American Society of Mechanical Engineers, 1995; 1998) are not in agreement.

The temperature-dependent values for the yield stress, ultimate strength, and Young's modulus of Titanium Grades 5 or 24 are not provided in the ASME B&PV Code. Note that the composition of Titanium Grades 5 and 24 are the same except that Grade 24 contains 0.04 to 0.08 percent palladium. As a result, it is expected that these two grades will exhibit similar mechanical behavior (i.e., mechanical properties). The *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures* (U.S. Department of Defense, 1998) and *Material Properties Handbook: Titanium Alloys* (American Society for Metals International, 1994) provide extensive material data for Titanium Grade 5. As Table 6 illustrates, the values for the yield stress, ultimate strength, and Young's modulus that were extracted from graphical data provided in the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures* (U.S. Department of Defense, 1998) are also strongly dependent on temperature. Even though Titanium Grade 5 exhibits much higher strengths than Titanium Grade 7, the relative effects of temperature are still significant and must be considered when assessing the ability of the drip shield to withstand rock block impacts.

Table 4. Relevant mechanical properties of Titanium/Grade 7 as a function of temperature according to the 1995 American Society of Mechanical Engineers Boiler and Pressure Vessel Code

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength† ksi (MPa)	Modulus of Elasticity‡ ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	—	15.5×10^3 (106.9)
200 (93)	32.2 (222.0)	—	15.0×10^3 (103.4)
300 (149)	25.2 (173.8)	—	14.6×10^3 (100.7)
400 (204)	18.6 (128.2)	—	14.0×10^3 (96.5)
500 (260)	14.1 (97.2)	—	13.3×10^3 (91.7)
600 (316)	11.4 (78.6)	—	12.6×10^3 (86.9)

* – 1995 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table Y-1.
† – No values published.
‡ – 1995 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table TM- 5.

Table 5. Relevant mechanical properties of Titanium/Grade 7 as a function of temperature according to the 1998 American Society of Mechanical Engineers Boiler and Pressure Vessel Code

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength† ksi (MPa)	Modulus of Elasticity‡ ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	50.0 (344.8)	15.5×10^3 (106.9)
200 (93)	40.0 (275.8)	43.6 (300.6)	15.0×10^3 (103.4)
300 (149)	40.0 (275.8)	36.2 (249.6)	14.6×10^3 (100.7)
400 (204)	40.0 (275.8)	30.9 (213.1)	14.0×10^3 (96.5)
500 (260)	40.0 (275.8)	26.6 (183.4)	13.3×10^3 (91.7)
600 (316)	40.0 (275.8)	22.8 (157.2)	12.6×10^3 (86.9)

* - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table Y-1.
† - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table U.
‡ - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table TM-5.

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Table 6. Relevant mechanical properties of Titanium/Grade 5 as a function of temperature.

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength* ksi (MPa)	Modulus of Elasticity† ksi (GPa)
Room Temperature	120.0 (828.0)	130.0 (895.0)	16.9×10^3 (116.5)
200 (93)	105.6 (728.6)	118.3 (814.5)	16.2×10^3 (111.8)
300 (149)	94.8 (654.1)	109.2 (751.8)	15.5×10^3 (107.2)
400 (204)	85.2 (587.9)	101.4 (698.1)	14.9×10^3 (102.5)
500 (260)	78.0 (538.2)	96.2 (662.3)	14.4×10^3 (99.0)
600 (316)	74.4 (513.4)	93.6 (644.4)	13.7×10^3 (94.4)

* Room temperature reference value obtained from American Society for Testing and Materials B 265-98. Temperature correction factor extracted from Figure 5.4.1.1.1 of the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures.*
† Room temperature reference value obtained from Table 5.4.1.0(c_1) and the temperature correction factor extracted from Figure 5.4.1.1.4 of the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures.*

Because the potential reductions in yield stress and ultimate strength for Titanium Grades 7 and 24 as a result of elevated emplacement drift temperatures are significant, there is some concern by the NRC staff that these materials will also be susceptible to creep related failures arising from the support of dead loads (e.g., backfill and/or fallen rock blocks). Further justification for the staff concerns pertaining to creep failure of the drip shield materials can be found in *Fracture Mechanism Maps for Titanium and its Alloys* (Krishnamohanrao et al., 1986) and *Material Properties Handbook: Titanium Alloys* (American Society for Metals International, 1994). Consequently, DOE should provide the technical basis for excluding creep as a potential failure mechanism from the MDEB abstraction within its TSPA code.

No DOE analyses pertaining to the assessment of the new EDA II design for the WP when subjected to rockfall were available at the time this report was prepared. Specific aspects of the new WP design of interest to the NRC staff are (i) the potential loss of material ductility in the immediate area of the closure lid welds; (ii) the design provisions made to account for the significant difference in thermal expansion between the inner and outer barriers of the WP; and (iii) the failure criteria used to assess the structural integrity of the WP. Potential failure mechanisms related to rockfall include breaching of the WP barriers and SCC potential arising from the residual stresses attributable to rock block impacts.

AC2 Sufficient data (e.g., field, laboratory, and natural analog data) pertaining to the EB materials, mechanical failure processes, and the characterization of potential disruptive events are available to adequately define relevant parameters and conceptual models necessary for developing the MDEB abstraction in the TSPA. The data are also sufficient to assess the degree to which FEPs related to MDEB and which affect compliance with 10 CFR 63.113(b) have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these FEPs are adequate.

- DOE demonstrates that the data for mechanical failure models of the EB are based on laboratory measurements and tests designed to simulate or appropriately bound conditions that can be expected during a given mechanically disruptive event.

- DOE considers the effects of prolonged exposure to the expected emplacement drift environment (e.g., the effects of temperature, corrosion degradation, hydrogen embrittlement, radiation exposure, etc) in the constitutive models and their concomitant properties and failure criteria for the different EB component materials.

- DOE justifies that the use of material test results not specifically designed or performed for the YM repository program incorporates or appropriately bounds environmental conditions expected to prevail in the emplacement drift at the proposed YM repository.

- DOE demonstrates that sufficient data are presented to support the conceptual models, process-level models, and alternative conceptual models of mechanical disruption of MDEB.

- DOE identifies the data that support the technical bases for FEPs related to MDEB that have been included or excluded in the DOE LA.

- DOE demonstrates the effects design features and/or fabrication methods for the WP and other relevant EB components have on mechanical stresses and material properties. These effects may include, but are not limited to, residual stresses and/or structural flaws introduced during fabrication, stresses induced by differential thermal expansion, and material strain hardening.

- DOE adequately evaluates seismic source characterization, recurrence, and ground-motion attenuation. For example, DOE justifies seismic source data, including: (i) the geologic and tectonic settings of the site and region; (ii) local and regional faults (Type I faults); (iii) areal sources; (iv) the historic earthquake record; (v) fault slip rates, (vi) recurrence activity rates; (vii) clustered events; and (viii) earthquake and strong motion data used to develop ground-motion attenuation models, are geologically consistent and reasonable, compatible with current understanding of the YM tectonic framework, and adequate to support the TSPA abstraction of MDEB, such that reasonable projections can be made of future YM seismic activity.

- DOE adequately evaluates rock block sizes, contact surface geometry of the rock, and relative impact velocities between the rock block and EB components. For example, DOE's interpretations of rock block size from surficial and underground mapping and geophysical or analog investigations are geologically consistent and reasonable, are compatible with current understanding of the YM joint spacing and orientation framework, and are adequate to support conceptual models, attendant assumptions, and boundary conditions such that reasonable projections can be made on how future rock fall within the emplacement drifts will affect EB integrity.

STATUS: Open. The mechanical properties of Titanium Grades 7 and 24 have a significant influence on the overall structural behavior of the drip shield. Specific mechanical properties of interest include

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yield stress, ultimate strength, Young's modulus, minimum elongation, and creep rate. These same mechanical properties are dependent on temperature and these temperature effects should be accounted for in the design analyses. Given the lack of consistency and/or absence of published data for Titanium Grades 7 and 24, independently qualified tests may have to be conducted to establish the variability of these mechanical properties over the temperature range expected to exist within the proposed repository emplacement drifts.

