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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 2

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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	4.3.3.1	July 1999	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

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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.

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1.0 INTRODUCTION

One of the primary objectives of the U.S. Nuclear Regulatory Commission (NRC) refocused prelicensing program is to direct its activities toward resolving the 10 key technical issues (KTIs) it considers to be most important to repository 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.

Consistent with existing regulatory requirements (RRs) and a 1992 agreement with the U.S. Department of Energy (DOE), staff-level issue resolution can be achieved during the prelicensing consultation period, however, such resolution at the staff level would not preclude the issue being raised and considered during the licensing proceedings. Issue resolution at the staff level during prelicensing 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 License Application (LA). Issue Resolution Status Reports (IRSRs) are the primary mechanism that the staff will use to provide feedback to DOE regarding progress toward resolving the subissues comprising the KTIs. IRSRs include: (i) acceptance criteria and review methods for use in issue resolution and regulatory review; (ii) technical bases 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 staff's annual/periodic progress reports, 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 will be removed from future versions of the IRSRs.

Each IRSR contains six sections, including this Introduction in Section 1.0. Section 2.0 defines the KTI, all the related subissues, and the scope of the particular subissue or subissues addressed in the IRSR. Section 3.0 discusses the importance of the subissue to repository performance, including: (i) qualitative descriptions; (ii) reference to a total system performance assessment (TSPA) flowdown diagram; (iii) results of available sensitivity analyses; and (iv) relationship to DOE's repository safety strategy (RSS) (i.e., DOE's approach to its safety case). Section 4.0

provides the review methods and acceptance criteria, which indicate the basis for resolution of the subissue 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. Section 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, Section 6.0 includes a list of pertinent references.

2.0 KEY TECHNICAL ISSUE AND SUBISSUES

2.1 PRIMARY ISSUE

The primary focus of the Repository Design and Thermal-Mechanical Effects (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. Consequently, that is the focus of both the preclosure and postclosure elements of this KTI. Design for adequate postclosure performance requires an understanding of the TM response of the jointed rock mass over 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 the preclosure operation period of approximately 100–150 years 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 comprising the issue. It is expected that resolution of the subissues will lead to resolution of the primary issue. These subissues address topics that are of regulatory concern because they are, in general, at the limit of or beyond conventional engineering experience and may jeopardize the safe preclosure operations or effective postclosure performance of the GROA, or both. 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:

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

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)]

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 flow into and out of emplacement drifts and fault setback distance)

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)

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.

Similarly, the following three components have been identified for the second 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 KTI addresses the remaining components.

The third subissue—consideration of TM effects in design and PAs—has three important 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.

The fourth subissue deals primarily with postclosure performance. It is 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. The RDTME and TSPA KTIs will jointly address these topics in the future.

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3.0 IMPORTANCE OF ISSUE TO REPOSITORY PERFORMANCE

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

DOE has 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 1998, (U.S. Department of Energy, 1998b)]. These hypotheses include:

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

(2) Bounds can be placed on thermally induced changes in seepage rates;

(3) The amount of seepage that contacts WPs can be limited;

(4) Engineered enhancements can extend the long period of containment of the inner barrier;

(5) The amount of water that contacts waste can be limited;

(6) 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) 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.

In addition to the above strategies, DOE 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 over a period of 150 years. 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).

Testing these hypotheses and design assumptions requires an understanding of DOE's design and the effects of time-dependent TM coupled processes 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.

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

Table 1. Relationship between repository design and thermal-mechanical effects on key technical issues and the U.S. Department of Energy repository safety strategy

	Hypotheses from Repository Safety Strategy						
	Seepage into Drifts	Changes in Seepage Rates	Limited Seepage to Waste Packages	Engineered Enhancements	Limited Water to Waste	Movement of Faults	Ground Motion
Design Control Process	X	X	X	X	X	X	X
Seismic Design Methodology					X	X	X
Thermal-Mechanical Effects	X	X	X				
Long-Term Performance of Seals	X		X			X	X

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 QAP. The application of criterion III for "design control" of repository structures, systems, and components (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 RRs 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, 1999). 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

There are four major preclosure performance objectives in the proposed 10 CFR Part 63: (i) 10 CFR Part 20 requirements; (ii) numerical guides for design requirements; (iii) retrievability; and (iv) 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 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 Thermal-Mechanical Effects

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

Furthermore, seismic effects will take place under 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 liners or other support systems are not designed adequately to maintain stable openings. Consequently, the evaluation of TM effects is considered important to preclosure performance.

3.2.4 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 provided by the four subissues of RDTME KTI to postclosure PA. Subsections 3.3.1–3.3.4 describe the importance of the four subissues to postclosure performance.

