conservative as both reports have stated.

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

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

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

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

Damage to Fuel Rods

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

Time Periods for Waste Package Damage Assessment

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

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

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

4.2.3 Thermal-Mechanical Effects on Flow into Emplacement Drifts

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

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

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

~~4.2.3.1 Acceptance Criteria~~

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

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

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

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

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

4.2.3.1 Technical Bases for Review

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

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

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

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

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

This subissue is closed.

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

~~4.3.1 Review Methods~~

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

~~4.3.2 Acceptance Criteria~~

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

4.3.1 ~~Technical Bases~~

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

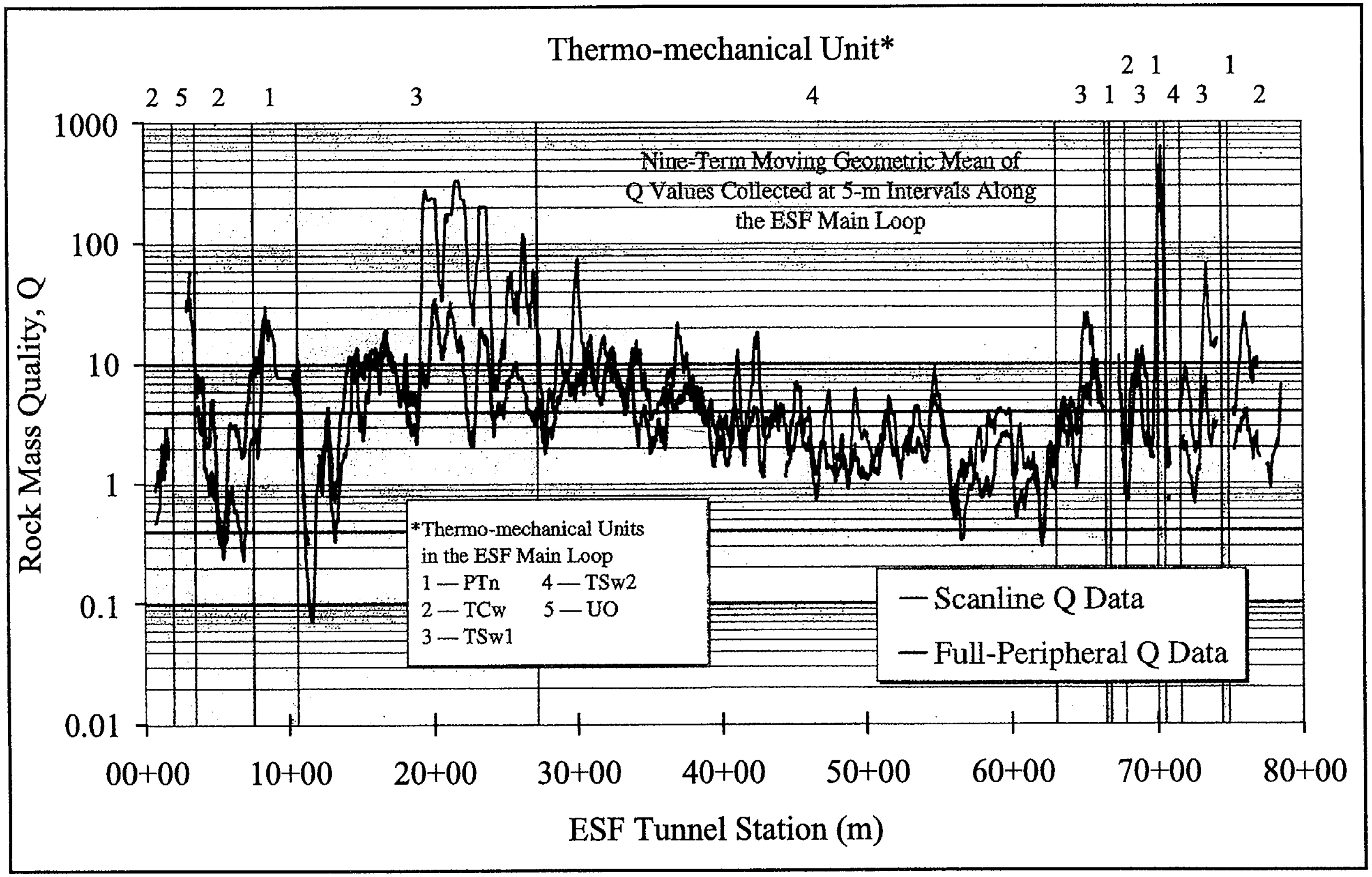


Figure 2. Profile of rock-mass quality, *Q*, along the Exploratory Studies Facility (CRWMS M&O, 1997a)