No discussion was provided in the *Rock Fall on Drip Shield* report detailing which components or types of strain measure were used in concluding that "... no crack develops in the drip shield due to the dynamic impact of a rock on the drip shield for any of the rock sizes ...." For generalized three-dimensional stress states, failure criteria are typically based on maximum shear stress, octahedral shear stress, Von Mises stress, or strain-energy density. These measures are used because they can be readily employed to discern failure when complex stress states exist using data derived from simple tension tests.

FE analysis results were used to assess the potential for the initiation of SCC in the drip shield arising from the residual stresses developed as a consequence of the rock block impact. The results indicated that the drip shield may be susceptible to SCC. No discussion was provided in the report detailing which components or types of stress were used in making this assessment. As pointed out in the *Threshold Stress Level for Initiation of Stress Corrosion Cracking (SCC) in Alloy 22, Ti Gr7 and Ti Gr24* (CRWMS, M&O, 2000g),

> "...no experimental test results on SCC initiation stress threshold (IST) values are available for any of the corrosion-resistant alloys selected for the drip shield (Ti Gr7 and Ti Gr 24) and for the waste package (Alloy 22 and 316NG) under expected bounding waste package/drip shield surface environments and temperatures. ...However, a review of the literature indicates that SCC IST evaluation test results obtained in boiling magnesium chloride solutions performed in accordance with ASTM G36 or similar test procedures are very likely lower bound values as compared to the range of IST values expected in bounding waste package/drip shield surface environments. Consequently, the lower bound IST values obtained in boiling magnesium chloride tests reported in the literature for similar classes of alloys should be conservatively used for design and PA [Performance Assessment] purposes until directly measured alloy/environment relevant IST values are generated in currently planned test programs. In particular, IST values of 20 to 30 percent of room temperature yield stress (reported for stainless steels Types 304, 304L, and 316) will be used for the subject drip shield alloys (Ti Grade 7 and Ti Gr24) and waste package alloys (Alloy 22, 316NG) for design and PA purposes. This lower bound ITS range is assumed to be uniformly distributed between 20 and 30 percent of room temperature yield stress"

Although a literature search pertaining to IST values for SCC was apparently conducted, no supporting references were cited in the report to justify the assumption that the lower bound IST range is uniformly distributed between 20 and 30 percent of room temperature yield stress. Moreover, there was no information provided that addresses the recommended procedure for how generalized 3D stress states obtained from engineering analyses should be interpreted to properly determine whether the 20 to 30 percent of yield stress criterion for IST has been exceeded. In other words, should the Von Mises or first principle stress be used for comparison with the 20 to 30 percent of yield stress criterion. In addition, given the significant reduction in yield stress for Titanium Grades 7 and 24 at emplacement drift temperatures relative to the values at room temperature, the assumed IST criterion does not appear to be conservative or technically defendable.

AC3 Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of MDEB are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the TSPA abstraction are provided.

- DOE justifies the process-level models used to determine corrosion-dependent parameter values that define the relevant behavioral characteristics and properties (e.g., SCC, hydrogen embrittlement, fracture toughness, ultimate tensile strength, etc.) of the materials of the EB components considered important to waste isolation and susceptible to mechanical disruptions. DOE adequately defines a range of variations for these parameter values that accounts for the effects of and uncertainties associated with fabrication flaws, accumulated damage caused by multiple disruptive events, and the temporal and spatial changes in the emplacement drift environment (e.g., temperature, redox conditions, pH, chemical composition of water contacting the relevant EBs, etc.). These variations: (i) have been incorporated into the MDEB abstraction such that the model will not underestimate the failure of the relevant EB components subjected to mechanically disruptive events and (ii) are consistent with the requirements of the CLST KTI IRSR (U.S. Nuclear Regulatory Commission, 2000).

- DOE justifies, through appropriate methods for nondestructive examination of fabricated EB, the type, size, and location of fabrication defects that may lead to premature failure as a result of rapidly initiated EB degradation. The parameter values used in the analysis are consistent with the results of the nondestructive examination. DOE considers these defect when evaluating rock fall.

- DOE addresses, through appropriate sensitivity analyses or conservatively chosen bounds, uncertainty and variability in the relevant EB component corrosion models and their effects on the response of the EB component to mechanically disruptive events.

- DOE justifies the process-level models used to represent seismic conditions within the emplacement drifts at the proposed YM repository. DOE parameter values are adequately constrained by YM seismicity data such that the effects of seismicity on EB integrity are not underestimated. DOE identifies parameters within conceptual models for seismicity are consistent with the range of seismicity characteristics observed at YM.

- DOE's seismicity model parameters account for variability in data precision and accuracy. For example, DOE adequately accounts for uncertainty and verified parameter distributions of (i) maximum magnitude, (ii) depth of seismogenic crust, (iii) earthquake recurrence or activity rates, (iv) fault recurrence and dip, (v) wave propagation characteristics between earthquake sources and the YM site, and (vi) empirical and theoretical factors controlling directivity and other near-field effects.

- DOE identifies the seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the repository design criteria and TSPA.

- DOE demonstrates with adequate consideration of associated uncertainties that the size distribution of rocks that may potentially fall on the WP and other relevant EB components is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions).

- DOE appropriately establishes that possible correlations between parameters are included in the TSPA abstraction.

- Where sufficient data do not exist, the definition of parameter values and conceptual models are based on appropriate use of other sources such as expert elicitation conducted in accordance with appropriate guidance such as NUREG–1563.

STATUS: Not reviewed at this time. Materials related to this AC will be reviewed and the results documented in subsequent revisions.

AC4 Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of MDEB. DOE has provided sufficient evidence that ACMs of FEPs have been considered, that the models are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effect of these ACMs on TSPA has been evaluated.

- DOE adequately considers the temporal and spatial variations of parameters relevant to the response of the EBs to mechanically disruptive events (e.g., fracture toughness, dimensional changes, residual stresses, and SCC).

- DOE investigates alternative modeling approaches for seismicity, such as recurrence relationships or ground-motion attenuation relationships. For example, DOE models adequately considers uncertainties in: (i) geologic and tectonic conditions, (ii) seismic activity of independent and clustered events, (iii) recurrence-magnitude models, or (iv) ground-motion attenuation models.

- DOE identifies alternative conceptual models for seismically induced rockfall on theWP and other relevant EBs. DOE demonstrates that the analytical models used in the estimation of impact load due to rock fall on the WP and other relevant EB components are: (i) based on reasonable assumptions and site data, (ii) consistent with the underground facility (e.g., emplacement drift geometry and backfill) and EB component designs, and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses. DOE considers the rock fall analyses, as functions of ground-motions: (i) the possibility of multiple blocks falling onto the EBs simultaneously and (ii) the extent of the potential rock-fall area around the individual emplacement drifts and the entire repository. Within the rockfall dynamic analyses, DOE considers the TM effect and time-dependent jointed rock behavior and provides the background conditions on which seismic loads are superimposed.

STATUS: Not reviewed at this time. Materials related to this AC will be reviewed and the results documented in subsequent revisions. For evaluation of the last item of this AC, refer to the discussion provided for AC1.

AC5 Output from the TSPA abstraction of the degradation of EB is justified through comparison with output from detailed process-level models and empirical observations arising from laboratory tests and field measurements.

- DOE defends modeling results for MDEB by seismicity by comparison to output from detailed process-level models, empirical observations, or both. DOE demonstrates that results of assessments of the seismic disruption of the WP and other relevant EB components used in TSPA models were verified against results from empirical observations (including appropriate analogs). DOE appropriately adopts acceptable and documented procedures to construct and test empirical and physical models used to estimate the seismic hazard. DOE defends the effectiveness of proposed models in quantifying ground-motion at YM as it relates to earthquake-induced rock fall and repository performance.

- DOE justifies the output from the abstraction of the effect of seismically induced rock fall on the WP and other relevant EB components, and compares the results with a combination of corrosion degradation, rock block size and shape, impact velocities, and temperature adjusted EB component material characterizations. DOE identifies detailed models of mechanical failure to evaluate the PA abstractions of MDEBs.