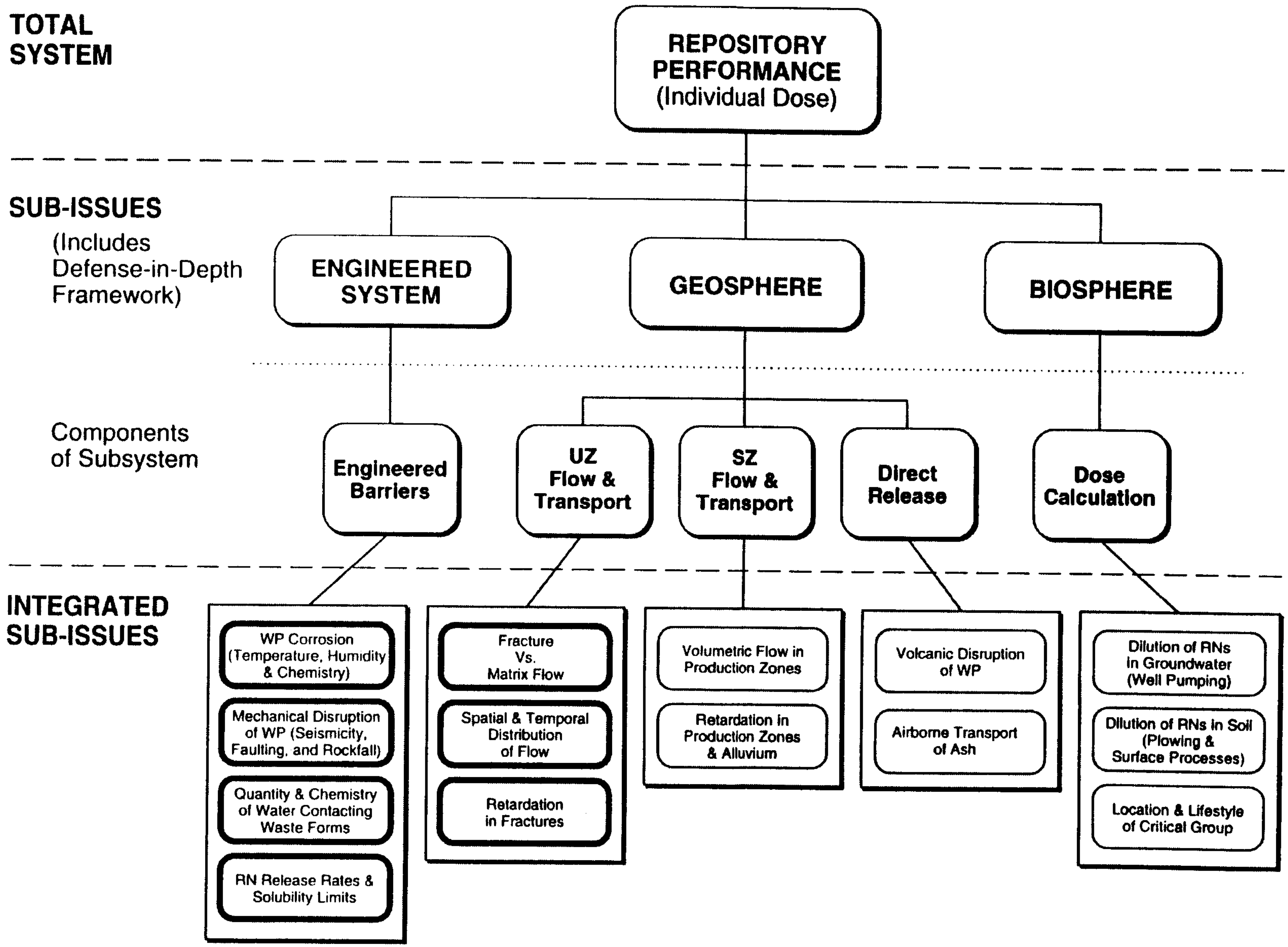

Figure 1. Inputs from repository design thermal-mechanical engineering subissues to postclosure performance

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 the design requirements in the proposed 10 CFR Part 63 are explicitly focused 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 engineered barriers 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. Backfill could act to more directly transfer load to the WPs, thus having a potentially detrimental effect with respect to direct fault disruption.

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 Performance Assessment (TPA) code (Manteufel et al., 1997) 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 beginning with the early stages of construction. The construction methods employed for the underground facility, the geometry of underground openings (shape, size, orientation, slopes, and waste emplacement configuration), the distribution of thermal load, presence or absence of backfill, and the 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). 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 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.

It is the current understanding 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. 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 the 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 under the EBS (Figure 1).

3.3.4 Design and Long-Term Contribution of Seals to Performance

Regulatory Requirement 10 CFR 60.134 provides a specific design requirement that calls for appropriate material selection and design methods for borehole and shaft seals so that they do not become preferential pathways during the postclosure period. At the present time, it is not certain how important the seals will be in meeting the postclosure performance objectives at the YM site. The staff has taken a position that until DOE demonstrates that seals are unimportant from a postclosure performance perspective, or the staff efforts on TSPA suggest that seals do not significantly contribute to meeting the performance objectives, this subissue will remain open. It should be noted that the proposed YM site-specific regulation does not contain requirements of using repository seals to meet the postclosure performance objectives. However, DOE does plan to seal shafts as one means to prevent human intrusion. The performance of such seals remains a concern to the staff. The seal design subissue is also expected to provide inputs to the "quantity and chemistry of water contacting waste form ISI in the flowdown diagram of PA (Figure 1).

4.0 REVIEW METHODS, ACCEPTANCE CRITERIA, AND TECHNICAL BASES

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 provides a discussion of the technical bases for the acceptance criteria and review methods. Included are descriptions of DOE's approach, summaries of staff evaluations of DOE's approach, and results of independent work conducted by the staff.

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

4.1.1 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 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 the "NRC's High-Level Radioactive Waste Program Annual Progress Report for Fiscal Year 1996" (Center for Nuclear Waste Regulatory Analyses, 1997).

Recent DOE audits identified severe deficiencies regarding the design control process (U.S. Department of Energy, 1998e,f,g,h,i, 1999). 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 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 VA 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;
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 anticipated;

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.

4.1.4 Technical Bases

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.

4.1.4.1 Exploratory Studies Facility—Geologic Repository Operations Area 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 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.

4.1.4.2 Regulatory Basis

As mentioned earlier, Appendix B to Part 50 (Quality Assurance Criteria for Nuclear Power Plants adopted by the proposed Part 63) provides the underpinning technical/regulatory basis for the staff review methods and acceptance criteria. 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.

4.1.4.3 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 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.

4.1.4.4 Quality Assurance 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.

4.1.4.5 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.

4.1.4.6 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 towards 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 review 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.

4.1.4.7 Meetings

DOE and NRC conducts 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.

4.1.4.8 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 OSR's reports are also used as bases for staff conclusions on DOE's design control process.

4.1.4.9 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.

4.1.4.10 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.

4.1.4.11 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.

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

4.1.5.1 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 acceptance criteria listed in Section 4.1.3 of this IRSR.

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-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, 1994c); and (iv) Engineered Barrier Design Requirements Document (U.S. Department of Energy, 1994d). 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 acceptance criteria of Section 4.1.3. 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 assumptions were also verified to relate to the topic discussed therein. Each reference section was cross-checked 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.

4.1.5.2 Comparison with Acceptance Criteria

During the June 1998 meeting, the 12 acceptance criteria discussed in Section 4.1.3 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 CRWMS M&O 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 CRWMS M&O for DOE consideration (CRWMS M&O, 1999). If this alternative is selected by DOE as the baseline for the LA, the previously mentioned documents will have to be reevaluated.

Acceptance Criterion 1: The applicable RRs are identified: 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, 1998b).

Acceptance Criterion 2: The design bases associated with the RRs are defined: 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).

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: 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 MTU (metric ton of uranium) value for the spent nuclear fuel, 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.

Acceptance Criterion 4: 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, 1998b).

Acceptance Criterion 5: Any deviations from the standards specified under Acceptance Criterion 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, 1998b). 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.

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: 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.

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Acceptance Criterion 7: 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.

Acceptance Criterion 8: 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).

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): The M&O established Product Checking Group (PCG) verifies the design calculations through independent reviewers. The PCG is discussed in-depth under Acceptance Criterion 11.

Acceptance Criterion 10 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.

Acceptance Criterion 11: <u>The design verification is conducted by independent and qualified professionals who did not participate in the original design efforts</u>: To address the issue of reviewer independence, the M&O 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, 1998c).

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

Acceptance Criterion 12: <u>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</u>: In Section 4.3.6, Overall Development and Emplacement Ventilation Systems which 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, 1998d). This indication that the design uses the earlier assumption (CRWMS M&O, 1996c) 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.

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

4.2.1 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

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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:

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.

4.2.4 Technical Bases

4.2.4.1 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 this IRSR. 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.

4.2.4.2 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 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, 1994b), 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, already mentioned above, addresses preclosure seismic design methodology, keeping in mind that SSCIS 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, 1994a). Upon staff review and recommendation, DOE revised TR-2 [Rev. 1, (U.S. Department of Energy, 1996)] 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 Part 60 rulemaking (U.S. Nuclear Regulatory Commission, 1996a).

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 during FY1999. 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.

4.2.4.3 Preclosure Seismic Design Methodology Presented by the U.S. Department of Energy

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 SSCIS.