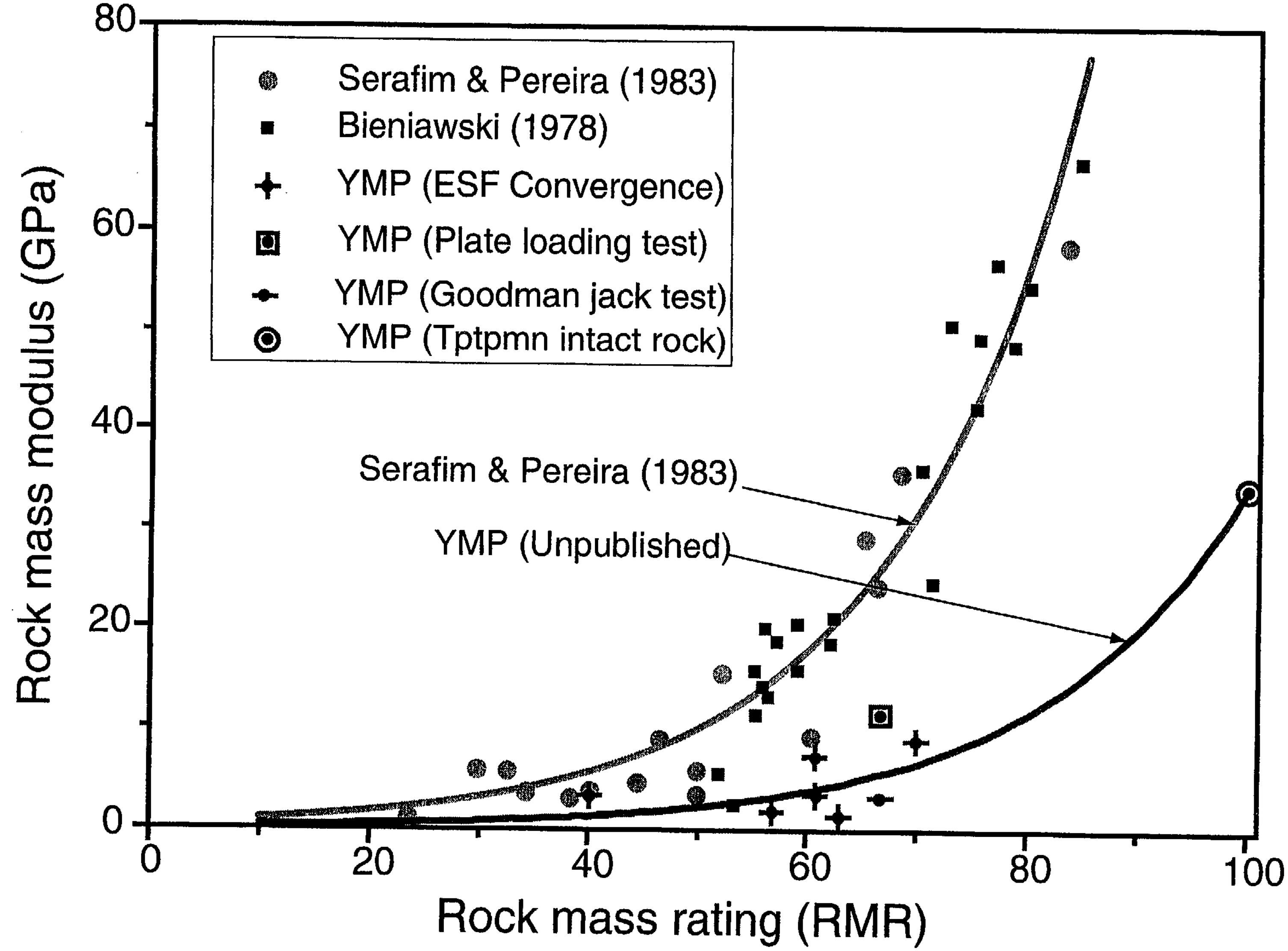


Figure 3. Variation of rock-mass modulus with rock-mass rating based on data available from the literature and the Yucca Mountain Project. The figure shows a curve suggested recently for YM tuff (Lin, 1998), the validity of which is questionable because the curve was derived by extrapolation of sparse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