STATUS: Not reviewed at this time. Materials related to this AC will be reviewed and the results documented in subsequent revisions.

~~**5.2.1.1.1 Acceptance Criterion 1**~~

~~**Approved QA and control procedures and standards were applied to collection, development and documentation of data, methods, models, and codes.** The M&O Contractor periodically conducts performance-based audits and surveillance on various activities related to repository PA. NRC staff will defer the determination of compliance with this acceptance criterion until the relevant audit is conducted.~~

~~**5.2.1.1.2 Acceptance Criterion 2**~~

~~**If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable approaches.** Expert elicitations have been used in developing probabilistic seismic hazard data. These data have been used in the TBD for determining damage level (see also Section 3.3.3.1). The report for developing the probabilistic seismic hazard data is available. In FY2000, the RDTME KTI will review the process the expert elicitation implemented, in conjunction with the Structural Deformation and Seismicity KTI to determine if acceptable guidelines have been followed.~~

~~**5.2.1.1.3 Acceptance Criterion 3**~~

~~**The seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the design and PAs as established in DOE's TR–3 reviewed and accepted by NRC.** As discussed in Section 3.3.3.1 of this IRSR, M&O used the annual probability of exceedence curve for horizontal *PGV* from the Probability Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada, Final Report, Volume 1, Text, based on the June 15, 1998, version in its TBD for rockfall assessment. This report has been subsequently revised and~~

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~~published on September 23, 1998. As a result, the annual probability of exceedence curve for horizontal *PGV* is substantially different in shape and annual probability. The new curve appears to produce higher *PGVs* than the one used in the TBD. The effect of the revised curve on WP damage needs to be evaluated.~~

~~5.2.1.1.4 Acceptance Criterion 4~~

~~Size distribution of rocks that may potentially fall on the WPs is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions) with adequate consideration of associated uncertainties.~~ ~~The distribution of rock block sizes determined in a CRWMS M&O report (1997i), based on the joint spacings obtained from the scanline mapping in the ESF, was used in the TBD to assess rockfall effects on WP disturbance. The rock block size was estimated using the approach suggested by Palmstrøm (1996). This approach has not been verified by the M&O.~~

~~In a TSPA Disruptive Events Workshop held February 9–11, 1999, in Albuquerque, New Mexico, it was proposed to refine the rockfall model in two areas: (i) determination of rock size distribution and relationship between seismicity and size of rockfall using the Key Block theory; and (ii) reassessment of rockfall effects on WP damage. The first proposed work item will attempt to determine available rock block size using a probabilistic Key Block theory. The NRC staff will continue to evaluate the approach adopted for rock size determination and the results generated as these become available.~~

~~5.2.1.1.5 Acceptance Criterion 5~~

~~The analytical model used in the estimation of impact load due to rockfall on the WP is: (i) based on reasonable assumptions and site data; (ii) consistent with the underground facility (emplacement drift geometry and backfill) and WP designs; and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses.~~ ~~The M&O rockfall model uses a WP damage criterion that links it to the rock size necessary to cause damages. This rock size was estimated by dynamically modeling the rockfall impact on WPs considering various stages of WP corrosion (CRWMS M&O, 1996a,b). In general, this approach is acceptable. However, there are a few concerns (Section 4.3.4.2) that need to be addressed.~~

~~The DOE model implicitly includes the possibility of repeated rockfalls at the same location by assuming that rockfalls will not cover up the WPs to protect them from further direct rockfall impact (CRWMS M&O, 1998d, Section 10.5.1). In its report, the M&O (1998d, Section 10.5.1) concluded that because of this implicit assumption, the DOE model encompasses the worst case condition. This assumption does not represent the worst case, however, because the distance the rocks fall is set to be from the drift ceiling to the WP (fall height)—approximately 3.5 m based on the reference design—for all the rockfalls that may occur at the same location (U.S. Department of Energy, 1998g, Section 4.4.3.1, Volume 3). The fall height for the first rockfall is 3.5 m based on the reference design; however, the fall height for the subsequent rockfalls at the same location should be greater than 3.5 m. For a given block size, the greater the fall height the more damage to the WP because the energy associated with the rock is higher. If the extent of the first rockfall is not sufficient to cover the WP, the potential effect of the second rockfall at the same location on WP damage needs to be assessed. In this regard, the critical rock size developed from the dynamic analysis as presented in the two M&O reports (CRWMS M&O, 1996a,b) is not appropriate for this assessment. Assuming the fall height is the same for subsequent rockfalls at the same location is not conservative in assessing WP damage.~~

~~The Enhanced Alterative Design No. 2 is currently under consideration to replace the TSPA-VA design. The WP damage criterion for assessing the effect of seismic activity should take into account this new design. The new design includes a 2-cm thick titanium drip shield and a thinner WP. The new design for the WP involves a 2-cm Alloy 22 outer barrier and a 5-cm A316 steel inner barrier. The total thickness of the new WP is 5 cm thinner than that proposed in the TSPA-VA. If designed properly, the drip shield may be able to withstand rockfall impact and thus delay or eliminate rockfall damage on WPs.~~

~~**5.2.1.1.6 Acceptance Criterion 6**~~

~~**The TM analyses that provide the background conditions on which seismic loads are superimposed consider time-dependent jointed rock behavior.** The TSPA-VA rockfall model does not consider the potential effect of time-dependent jointed rock behavior that will likely make the rockfall scenario more plausible than the *DL* approach adopted.~~

~~As discussed in Section 5.3.2.4, M&O plans to completely rework the rockfall model. This includes: (i) determination of rock size distribution and relationship between seismicity and size of rockfall using the Key Block theory; and (ii) reassessment of rockfall effects on WP damage. The first proposed work item attempts to associate the Key Block analysis with the thermal and seismic conditions expected in the emplacement horizon. In conducting this work, staff expects that the time-dependent jointed rock behavior also should be taken into consideration by M&O. The NRC staff will review the results of this work as they become available.~~

~~**5.2.1.1.7 Acceptance Criterion 7**~~

~~**Rockfall analyses consider, in a rational and realistic way through dynamic analyses, the possibility of multiple blocks falling onto a WP simultaneously, and the extent of the potential rockfall area around an individual emplacement drift as well as over the entire repository as functions of ground-motions.** A recent study showed that variability in joint patterns (mainly joint trend and plunge) appears to have a controlling effect on the potential and amount of rockfall (Chen, 1999). For a given rock type, the potential for rockfall is the smallest for a constant joint pattern (i.e., one without variations in joint trend and plunge). When variations are considered, the likelihood and extent of the rockfall and the number of multiple coherent rock blocks that can fall increase as the variability of joint patterns increases (Chen, 1999). The potential for rock blocks located one above the other to fall in unison (as opposed to individual rocks) will increase the "effective" size of rockfalls that hit the WPs. As a result, WPs will be damaged more severely and possibly experience earlier failures—a condition that could induce earlier, higher, or both doses at receptor locations. Both DOE (CRWMS M&O, 1998d) and NRC (1998) rockfall models recognize the effect of rock size on performance. As a general rule, the larger the rock block, the more damage it will cause the WPs. Consequently, mechanisms that may increase the "effective rock size" should be considered in the model.~~

5.2.1.2 Thermal-Mechanical Effects on Flow into Emplacement Drifts

TM Effects on Repository Performance address three aspects of DOE's PA abstractions change in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading; and (iii) the characterization of repository thermal loading and ventilation. The following PA abstractions are affected by these three concerns:

- Degradation of EBs
- Quantity and Chemistry of Water Contacting WP and WF
- Spatial and Temporal Distribution of Flow

~~This component of the Subissue on TM Effects on Repository Design and Performance relates to the determination if TM effects have been considered properly in the PA. Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.5.1 of this IRSR.~~

U.S. Department of Energy Approach

Change in Emplacement-Drift Geometry

DOE is likely to rely on analyses documented in the *Drift Degradation Analysis* report (CRWMS M&O, 1999h) for the prediction of potential changes in emplacement-drift geometry. The AMR defined its objective as: (i) to provide a statistical description of block sizes formed by fractures around the emplacement drifts; (ii) to estimate changes in drift profiles resulting from progressive deterioration of the emplacement drifts both with and without backfill, and (iii) to provide an estimate of the time required for significant drift deterioration to occur.