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.

4.2.4.4 Staff Review of Seismic Design Topical Report-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).

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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. 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 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 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 acceptance criteria 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, final resolution of this subissue will occur after the review of DOE's TR-3 scheduled for completion in FY2000.

4.3 THERMAL-MECHANICAL EFFECTS ON UNDERGROUND FACILITY DESIGN AND PERFORMANCE

4.3.1 Background

The subissue of the TM effects on underground facility design and performance consists of three major components. One is related to repository design while the other two areas focus on performance. More specifically, these three 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.

4.3.2 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 VA 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.)

4.3.3 Thermal-Mechanical Effects on Design of Underground Facility

4.3.3.1 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 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 TM design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. These models are verified, validated, and calibrated 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 7: 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 8:	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 9:	The analytical methodology considers plausible, potentially important TM processes appropriate to the design and YM site characteristics.
Acceptance Criterion 10:	The methodologies used for the TM design and analyses are consistent with those established in DOE Seismic TR-2.
Acceptance Criterion 11:	Time sequences of thermal loading used in TM design and analyses are clearly defined.
Acceptance Criterion 12:	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 13:	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 14:	The design discusses maintenance plans for keeping the underground openings stable, with particular attention to retrieval operations. (If the details of retrieval operations/plans are found in other sections of the LA, a reference to such sections would be acceptable.)

4.3.3.2 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, 1998e, Table 4-3; Hardin, 1998, Table 3-5). One set of values is given for conduction-only analyses (CRWMS M&O, 1998e, 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 TMHC processes within the rock mass.

Intact-Rock 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. (1993) 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

significant differences in intact-rock properties among the four units (e.g., Peters and Datta, 1999). As a result, it may be more appropriate to follow the Buesch et al. (1995) stratigraphy in presenting intact-rock data for YM.

Effects of Fractures on Rock-Mass Properties

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., 1993b). 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, 1998e), were derived using the Serafim and Pereira (1983) relationship. An observation that stands out clearly from Figure 3 is that the YM data are too 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 predictions) at low to medium RMR values. The attempt 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, is not correct. 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*) behavior 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 GSI index. 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).

Effects of Lithophysae on Rock-Mass Properties

Discussion on this subject will be provided in a future version of this IRSR.

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.

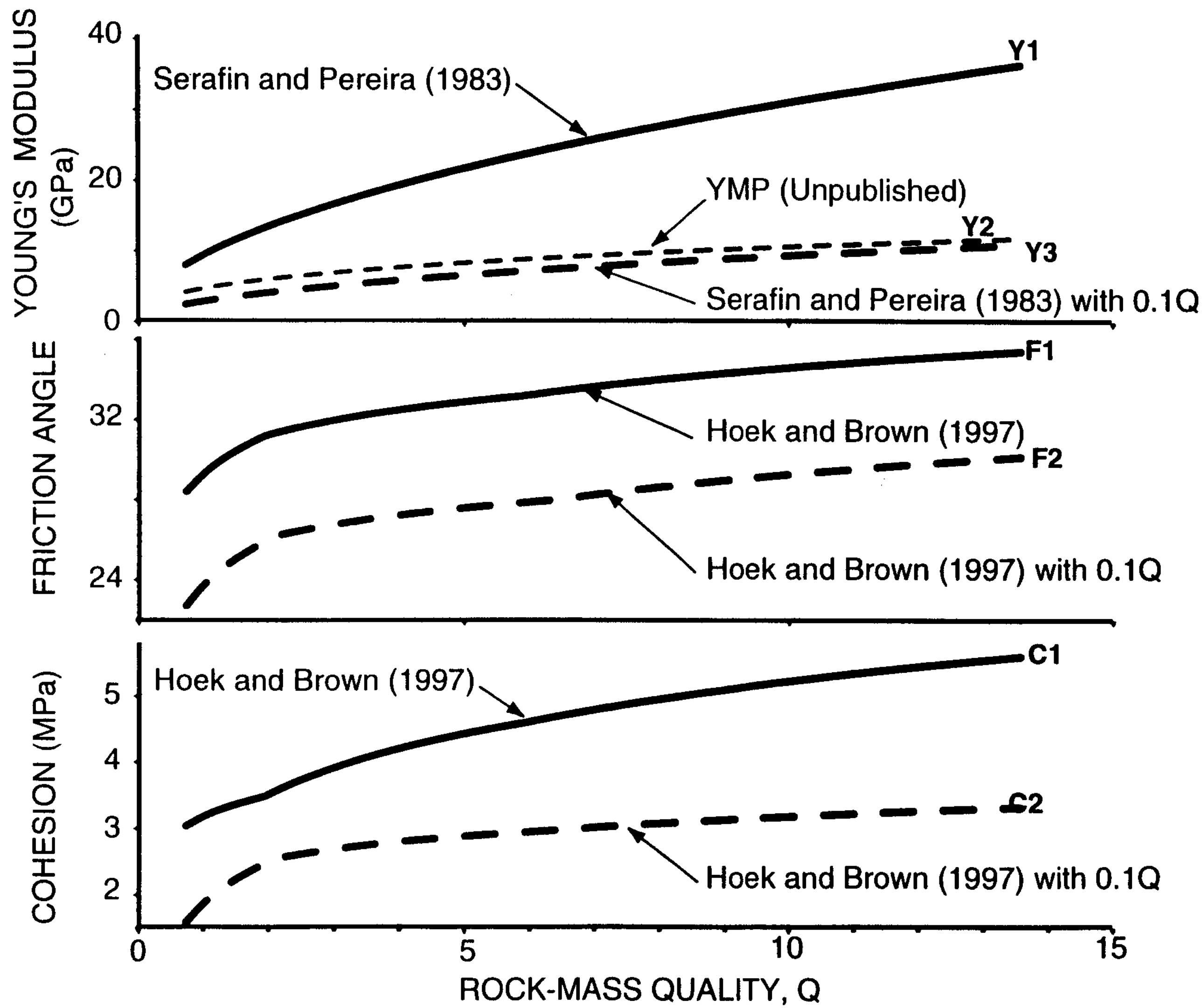

Figure 4. Mechanical parameters estimated from *Q* for the TSw2 stratigraphic unit using empirical relationships (Hoek, 1994; Hoek and Brown, 1997) for: (i) current rock-mass conditions (curves Y1, F1, and C1); and (ii) degraded rock-mass conditions (curves Y3, F2, and C2). The reduction of *Q* to 10 percent of its current value simulates the effects of fracture-wall alterations from extended exposure to heat and moisture.

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Characterization of Mechanical Properties: Discontinuum Rock-Mass Model

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

(1) TM 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, 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, 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, 1996d). 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, 1998e). Fracture tensile strength was assumed to be half of the fracture cohesion according to Lin et al. (1993a) in ESF ground support analyses (CRWMS M&O, 1996d) and assumed to be zero for conservatism in ground support analysis for the VA (CRWMS M&O, 1998e). Fracture shear stiffness was estimated in Lin et al. (1993a). Fracture normal stiffness is often assumed to be the same as fracture shear stiffness (e.g., CRWMS M&O, 1998e).