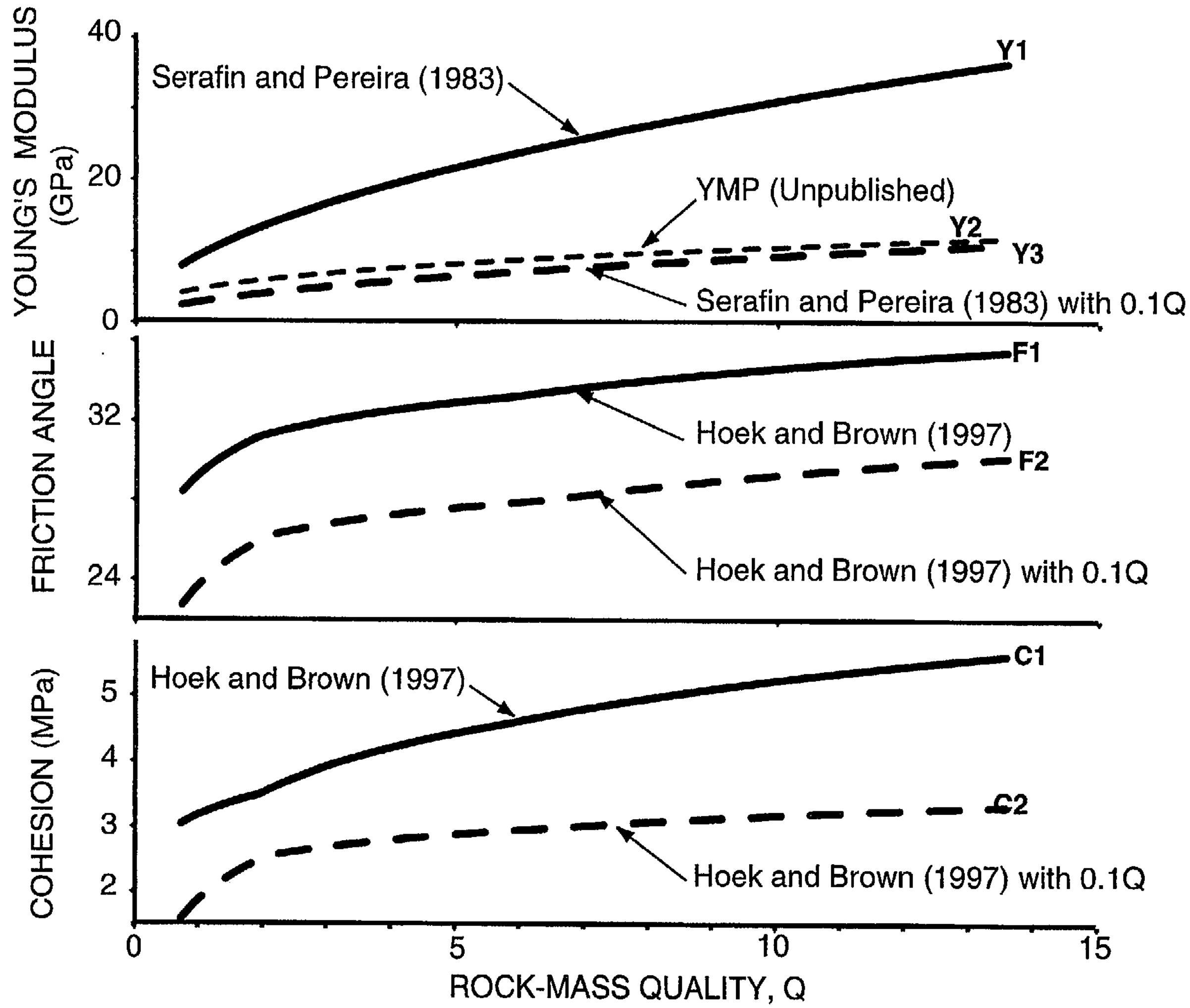


Figure 4. Mechanical parameters estimated from *Q* for the TSw2 stratigraphic unit using empirical relationships (Hoek, 1994; Hoek and Brown, 1997) for: (i) current rock-mass conditions (curves Y1, F1, and C1); and (ii) degraded rock-mass conditions (curves Y3, F2, and C2). The reduction of *Q* to 10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