The analyses reported in the AMR were conducted using a computer code DRKBA (Stone Mineral Ventures, Inc., 1998), which is based on a statistical analysis of fracture networks to determine the occurrence of key blocks (i.e., the rock blocks that would have to fall before their neighboring blocks can fall) and calculates the factor of safety against the fall of key blocks under their own weight. The only driving force in the code (i.e., the force that may cause a key block to fall) is gravity. Resistance against block fall is provided by the shear strength of the fracture surfaces that define the key block.

The DRKBA code has no mechanism for the analysis of distributed internal forces such as are associated with thermal and seismic loadings. The AMR stated that thermal and seismic loadings were incorporated in the analyses through reductions of the shear strength of fracture surfaces. The procedure of accounting for thermal and seismic loadings through fracture-strength reductions is, however, inadequate for the following reasons.

- A key characteristic of thermal and seismic loading is that they generate distributed internal forces with varying orientations and magnitudes, such that the geomechanical response of a rock mass to thermal or seismic loading depends partly on the stress-strain response of the rock blocks and partly on the response of fracture surfaces. A code such as DRKBA that is based on the kinematic modeling of rigid blocks separated by fractures is not able to account for the stress-strain response of rock blocks and, consequently, is not appropriate for modeling the geomechanical response of a rock mass to thermal or seismic loading.

- Because the only driving force in the DRKBA code is vertical, the strength-reduction approach can only affect movement on vertical and near-vertical fracture planes. Block movements that may be caused by slip on subhorizontal fractures cannot be detected by the analysis procedure. Analyses conducted by other investigators using numerical codes based on stress analysis (e.g., Chen, et al., 2000; Ofoegbu, 2000) indicate that slip on subhorizontal fractures may be a predominant aspect of geomechanical response at YM because of the anticipated horizontal orientation of the maximum principal compressive stress during the thermal regime (e.g., Section 4.1.3.1).

Consequently, the analyses presented in the *Drift Degradation Analysis* report (CRWMS M&O, 1999h) are not capable of leading to any conclusion on the second and third objectives defined in the report. The first objective of the analysis, that is, providing a statistical description of block sizes formed by fractures around the emplacement drifts, can possibly be satisfied using the DRKBA code, depending on evaluations in Section 5.2.1.1, but the code is not appropriate for estimating potential changes in emplacement-drift geometry owing to thermal and seismic loading.

CRWMS M&O (CRWMS M&O, 2000h,i) proposed a procedure for incorporating drift-geometry changes in drift-seepage abstraction, but at the same time argued that only a small percentage of the emplacement drifts would be expected to experience significant changes in geometry. The conclusion regarding the percentage of drifts that may experience significant geometry changes was taken from the *Drift Degradation Analysis* report, which, as discussed earlier, is not capable of providing a technical basis for such a conclusion.

Change in Rock-Mass Hydrological Properties

The DOE approach to evaluating TM-induced hydrological-property changes is summarized in a statement, presented at the April 2000 DOE/NRC Technical Exchange, that "thermal loading will produce negligible changes in rock hydrologic properties."[7] This conclusion is based on an analysis by Blair (in Hardin, 1998) and numerical modeling by Berge et al. (1998, 1999), from which it was concluded that: (i) slip on a single vertical-fracture set can cause the permeability of the set to increase by a factor of two or less and (ii) if slip occurs simultaneously on two orthogonal sets of vertical fractures, the permeability of the sets can increase by a factor of four or less. As argued in Ofoegbu (2000), this suggested upperbound for thermally induced permeability increase is incorrect, having been calculated from an assumption that the magnitude of thermally induced slip on a given fracture is equal to the preexisting (i.e., before thermal loading) slip on the same fracture. No justification was offered for the assumption [Blair (in Hardin, 1998); Berge et al., 1998; 1999)]. In fact, there is no reason at all to expect a relationship between preexisting slip and thermally induced slip.

In contrast to the DOE position, information presented in Ofoegbu (2000) indicates that: (i) rock-mass permeabilities near the repository horizon can be expected to increase within laterally discontinuous zones centered at the emplacement drifts and in the middle of pillars, owing to fracture dilation associated with geomechanical response to thermal loading; (ii) the magnitude of permeability increase can be expected to greatly exceed the upper bound suggested by DOE and would be greater around the drift openings than in the pillars; (iii) the magnitudes would depend on thermal loading, rock-mass mechanical properties, and time-dependent mechanical degradation; (iv) altered zones characterized by horizontal-fracture dilation in areas of high rock-mass quality and vertical-fracture dilation in areas of low rock-mass quality can be expected, but fracture closure from thermally induced stresses is likely to be small and insignificant to rock-mass permeability; and (v) lateral flow of moisture can be expected in the altered zones and would result in elevated vertical percolation flux within and at the downstream end of the altered zones.

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[7]Barr, D. *Thermal Effects on Flow. Presentation at DOE/NRC Technical Exchange on Yucca Mountain Pre-Licensing Issues.* Las Vegas, NV: U.S. Department of Energy, Yucca Mountain Site Characterization Office. April 2000.

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Characterization of Repository Thermal Loading and Ventilation

This aspect of DOE's PA abstractions deals with thermal-load characterization of the emplaced nuclear waste, representation of thermal loading and ventilation in PA abstractions, and analysis to demonstrate that the ventilation design would remove the amount of heat assumed in PA abstractions.

A characterization of thermal loading for the proposed EDA II design concept is documented in a calculation report (CRWMS M&O, 2000j) that has not been reviewed by NRC.

Process level models that develop input information for TH abstractions (CRWMS M&O, 2000k) make an assumption that 70 percent of the waste-generated heat during the first 50 year would be removed by ventilation. The process level models implement this assumption by using only 30 percent of waste-generated heat as input thermal load during the first 50 years and 100 percent of the waste-generated heat thereafter (CRWMS M&O, 2000k). The procedure of using only 30 percent of the waste-generated heat (assuming that 70 percent of the heat is removed by ventilation) would satisfy the total energy balance of the repository control volume. The calculated temperatures within the repository volume are, however, likely to be incorrect, because the temperature gradients that drive heat transfer (by conduction, convection, and radiation) cannot be represented satisfactorily by using only 30 percent of the heat source. Heat transfer by radiation from the WP to the drift wall would be represented incorrectly using this procedure, possibly resulting in underestimation of the drift-wall and pillar temperatures.

Analyses to demonstrate that the proposed ventilation design would remove 70 percent of the waste-generated heat during the ventilation period are documented in the *Ventilation Model* report (CRWMS M&O, 1999g). The analyses are based on a combination of two-dimensional finite-element modeling for heat transfer in drift-normal planes, and spreadsheet calculations for heat transfer along the drift. The spreadsheet calculations use an explicit incrementation algorithm to advance the solution process in time and spatially along the drift. The conditions for numerical stability of the incrementation algorithm, which would define allowable limits for the time and drift-length increments, were not investigated. Furthermore, the algorithm did not use a predictor-corrector scheme to ensure consistency of corresponding estimates of drift-wall, air, and WP temperatures. These omissions from the algorithm raised a concern that the calculated drift-wall, air, and WP temperatures, and, consequently the predicted amounts of heat removal by ventilation, might not be correct. The concern was heightened by the results of calculations performed by CNWRA to check the consistency of the air and drift-wall temperatures given in the *Ventilation Model* report. The two sets of temperatures were found to be inconsistent: the drift-wall temperatures were not reproduced by analyses that used the air temperatures as input.

U.S. Nuclear Regulatory Commission Staff Evaluation

Degradation of Engineered Barriers

AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of degradation of EBs and other related abstractions in the TSPA, and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes design features of the EBS and aspects of the degradation of EBs that are important to waste isolation and includes the technical bases for these descriptions.

- DOE: (i) considers the effects of TM processes and thermohydrologic processes on the EB environment, taking into account heterogeneities such as joints and faults; (ii) bounds the range of thermally driven flux; and (iii) considers the possibility of water reflux during cool-down.