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 was retained in the current version of the IRSR until the SR report is issued and confirms 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.

4.3.4 Effects of Seismically Induced Rockfall on Waste Package Performance

4.3.4.1 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.

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 emplacement drift 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.

4.3.4.2 Technical Bases

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

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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 thermomechanical 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 blocks 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. 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 inherently statistical. Beside 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 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[1] conducted Key Block analyses in three dimension 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,

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

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.[2] 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.

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

where

OccRate	—	occurrence rate for rockfall greater than the block size,
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 appear to lack realism and limit the practical merits 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 our opinion, 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 case of earthquake-induced rockfall, rockfall frequency depends on the frequency of ground motion event. In thermal-load induced rockfall, frequency may be a time function of the evolution of the thermal load and the degradation of rock properties.

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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.

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. 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

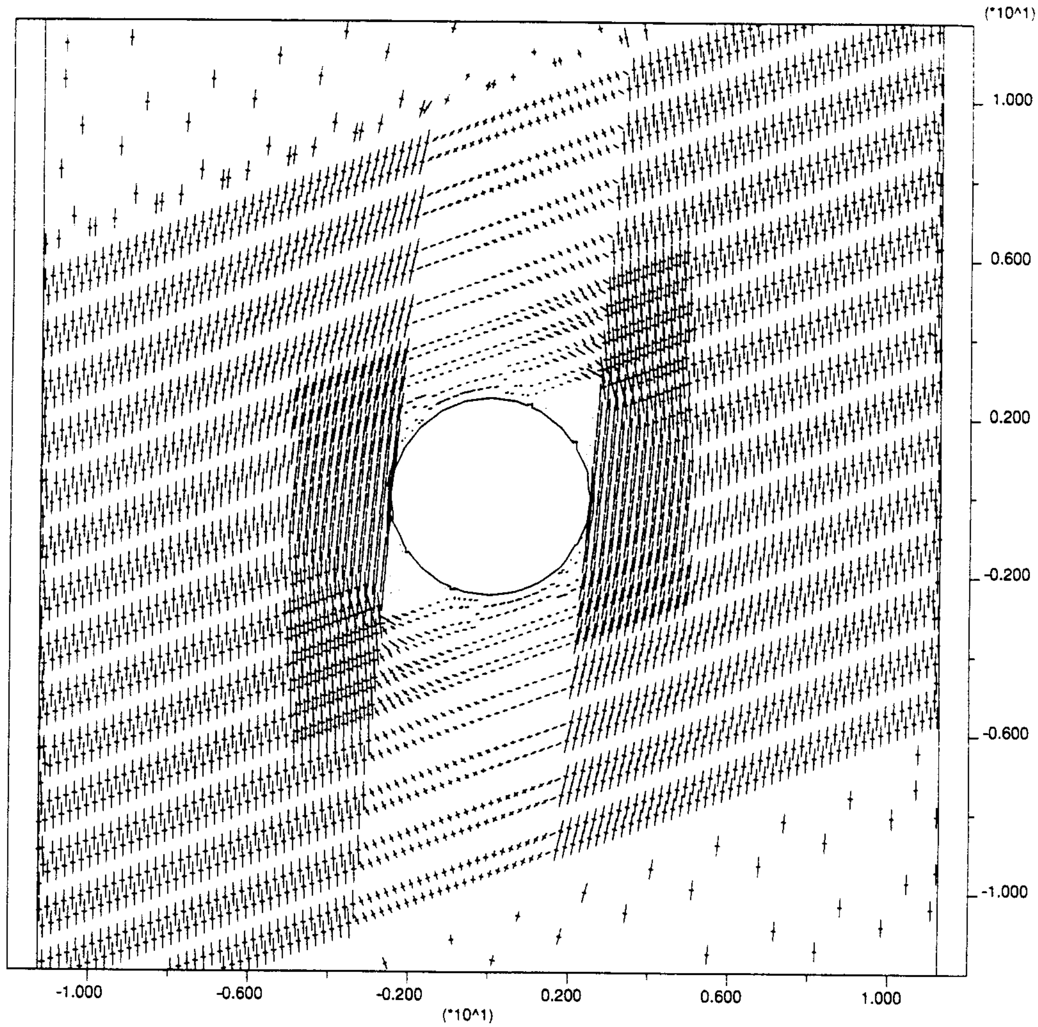

Figure 11. Distribution of principal stresses after drift excavation

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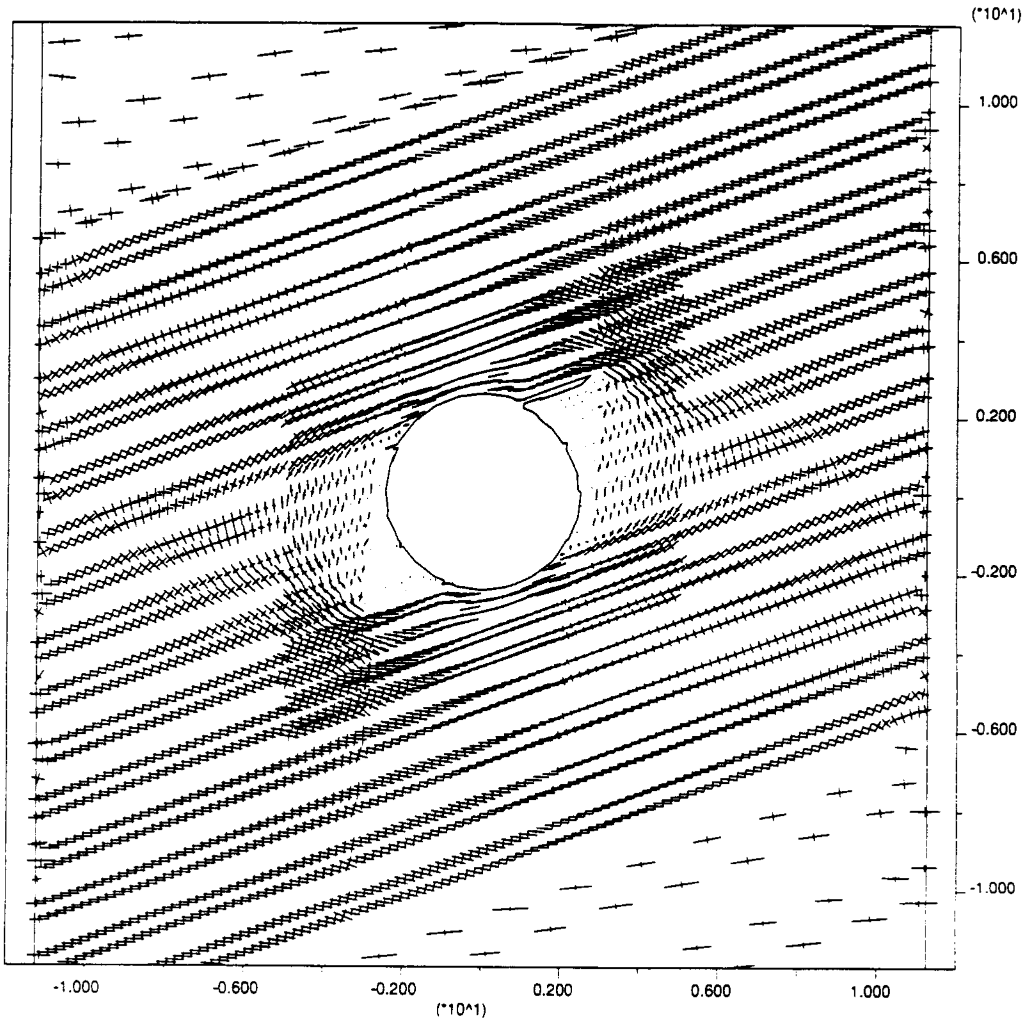
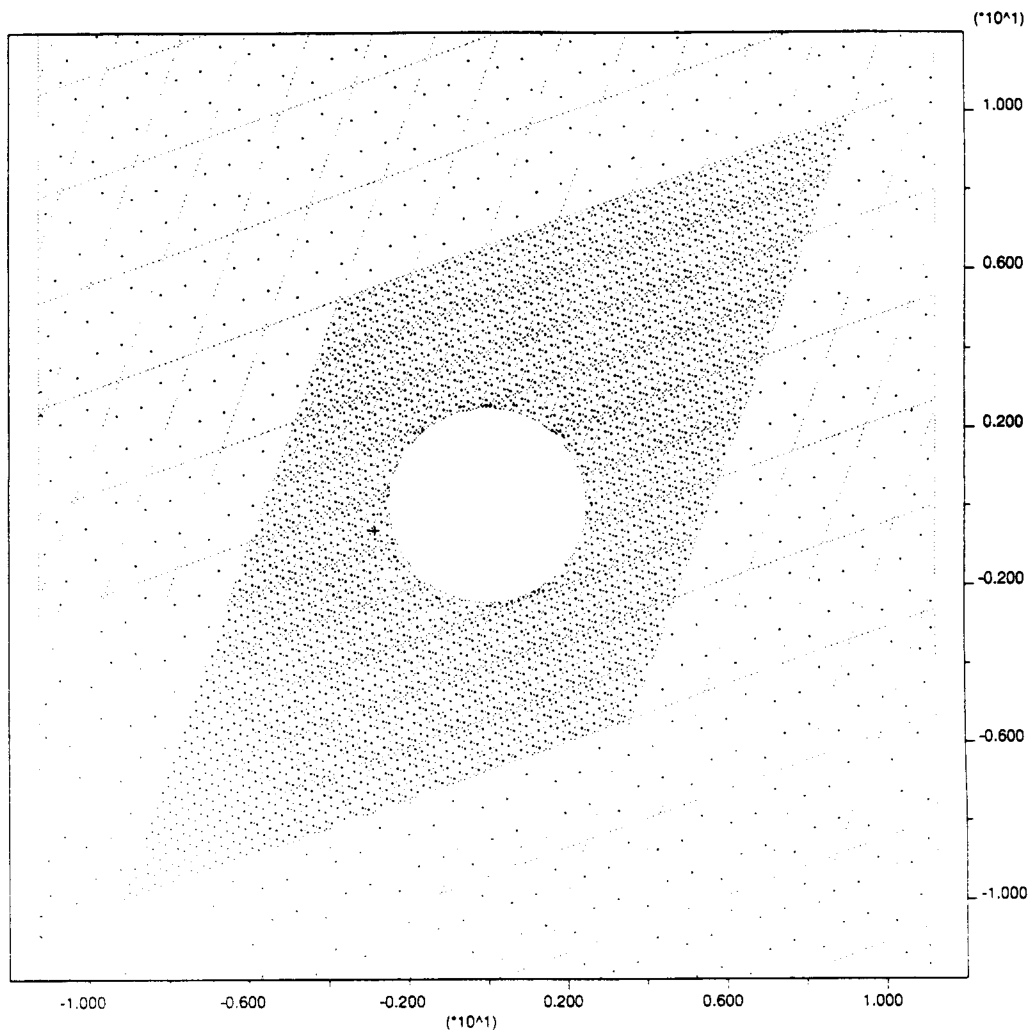