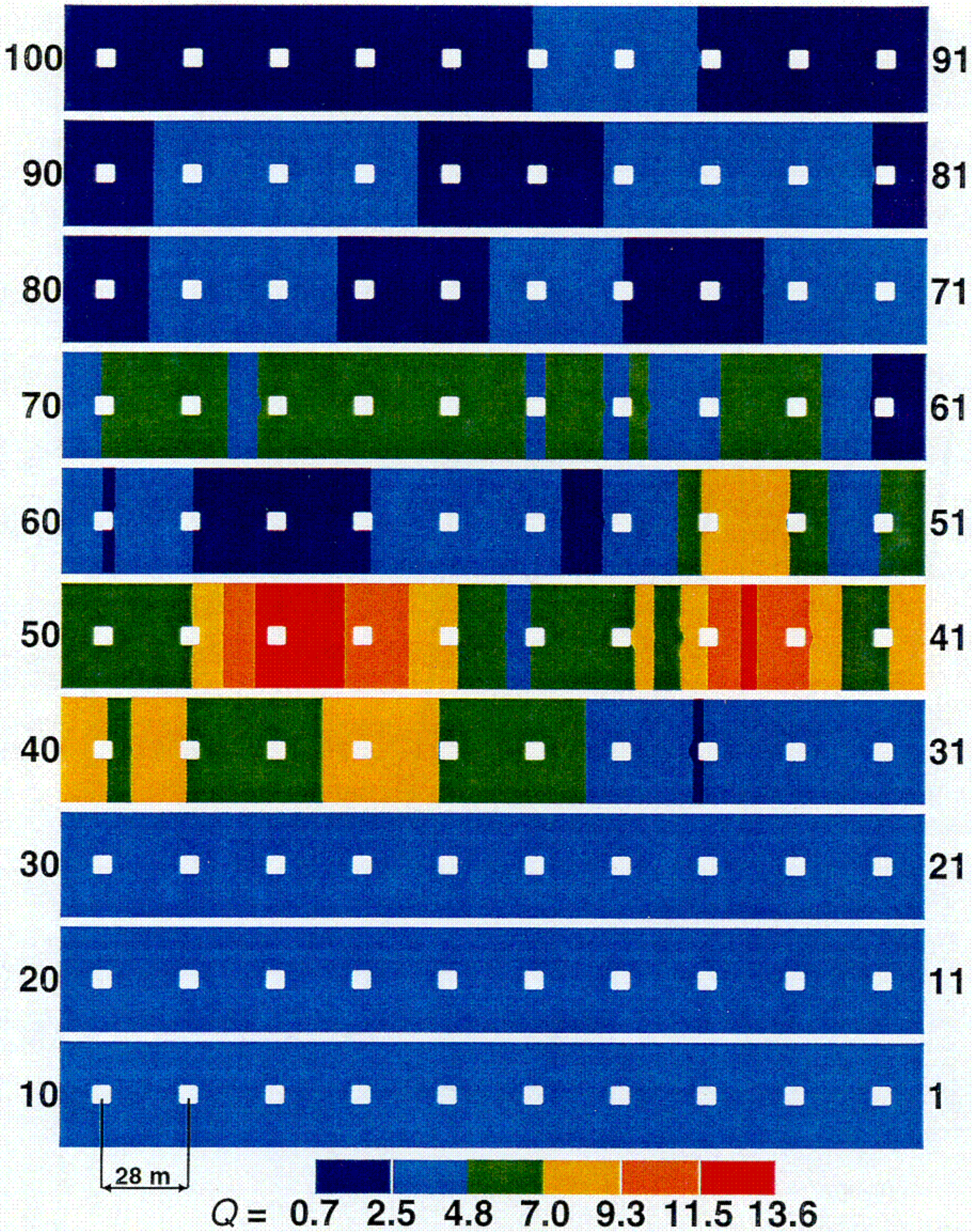


Figure 5. South-to-north profile of rock-mass quality, *Q*, adopted from the ESF main-drift profile. The profile is presented in ten 35-m high and 280-m long sections. Each section includes 10 drifts (end-drift numbers shown). Drifts #1 and #100 are at the north and south ends of the drift array. Areas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