- DOE considers the effects of TM processes on ground movement (including rock fall, rock deformation, and alterations to porosity and existing fractures) and changes to the drift geometry that may affect the EB chemical environment.

- DOE's thermohydrologic models used to assess the effects of evaporation, thermally driven flow, and groundwater condensation on the EB environment include significant repository design features and evaluate the following potential thermohydrologic phenomena: (i) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

Status: Open. Change in emplacement-drift geometry (from roof and side-wall collapse and floor heave) is screened out from the abstraction of degradation of EBs (CRWMS M&O, 2000l) based on conclusions from the *Drift Degradation Analysis* report (CRWMS M&O, 1999i). The *Drift Degradation Analysis* report is, however, incapable of drawing conclusions regarding the long-term geometry of emplacement drifts because thermal and seismic loadings are not considered satisfactorily in the analyses. Therefore, the conclusions from the report cannot be used as a basis to screen out TM processes from the abstraction of degradation of EBs.

TM-induced change in hydrological properties are included in the abstraction of degradation of EBs through changes in the drift-seepage flux. Therefore, the treatment of TM effects on hydrological properties is evaluated as part of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms (CRWMS M&O, 2000l).

The assessment of TH effects on the EB environment is documented in a CRWMS M&O report (CRWMS M&O, 1999i), which ignored the first 50 or 100 years of thermal loading in the calculations. This report did not explain how the distributions of temperature, saturation, and relative humidity at 50 or 100 years (i.e., the initial conditions used in the analyses) were obtained without considering thermal loading during the earlier period (of 50 or 100 year). The thermal-load characterization of the emplaced waste and ventilation are significant design features that need to be considered in the assessment of TH effects on the EB environment.

Quantity and Chemistry of Water Contacting WPs and WFs

AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of the quantity and chemistry of water contacting WP and WF in the PA and other related abstractions in the TSPA, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract the quantity and chemistry of water contacting WP and WF have been provided. The TSPA abstraction is consistent with the identification and description of those aspects of the quantity and chemistry of water contacting WP and WF that are important to waste isolation. The TSPA abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically:

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- DOE evaluates the potential for focusing of water flow into drifts caused by coupled THMC processes.

- DOE abstractions, including dimensionality of the abstractions, appropriately account for the various design features, site characteristics, and alternative conceptual approaches.

- DOE spatial and temporal abstractions appropriately address the physical couplings (thermal-hydrologic-mechanical-chemical).

- DOE provides the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled THMC effects on seepage and flow and the WP chemical environment are used for PA.

- DOE provides adequate technical bases, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for exclusion of any THMC couplings and FEPs.

- DOE uses important design features, including WP design and material selection, backfill, drip shield, ground support, cladding, thermal loading strategy, and degradation processes, to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting WP and WF.

Status: Open. CRWMS M&O (CRWMS M&O, 2000h,i) proposed an approach based on drift surface area for including drift-geometry changes in the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms. The long-term emplacement-drift geometry required as input to the abstraction needs to be estimated using a procedure that accounts for the rock-mass geomechanical response to thermal and seismic loading. The *Drift Degradation Analysis* report (CRWMS M&O, 1999h) is unable to provide this information because the analyses did not consider thermal and seismic loadings satisfactorily.

TM effects on hydrological properties are screened out of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms for two reasons (CRWMS M&O, 2000k): First, TM effects on fracture permeability were considered to be small based on the Berge, et al. (1998) analyses (see *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach of this section). The upper bound permeability increase suggested by Berge, et al., (1998) is, however, too small and can be exceeded as discussed in Section 5.2.1.2 in *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach subsection. Second, analyses presented by CRWMS M&O (2000h) indicate that an increase in fracture permeability would result in decreased water flow into emplacement drifts. Alternative model calculations summarized in the *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach subsection of this section (Ofoegbu, 2000; Ofoegbu et al., 2000), however, indicate that lateral flow of moisture can be expected within a TM-altered zone and would cause increased vertical percolation flux and, therefore, drift seepage, at the downstream end of the altered zone. One difference between the two studies that may explain the divergence in the findings relates to the change in capillarity associated with a change in fracture aperture. In the study conducted by CRWMS M&O (2000h), a two-fold increase in fracture aperture (ten-fold increase in fracture permeability) was combined with a ten-fold decrease in capillarity, which effectively caused the altered zone to function as a capillary barrier. On the other hand, a change in capillarity was not applied in the alternative study (Ofoegbu, 2000;

Ofoegbu et al., 2000) in which an increase in fracture aperture by a factor of up to 10 was applied. DOE needs to provide the technical bases for the parameter values used to assess the effects of TM-altered hydrological properties on the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms.

As discussed previously (in the *Characterization of Repository Thermal Loading and Ventilation*, U.S. Department of Energy Approach subsection of Section 5.2.1.2), process level models that develop input information for the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms implement preclosure ventilation by using only 30 percent of waste-generated heat as input thermal load during the first 50 years after waste emplacement. Thereafter, the models use 100 percent of the waste-generated heat (CRWMS M&O, 2000k). To justify this representation of ventilation, DOE needs to demonstrate that: (i) the ventilation design would actually remove 70 percent of the waste-generated heat during the ventilation period, and (ii) the temperature distributions calculated using 30 percent of the heat source adequately represent the temperature distributions that would be calculated using 100 percent of the heat source with a proper representation of the ventilation design.

AC2 Sufficient data on design features (including drip shield, backfill, WP, cladding, other EB components, and thermal loading), geology, hydrology, geochemistry, and geomechanics of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of the quantity and chemistry of water contacting WP and WF in the TSPA. The data are also sufficient to assess the degree to which FEPs related to the quantity and chemistry of water contacting WP and WF and which affect compliance with post-closure performance objectives have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the abstraction process. Specifically:

- DOE demonstrates that sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variations in conditions, for conceptual models and simulations of thermal-hydrologic-mechanical-chemical coupled processes that affect seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

Status: Open. There are unresolved issues regarding data used to define potential changes in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading, and (iii) the characterization of repository thermal loading and ventilation. The information needed to resolve these issues is discussed in Sections 4.1.3.1 and 5.1.4.2 (under **AC5** of *Design of Subsurface Facilities* component).

AC3 Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of quantity and chemistry of water contacting WP and WF, such as the pH, chloride concentration, and amount of water flowing in and out of the breached WP, are consistent with site characterization data, design data, laboratory experiments, field measurements, and natural analog data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the TSPA abstraction are provided. Specifically,

- DOE demonstrates that input values used in the quantity and chemistry of water contacting EBs (e.g., drip shield, WP, and cladding) calculations in TSPA are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the YM site, such as WP and EBS design (including backfill, drip shield, ground support, and cladding), WP degradation (corrosion and mechanical disruption), cladding degradation, deep percolation flux, important thermal-hydrologic-mechanical-chemical coupling effects, the thermal reflux model, the thermal loading strategy (including effects of ventilation), natural system masses and fluxes, and other design features that may affect performance.

- DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled thermal-hydrologic-mechanical-chemical processes on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release.

- DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release, are consistent with available data.

- DOE adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THMC coupled processes that affect seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

Status: Open. There are unresolved issues regarding data used to define potential changes in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading, and (iii) the characterization of repository thermal loading and ventilation. The information needed to resolve these issues is discussed in Sections 4.1.3.1 and 5.1.4.2 (**AC5** *of Design of Subsurface Facilities* component).

AC4 Alternative modeling approaches consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of quantity and chemistry of water contacting WP and WF. DOE has provided sufficient evidence that alternative conceptual models of FEPs have been considered, that the models are consistent with available data and current scientific understanding, and that the effect of these alternative conceptual models on TSPA has been evaluated. Specifically:

- DOE adequately considers the effects of THMC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products in their assessment of alternative conceptual models. DOE considers: (i) thermohydrologic effects on gas and water chemistry; (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect flow pathways, water chemistry and WP environmental conditions; (iii) dehydration of hydrous phases liberating moisture that may affect the WP chemical environment and the chemical environment for radionuclide release; (iv) effects of microbial processes on the WP chemical environment and the chemical environment for radionuclide release; (v) changes in water chemistry that may result from the release of corrosion products from the WP and interactions between engineered materials and groundwater, which, in turn, may affect-flow and the WP chemical environment, as well as the chemical environment for radionuclide release; and (vi) changes in boundary conditions (e.g., drift shape and size) and hydrologic properties relating to the response of the geomechanical system to thermal loading, in their assessment of alternative conceptual models.