Figure 12. Distribution of principal stresses after 100 years of heating



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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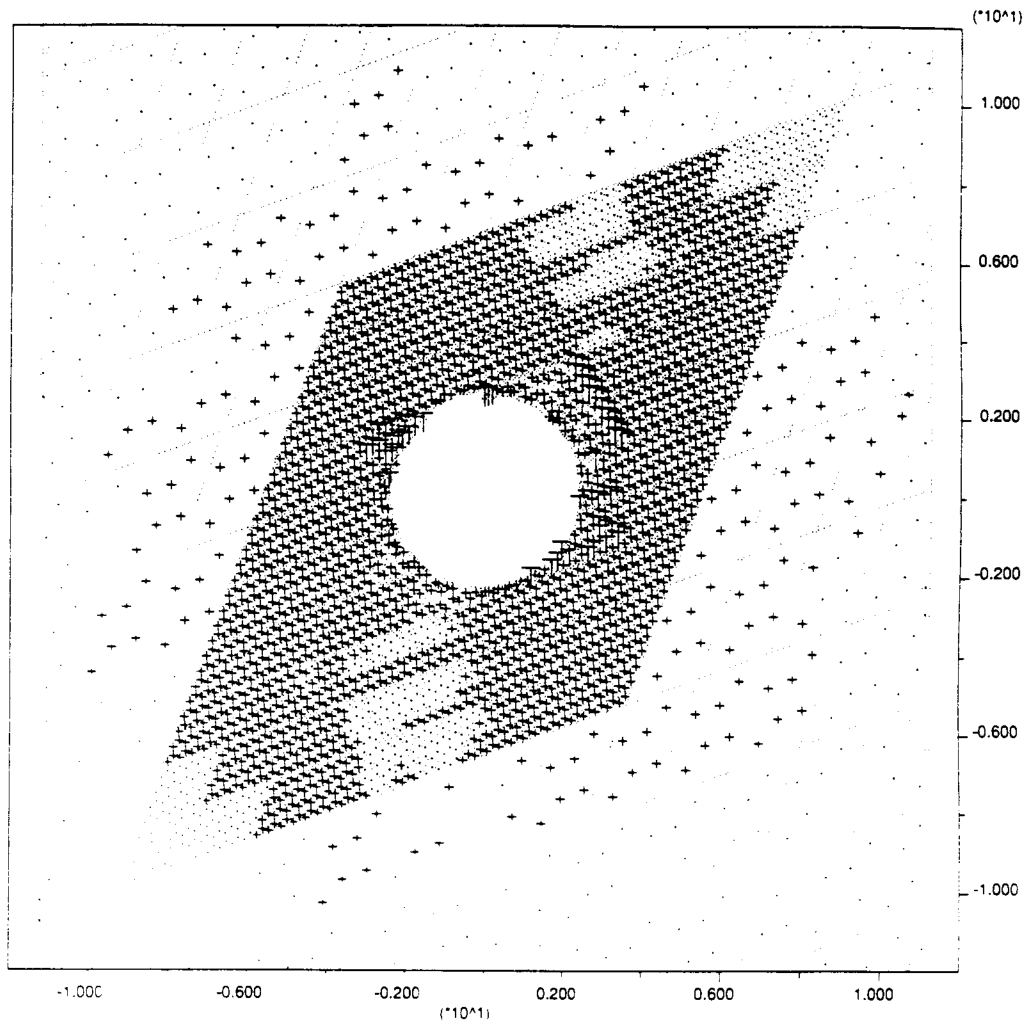
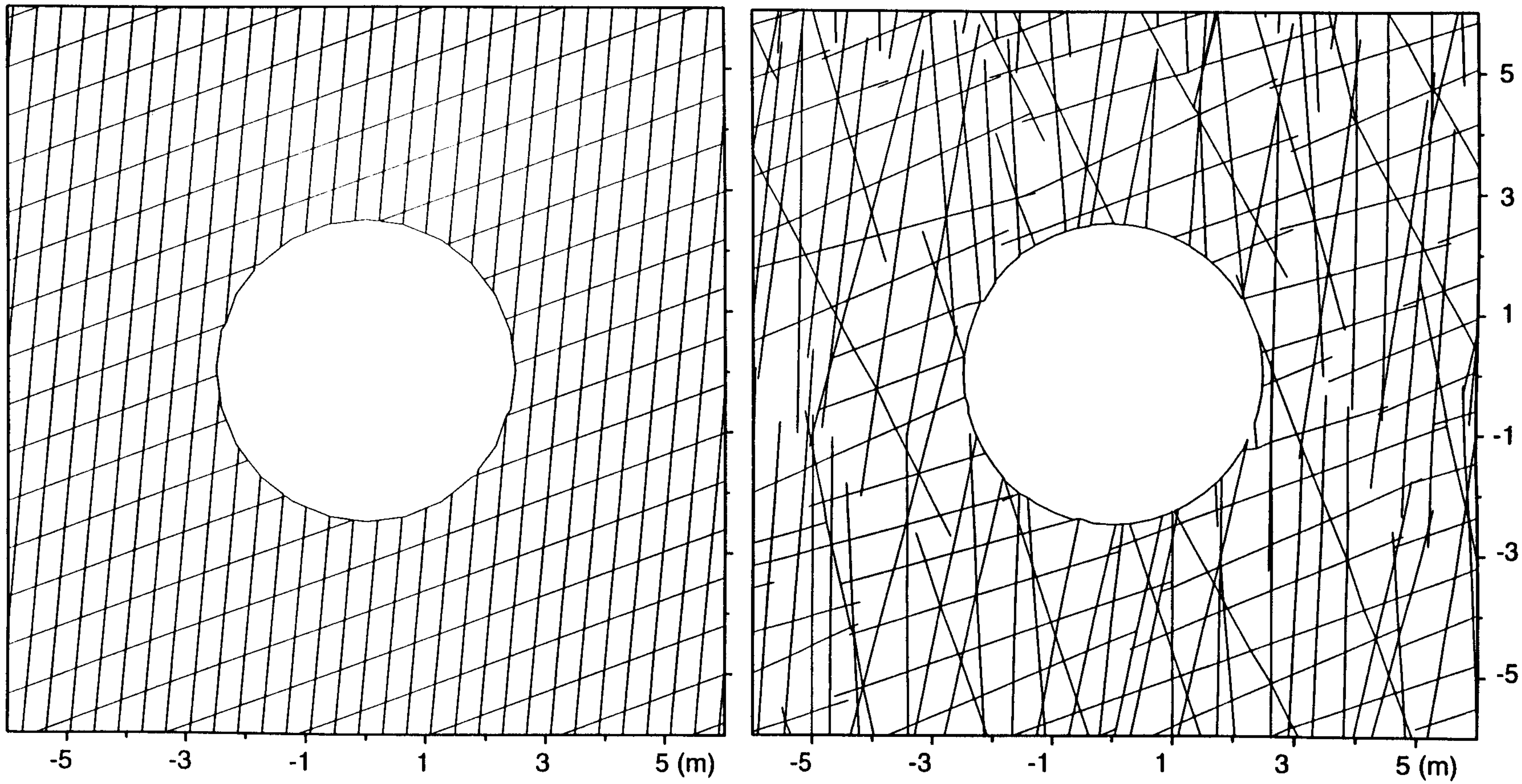


Note: Dots represent elastic state. Crosses represent yield zones. Dash lines represent joints.