C01

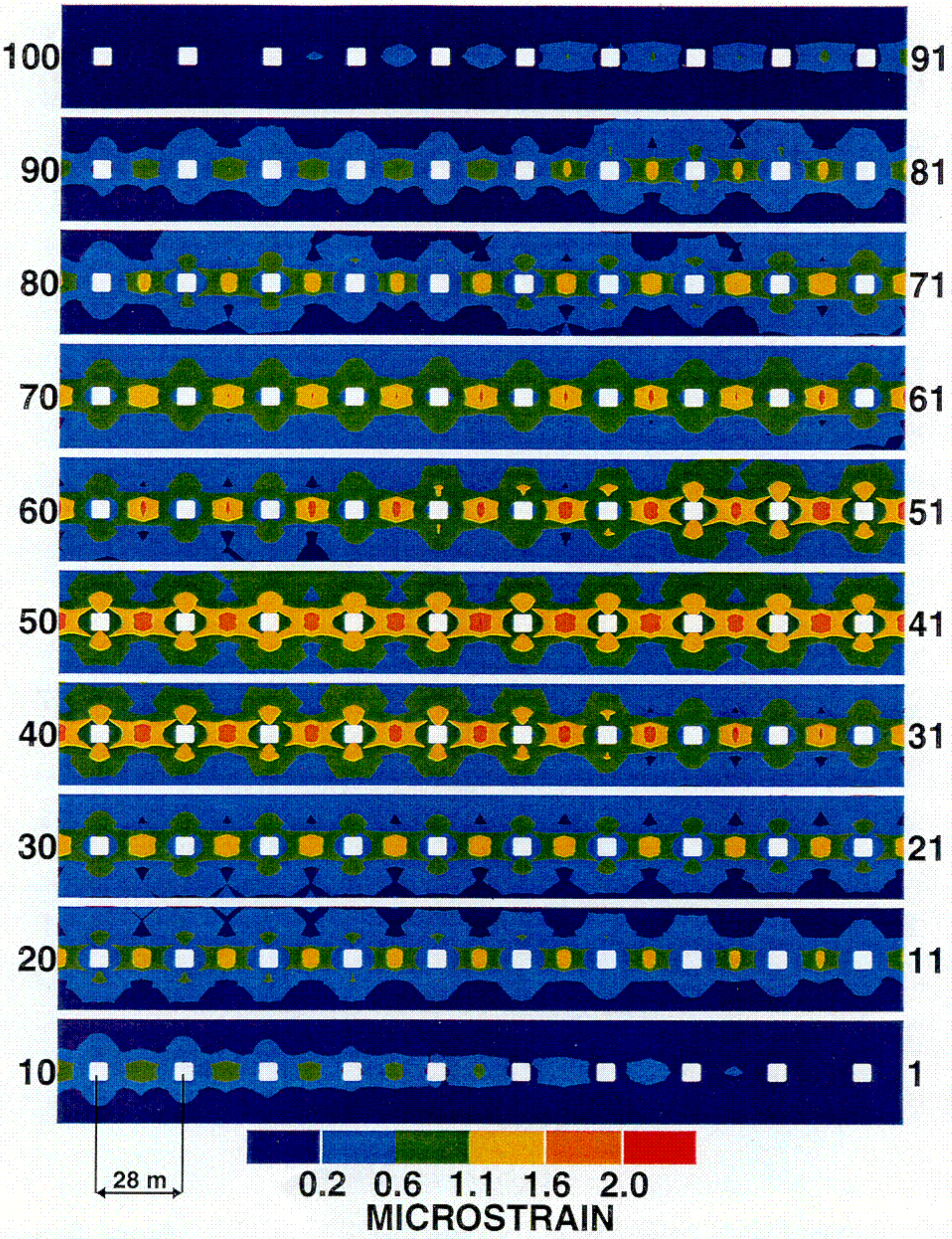


Figure 6. Inelastic strain distribution at 150 years with stiff drift support, shown in 10 sections as explained in Figure 5.