Status: Open. DOE should provide adequate description of the alternative conceptual models used to assess the effects of change in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loadings; and (iii) ventilation on the abstraction of quantity and chemistry of water contacting WP and WF. For example, an alternative conceptual model for change in emplacement-drift geometry and hydrological properties may consist of two sets of abstractions, one set based on completely collapsed drifts and the other set based on the initial drift geometry with predictions from the two sets combined using a time-dependent weighting function. Similar alternative models may also be developed to explore the effects of ventilation, if it is determined that it is not practical to model ventilation explicitly.

AC5 Output from the TSPA abstraction of quantity and chemistry of water contacting WP and WF is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, natural analogs).

- DOE demonstrates that abstracted models for coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release, are based on the same assumptions and approximations demonstrated to be appropriate for closely analogous natural or experimental systems.

- DOE clearly describes changes, if any, in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements, and demonstrates that the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility.

Status: Open. DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the anticipated geomechanical response to the proposed thermal loading and potential seismic loading.

Spatial and Temporal Distribution of Flow

AC1 Important design features, site-specific physical phenomena and couplings, and consistent and appropriate assumptions have been incorporated into the spatial and temporal distribution of flow abstraction in the PA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of spatial and temporal distribution of flow that are important to waste isolation and includes the technical bases for these descriptions. Specifically:

- DOE temporal abstractions of the spatial and temporal distribution of flow appropriately incorporate the physical couplings (THMC) or sufficient justification is provided for exclusion of these couplings. The DOE abstraction incorporates or conservatively bounds coupled THMC processes based on, for example, independent models, laboratory and field analyses, literature reviews, natural analog data, and other available information.

- DOE estimates of performance are not over optimistic, given the excluded set of phenomena and the implementation of coupled THMC processes in the TSPA.

Status: Open. TM effects on spatial and temporal distribution of flow are screened out of the DOE PA abstraction (CRWMS M&O, 2000m) using an argument that assumes that important TM effects would be reversible. The argument assumes that: (i) TM effects on hydrological properties would develop during the period of increasing temperature, (ii) drift seepage would not occur during this period because hot and dry conditions at the repository level, and (iii) the TM effects would be reversed before moisture returns to the repository level. These assumptions are not correct. Permanent TM-induced changes in hydrological properties and emplacement-drift geometry can be expected as discussed under the U.S. Department of Energy Approach subsection of this section (also, Ofoegbu, 2000; Ofoegbu et al., 2000). DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the, anticipated geomechanical response to the proposed thermal loading and potential seismic loading; and account for such changes in the abstraction of spatial and temporal distribution of flow.

AC3 Determine that parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the spatial and temporal distribution of flow abstraction are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the PA have been provided. Specifically:

- Input values used in the abstraction are consistent with the initial and boundary conditions and the assumptions of the conceptual models for the YM site. For example, estimation of the deep percolation flux into the drift is based on the infiltration rate, structural control (for flow diversion via faults), thermal loading strategy (for reflux), and other design features that may affect spatial and temporal distribution of flow.

Status: Open. The representation of repository thermal loading and ventilation in DOE's abstraction of the spatial and temporal distribution of flow is discussed under AC1 of *Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms* under the U.S. Nuclear Regulatory Commission Staff Evaluation subsection of this section. There are unresolved issues, and the path to resolution of these issues is discussed in the same section.

~~5.2.2.1 Acceptance Criterion 1~~

~~**Approved QA, control procedures, and standards were applied to collection, development and documentation of data, methods, models, and codes.** The M&O Contractor periodically conducts performance-based audits and surveillances on various activities related to the repository~~

~~PA. NRC staff will defer the determination of compliance with this acceptance criterion until relevant audits are conducted.~~

~~5.2.1.1 Acceptance Criterion 2~~

~~If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable approaches.~~ ~~DOE conducted an expert elicitation on the near-field/altered zone. This component of the Subissue on TM Effects on Repository Design and Performance is considered part of the near-field/altered zone subject area. The final report by the expert elicitation panel was published during 1998 (Geomatrix Consultants, Inc. and TRW, 1998).~~

~~To date, no questions or comments regarding the use of expert elicitation, in areas related to this component, have been raised by the staff. The expert elicitation process for the near-field/altered zone will be reviewed under the Evolution of the Near-Field Environment KTI.~~

~~5.2.1.2 Acceptance Criterion 3~~

~~Time-dependent changes in size and shape of the emplacement drifts due to thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) are estimated taking into account the uncertainties in the context of their impacts on performance.~~ ~~Thermally and seismically induced ground movements will affect inputs to hydrological flow assessment in two ways: changes in fracture permeability and porosity associated with rock deformation and changes in geometry (size and shape) of underground openings. Both effects have been recognized within the DOE program. The assessment of the impact of thermal loading on the fracture porosity and permeability throughout the host rock, particularly near the emplacement drifts and within the intervening pillars, is one of the topics that was presented to a panel of experts assembled by DOE to examine the role and assessment of near-field/altered zone coupled effects (Geomatrix Consultants, Inc. and TRW, 1998).~~

~~Change in geometry has been recognized to have a potential effect on dripping characteristics into emplacement drifts (Hughson and Dodge, 1999). This effect was not considered in the TSPA-VA (CRWMS M&O, 1998a).~~

~~5.2.1.3 Acceptance Criterion 4~~

~~Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are estimated taking into account the uncertainties in the context of their impacts on performance.~~ ~~Thermally and seismically induced ground movements will alter the hydraulic properties of the environment immediately next to the WP. The RDTME KTI staff is working with the Thermal Effects on Flow KTI staff to evaluate the importance of such changes to PA.~~

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5.2.2 Status of Open Items from Site Characterization Plan/Site Characterization Analysis and Study Plans

Item ID: OSC0000001347C055 Comment 055 SCA
Title: Use of statistics in TM properties
Status: Closed
Basis: Overtaken by changing of testing program. Related concerns are being reviewed under Design of GROA subissue

Item ID: OSC0000001346C056 Comment 056 SCA
Title: Validation of models/TM properties
Status: Closed
Basis: Subsumed under Acceptance Criterion 6 of Section 4.3.3.1 listed in Revision 2. For status, see Section 5.1.4 .

Item ID: OSC0000001347Q042 Question 009 SCA
Title: Systematic drilling program implementation strategy
Status: Open
Basis: To be determined

5.2.3 Other Related Items

To be determined.

5.3 DESIGN AND LONG-TERM CONTRIBUTION OF SEALS TO PERFORMANCE

~~This subissue will be addressed in subsequent revisions of this IRSR as DOE and NRC begin to focus more attention on it.~~

STATUS: Closed. The proposed 10 CFR Part 63 is a risk-informed and performance-based regulation. This regulation offers ample flexibility for DOE to demonstrate its case that the design of GROA meets preclosure and postclosure performance. Since this regulation does not specifically provide requirements for design and performance of seals and DOE does not current include seals in its PA, the staff determines that this subissue is closed. If DOE decides to take credit on seals to demonstrate meeting postclosure performance objectives in the future, the status of this subissue will be reexamined.

5.3.1 Status of Open Items from Site Characterization Plan/Site Characterization Analysis and Study Plans

Item ID: OSC0000001347Q042 Comment 074 SCA
Title: DOE's plan for *in-situ* testing of seal components
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSC0000001347Q025 Question 025 SCA
Title: Sealing program/gaseous transport
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSC0000001347Q028 Question 028 SCA
Title: Impacts on sealing program/calico hills penetration
Status: Closed
Basis: The current site characterization efforts have eliminated the need for penetrating the Calico Hills unit. Should DOE decide to revise its position to penetrate the Calico Hills unit, this concern may be reinstated.