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

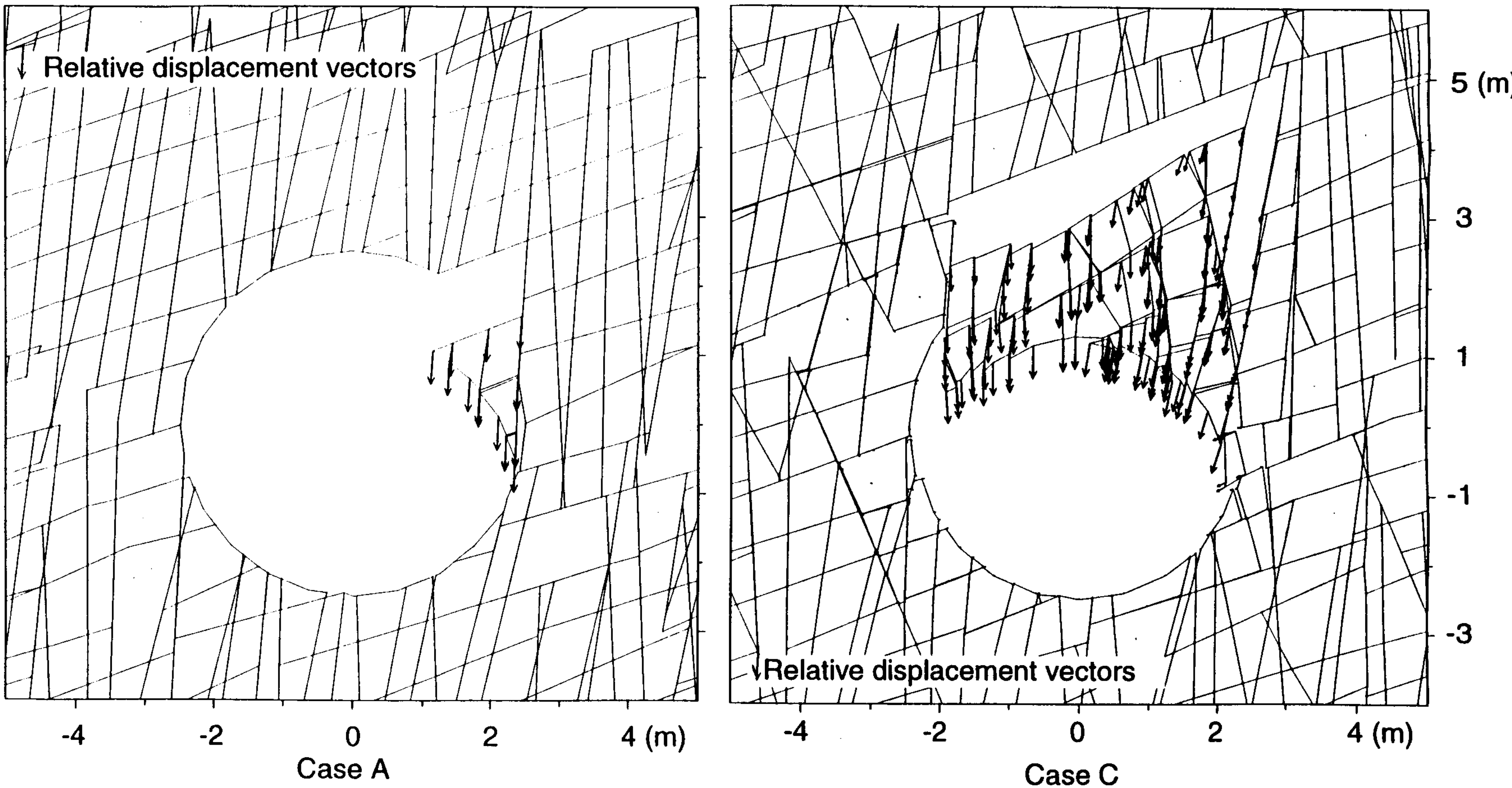


Figure 16. Simulated rockfall after 100 years of thermal loading and one episode of dynamic ground motion for two slightly different fracture patterns

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.

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.

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 underway 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 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 IRSR, new information generated through expert elicitation regarding potential seismic hazards at the YM site became available (U.S. Department of Energy, 1998b). 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):

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

where

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

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

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

$$k_b = \frac{AE}{L} \tag{4}$$

and k_{wp} can be calculated by

$$k_{wp} = \frac{48EI}{L_{wp}^3} \tag{5}$$

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

L_{wp}	—	length of the WP, and
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

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

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, and

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

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

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 spent fuel 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, 1998c) 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, 1998c). 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, 1998d), referred to as TSPA-VA] and the Technical Basis Document (TBD) (CRWMS M&O, 1998a), 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, 1998a).

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

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

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 a gross 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 (*PGV*s) 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 *PGV*s 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, 1996a,b). The dynamic analysis conducted in the two reports published by CRWMS M&O (1996a,b) 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 recent CNWRA analysis,[3] the effects of several types of impact contacts were analyzed. The results indicate that a spherical rock would cause the most damage to the WPs.

The finite element 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, 1996a,b) 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

[3]Krauthammer, T. et al., Investigation of Rock Impact Effects on the 21-PWR Waste Package, to be published.

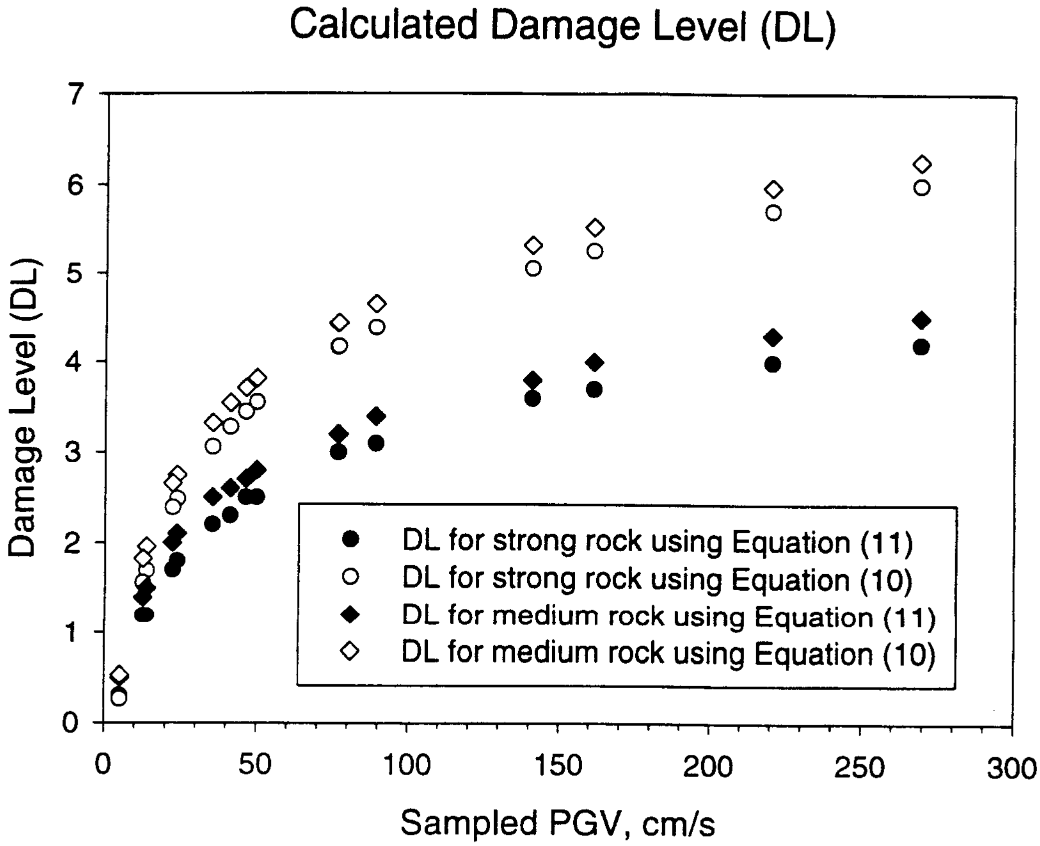


Figure 19. Damage level versus peak ground velocity

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, 1996a,b). 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, 1996a,b). 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, 1996a,b). While assuming a fixed full height appears to be intuitive, it does not allow for consideration of the effects of the possibility that the subsequent rockfalls at the same location before the WP in question is covered by rock debris. In that situation, the fall height will be greater and so will be the effect of the same size rock.

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."

4.3.5 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, 1998c, 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 is expected to have significant effect on 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.

4.3.5.1 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 clearly described, and the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility.

Acceptance Criteria 4: Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are clearly described, and the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility.

4.3.5.2 Technical Bases

The focus of the technical bases provided in the following paragraphs is placed on Acceptance Criteria 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.

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

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

4.4.1 Review Methods

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

4.4.2 Acceptance Criteria

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

4.4.3 Technical Bases

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

5.0 STATUS OF ISSUE RESOLUTION AT THE STAFF LEVEL

5.1 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 the NRC 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 acceptance criteria 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).

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 of DOE's compliance/noncompliance with the twelve acceptance criteria (Section 4.1.3) 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 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 4.1.5.2). 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, 1998e,f,g,h,i, 1999). To address these deficiencies, the M&O contractor is developing new administrative procedures (APs) to replace the existing QAPs so that the new APs will provide a wider coverage to apply to its subcontractors (e.g., National Laboratories). It is understood these new APs will be in effect in the near future. The staff observed a performance-based audit conducted by the Office of Quality Assurance on the CRWMS

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M&O Contractor. The official results of the audit were not available when preparing Revision 2 of this IRSR, but will be documented in a future version of the IRSR.