Item ID: OSP0000831421Q001 Question 001 SP831421
Title: Status of borehole seal design
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSP000831421Q002 Question 002 SP831421
Title: Specification for sealing boreholes
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

5.3.2 Other Related Items

To be determined.

5.4 OTHER OPEN ITEMS NOT INCLUDED UNDER THE FOUR SUBISSUES

5.4.1 Status of Open Items from Site Characterization Plan/Site Characterization Analysis and Study Plans

Item ID: OSC0000001347C077 Comment 077 SCA
Title: Retrieval accidents/radiation exposure
Status: Closed
Basis: Related concerns will be reviewed under retrievability subissue.

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Item ID: OSC0000001347Q042 Comment 120 SCA
Title: Comprehensive, integrated and prioritized plan for model and code validation
Status: Closed
Basis: Transferred to TSPAI KTI IRSR Revision 2.

Item ID: OSC0000001347Q042 Comment 122 SCA
Title: Criteria for determining the acceptability of dry coring method
Status: Closed
Basis: Dry coring technology has been demonstrated.

Item ID: OSC0000001347Q042 Question 055 SCA
Title: Analysis of potential test interference from water storage facilities
Status: Closed
Basis: ESF construction completed. No evidence of test interference from surface water storage facilities.

5.4.2 Status of Open Items from the Annotated Outline

Item ID: OAO030SEP1992C00 Comment 003 AO30SEP1992
Title: Planned area/controlled area
Status: Closed
Basis: DOE repository design is being revised.

Item ID: OAO030SEP1992C00 Comment 004 AO30SEP1992
Title: Legal definition of controlled area
Status: Closed
Basis: NRC has revised the definition of controlled area under DBE rule making.

Item ID: OAO030SEP1992Q00 Question 001 AO30SEP1992
Title: Figure reference/underground facility
Status: Closed
Basis: The underground facility design is being updated. The concern does not apply to the latest DOE design presented in the VA.

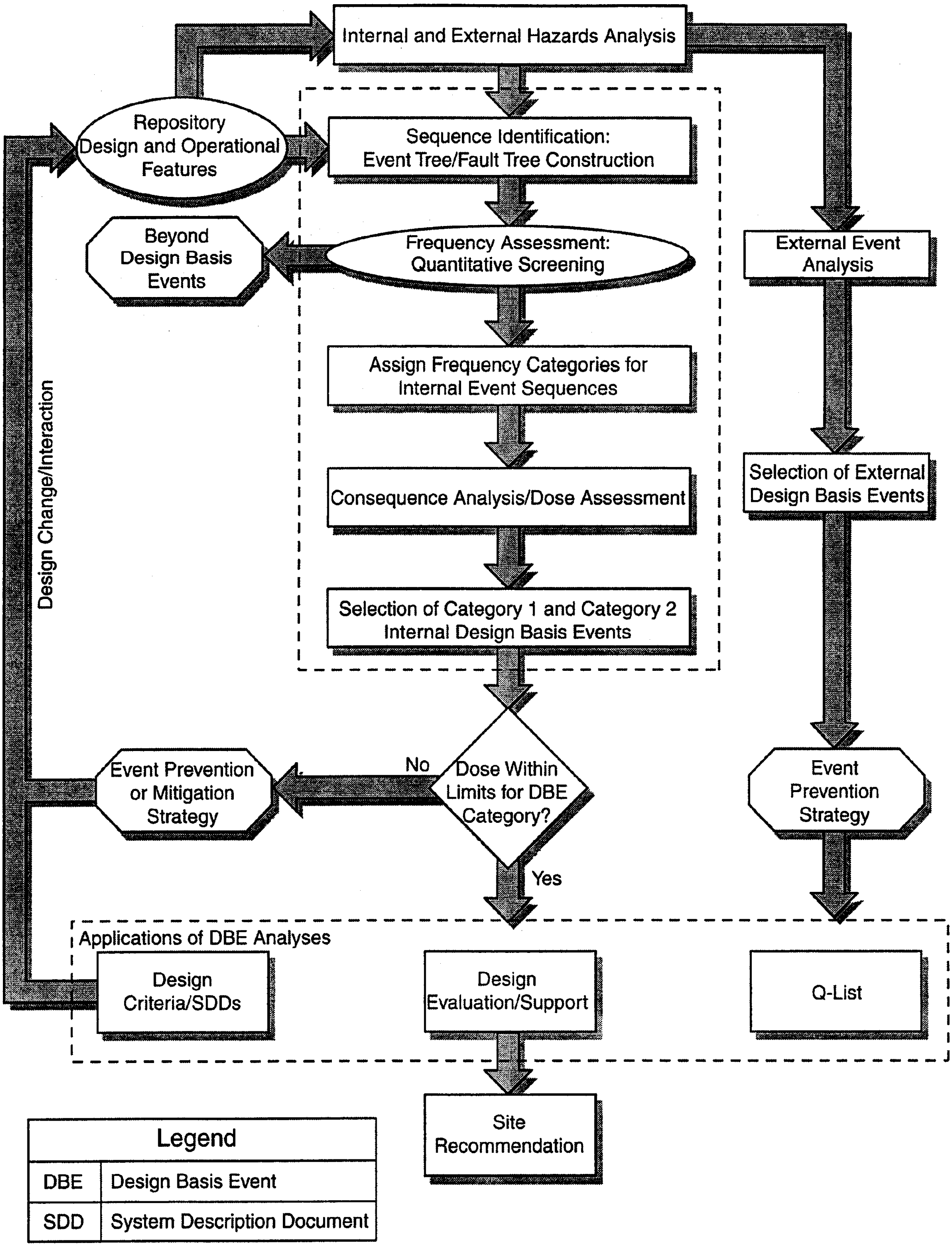

Figure 20. Department of Energy integrated safety analysis methodology

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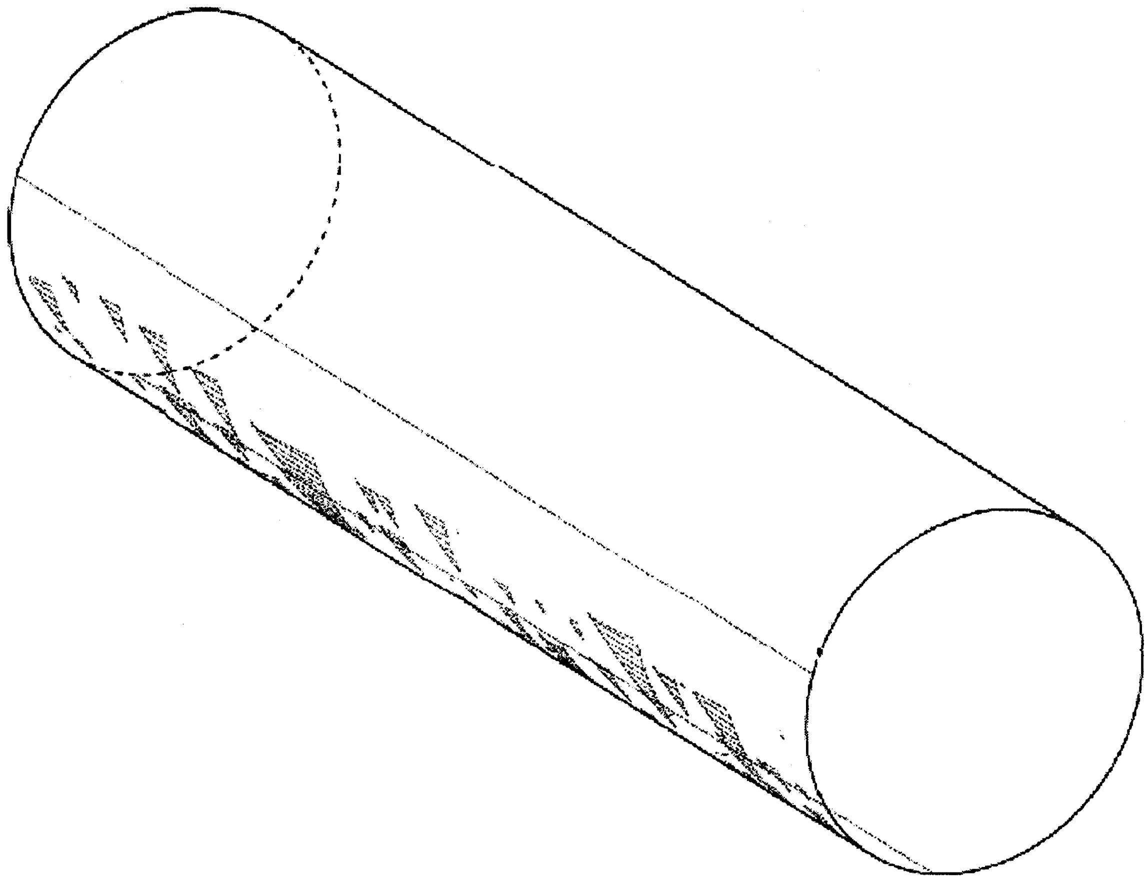

Figure 21. Traces of key blocks on emplacement surface for TSw2 lower lithophysal unit

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APPENDIX

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APPENDIX

This appendix lists important correspondences and interactions between the Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) related to the subissue of exploratory studies facility (ESF) design and design control process and briefly summarizes relevant details at the end of each item:

(1) U.S. Nuclear Regulatory Commission letter from R.M. Bernero to S. Rousso of U.S. Department of Energy, [cover letter to NRC's Site Characterization Analysis (SCA)] dated July 31, 1989.

[The letter and SCA raise two objections to DOE's continued deficiencies in its overall Quality Assurance Procedures (QAP) and inadequacy of its ESF design and design control process.]

(2) U.S. Nuclear Regulatory Commission letters from R.M. Bernero to J. Bartlett of U.S. Department of Energy, dated March 2, 1992, and November 2, 1992.

[The letters lift NRC's objections 1 and 2 based in part, on DOE's demonstration that it had revised its process of controlling ESF design and implementation of such a process.]

(3) U.S. Nuclear Regulatory Commission letters from J.J. Holonich to D. Shelor of U.S. Department of Energy, dated March 24, 1993, and May 5, 1993.

[The letters express renewed concerns related to ESF design and design control process.]

(4) U.S. Nuclear Regulatory Commission letter from B.J. Youngblood to D. Shelor of U.S. Department of Energy, dated August 20, 1993.

[The letter requests specific information from DOE including an action plan for implementing an acceptable design control process before proceeding with further design activities.]

(5) U.S. Department of Energy letter from D. Shelor to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated November 1, 1993.

[This letter provides details related to the technical and regulatory design requirements and document hierarchy.]

(6) U.S. Department of Energy letter from D. Shelor to B.J. Youngblood of U.S. Nuclear Regulatory Commission, dated November 18, 1993.

[This letter provides response to specific NRC requests made in (4) above.]

(7) DOE–NRC interactions related to ESF design and design control process dated September 17, 1993, October 4–5, 1993, December 8, 1993, and January 5–7, 1994.

[The discussions held during these interactions provide additional responses and clarifications to earlier staff requests.]

APPENDIX (cont'd)

(8) U.S. Nuclear Regulatory Commission letter from B.J. Youngblood to D. Shelor of U.S. Department of Energy, dated March 30, 1994.

[This letter expresses limited satisfaction at the progress made by DOE and recommends further followup, such as quality assurance (QA) audits and surveillances for additional verification of DOE actions.]

(9) U.S. Nuclear Regulatory Commission from R.M. Bernero to D. Dreyfus of U.S. Department of Energy, dated October 13, 1994.

[This letter notifies DOE of staff continued concerns with DOE and its management and operating (M&O) Contractor QAP and transmits one major comment related to DOE and M&O QAP and three specific questions related to ESF design and its interface with geologic repository operations area (GROA) conceptual design.]

(10) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated October 17, 1994.

[This letter provides a quick initial response to staff letter of October 13, 1994, and proposes a set of actions and commitments.]

(11) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated November 14, 1994.

[This letter provides a detailed response to NRC's letter of October 13, 1994, and a series of actions and commitments. The staff uses this letter to develop a checklist of 51 items to be verified during an in-field verification.]

(12) U.S. Department of Energy letter from R.A. Milner to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated January 27, 1995.

[This letter provides a list of DOE's commitments in response to staff recommendations.]

(13) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated March 9, 1995.

[This letter summarizes Phase-1 staff review of DOE's detailed response of November 14, 1994, and concludes that the responses provided by DOE are acceptable and presents a schedule for Phase-2 in-field verification.]

(14) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated March 14, 1995.

[This letter provides continued response to staff letter of October 13, 1994, and attaches the Regulatory Compliance Review Report (RCRR) showing the allocation and traceability of 10 CFR Part 60 requirements to the ESF.]

APPENDIX (cont'd)

(15) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated March 16, 1995.

(This letter summarizes staff observations of DOE's QA audit of M&O.)

(16) U.S. Nuclear Regulatory Commission conducted in-field verification (phase-2) during April 3–6, 1995.

[See NRC (1995b), for in-field verification procedures and NRC (1995c), for the summary of findings from 6.0 List of References.]

(17) U.S. Department of Energy letter from R.A. Milner to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated May 1, 1995.

[This letter informs NRC of DOE's decision to lift a self-imposed "hold" on tunnel boring machine (TBM) progress beyond upper Paintbrush Tuff nonwelded (Ptn) contact.]

(18) U.S. Nuclear Regulatory Commission letter from J.G. Greeves to R.A. Milner of U.S. Department of Energy, dated May 12, 1995.

[This letter concludes that an "objection" level concern does not exist with respect to the "pneumatic pathway" issue and documents that establishing or lifting "hold points" for TBM progress was a matter left to DOE's discretion.]

(19) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated June 16, 1995.

[This letter transmits staff in-field verification report, along with a commendation, closing several open items from the 51 items of the checklist and making three specific recommendations and proposals for followup.]

(20) U.S. Department of Energy letter from D. Dreyfus to C.J. Paperiello of U.S. Nuclear Regulatory Commission, dated August 3, 1995.

(This letter provides the balance of responses to NRC's letter of October 13, 1994, and provides the supplement to RCRR.)

(21) U.S. Department of Energy letter from S.J. Brocoum to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated October 25, 1995.

[This letter acknowledges the "cumbersome" nature of demonstrating regulatory flowdown and reports on two specific design process improvements: change to QAP-3-9 and modification to the structure and content of the Design Requirements Document.]

APPENDIX (cont'd)

(22) U.S. Nuclear Regulatory Commission letter from M.J. Bell to S.J. Brocoum of U.S. Department of Energy, dated December 14, 1995.

[This letter transmits the staff review of DOE's RCRR and concludes that DOE made an acceptable demonstration of regulatory flowdown via the example of design package 2C and considered most of the applicable regulatory requirements from 10 CFR Part 60. In addition, the staff requests two specific items: a design example conducted under the new and improved design QA/design procedure and current versions of revised ESF Design Requirements Document along with DOE's latest description of "Document Hierarchy."]

(23) U.S. Department of Energy letter from S.J. Brocoum to M.J. Bell of U.S. Nuclear Regulatory Commission, dated September 1996.

[This letter responds to staff requests made in December 14, 1995, letter and provides clarifications sought by the staff.]

(24) U.S. Nuclear Regulatory Commission conducts an Appendix 7 meeting on June 12–13, 1997, at DOE/M&O Offices and at the YM site to gather data, conduct onsite reviews, and complete activities intended to be covered under phase-3 of the in-field verification, which had to be canceled because of personnel and budgetary reasons.

[The staff concludes that most of the checklist items that were not verified during phase-2 of the in-field verification conducted on April 3–6, 1995, could be closed out based on interviews with DOE/M&O staff and onsite reviews. The staff also concludes to keep two items open: (i) quality classification for the concrete inverts used for the ESF construction; and (ii) hierarchy of documents that control site characterization, design, construction, and operations activities at the YM site.]