5.1.1 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: Open
Basis: To be determined

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.

5.1.2 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

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).

5.1.3 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 AP–6.14).

Item ID: In-field Verification Recommendation–3
Title: Quality classification of precast concrete inverts
Status: Open
Basis: 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.

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.

5.2 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 acceptance criteria used for the review. TR-3 will be reviewed during FY2000. The status of resolution for the report will be documented in a fashion consistent with Section 5.3.

5.2.1 Status of Topical Report-1

The details of status of open items for TR-1 have been documented in the Structural Deformation and Seismicity KTI IRSR.

5.2.2 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 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.

5.2.3 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 FY2000 and review results will be documented in Rev. 3 of this IRSR.

5.3 THERMAL-MECHANICAL EFFECTS ON UNDERGROUND FACILITY DESIGN AND PERFORMANCE

As discussed previously, this subissue includes three 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.

5.3.1 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.

5.3.1.1 Acceptance Criterion 1

Approved QA control procedures and standards were applied to collection and documentation of data, methods, models, and codes. The CRWMS 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 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.

5.3.1.2 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 either late this FY or 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.

5.3.1.3 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 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 quite 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, with a goal of resolving related concerns.

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.

5.3.1.4 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 verify these empirical equations. Although plans are included in the VA report for verification of these empirical equations (U.S. Department of Energy, 1998j, Section 3.1.1.8), no specifics regarding how these empirical relationships will be verified have been provided. Verification of the empirical equations will be a subject of the proposed Appendix 7 meeting discussed in Section 5.3.1.3.

5.3.1.5 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 due to the delay of issuance from DOE.

5.3.1.6 Acceptance Criterion 6

The TM design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. The models are 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 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 are 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 are considered 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.

5.3.1.7 Acceptance Criterion 7

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.

5.3.1.8 Acceptance Criterion 8

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.

5.3.1.9 Acceptance Criterion 9

The analytical methodology considers plausible, potentially important TM processes appropriate to the design and YM site characteristics. The staff will review DOE's design and analysis related documents during FY2000 to determine progress on this acceptance criterion.

5.3.1.10 Acceptance Criterion 10

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 be delayed until the design for site recommendation becomes available.

5.3.1.11 Acceptance Criterion 11

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 CRWMS 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.

5.3.1.12 Acceptance Criterion 12

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 long-term deterioration of ground support effectiveness needs to be factored into the repository design and analyses. This acceptance criterion will be addressed at the proposed Appendix 7 meeting.

5.3.1.13 Acceptance Criterion 13

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.

5.3.1.14 Acceptance Criterion 14

The design discusses maintenance plans for keeping the underground openings stable, with particular attention to retrieval operations. (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.

5.3.2 Status of Effects of Seismically Induced Rockfall on 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.

5.3.2.1 Acceptance Criterion 1

Approved QA and control procedures and standards were applied to collection, development and documentation of data, methods, models, and codes. The CRWMS 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.

5.3.2.2 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.

5.3.2.3 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, CRWMS 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 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 *PGV*s than the one used in the TBD. The effect of the revised curve on WP damage needs to be evaluated.

5.3.2.4 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 CRWMS 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.

5.3.2.5 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 emplacement drift and WP designs; and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses. The CRWMS M&O rockfall model uses a WP damage criterion that links 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 CRWMS 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 CRWMS 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 can withstand rockfall impact and thus delay or eliminate rockfall damage on WPs.

5.3.2.6 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. It is therefore necessary to include consideration of time-dependent effects when estimating rockfall.

As discussed in Section 5.3.2.4, CRWMS 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 second 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 CRWMS M&O. The NRC staff will review the results of this work as they become available.

5.3.2.7 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 multiple coherent rock blocks 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. Because the DOE model did not include this level of consideration, the results tend to be less conservative.

5.3.3 Thermal-Mechanical Effects on Flow into Emplacement Drifts

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.

5.3.3.1 Acceptance Criterion 1

Approved QA, control procedures, and standards were applied to collection, development and documentation of data, methods, models, and codes. The CRWMS 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.

5.3.3.2 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.

5.3.3.3 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 clearly described, and the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility. 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).

5.3.3.4 Acceptance Criterion 4

Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are clearly described, and the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility. 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.

5.3.4 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: Open
Basis: To be determined

Item ID: OSC0000001346C056 Comment 056 SCA
Title: Validation of models/TM properties
Status: Open
Basis: To be determined

Item ID: OSC0000001347Q042 Question 009 SCA
Title: Systematic drilling program implementation strategy
Status: Open
Basis: To be determined

5.3.5 Other Related Items

To be determined.

5.4 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.

5.4.1 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

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Status: Open
Basis: To be determined

Item ID: OSC0000001347Q025 Question 025 SCA
Title: Sealing program/gaseous transport
Status: Open
Basis: To be determined

Item ID: OSC0000001347Q028 Question 028 SCA
Title: Impacts on sealing program/calico hills penetration
Status: Closed
Basis: To be determined

Item ID: OSP0000831421Q001 Question 001 SP831421
Title: Status of borehole seal design
Status: Open
Basis: To be determined

Item ID: OSP000831421Q002 Question 002 SP831421
Title: Specification for sealing boreholes
Status: Open
Basis: To be determined

5.4.2 Other Related Items

To be determined.

5.5 OTHER OPEN ITEMS NOT INCLUDED UNDER THE FOUR SUBISSUES

5.5.1 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: Open
Basis: To be determined

Item ID: OSC0000001347Q042 Comment 120 SCA
Title: Comprehensive, integrated and prioritized plan for model and code validation
Status: Open
Basis: To be determined

Item ID: OSC0000001347Q042 Comment 122 SCA
Title: Criteria for determining the acceptability of dry coring method
Status: Open
Basis: To be determined

Item ID: OSC0000001347Q042 Question 055 SCA
Title: Analysis of potential test interference from water storage facilities.
Status: Open
Basis: To be determined

5.5.2 Status of Open Items from the Annotated Outline

Item ID: OAO030SEP1992C00 Comment 003 AO30SEP1992
Title: Planned area/controlled area
Status: Open
Basis: To be determined

Item ID: OAO030SEP1992C00 Comment 004 AO30SEP1992
Title: Legal definition of controlled area
Status: Open
Basis: To be determined

Item ID: OAO030SEP1992Q00 Question 001 AO30SEP1992
Title: Figure reference/underground facility
Status: Open
Basis: To be determined

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APPENDIX

This appendix lists important correspondences and interactions between Nuclear Regulatory Commission (NRC) and 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 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 follow-up, such as 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 M&O Contractor Quality Assurance Procedure (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 RCRR showing the allocation and traceability of Part 60 requirements to the ESF.]

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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 quality assurance (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 follow-up.]

(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 Regulatory Compliance Review Report (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 flow-down 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 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.]