C02

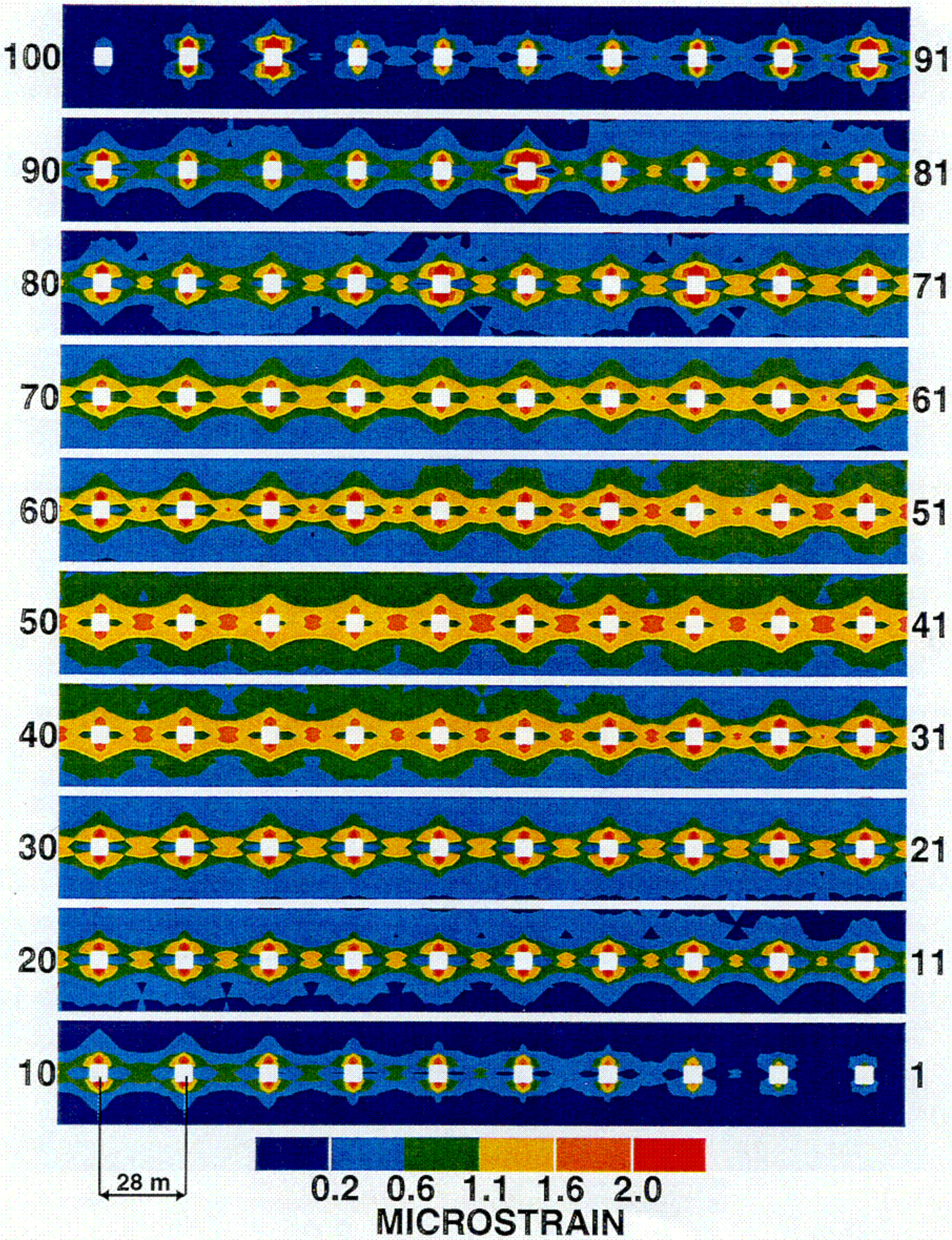


Figure 7. Inelastic strain distribution at 150 years with degraded drift support. Support degradation was simulated by deactivating the support system rapidly (over 1 year) after 150 years.

C03

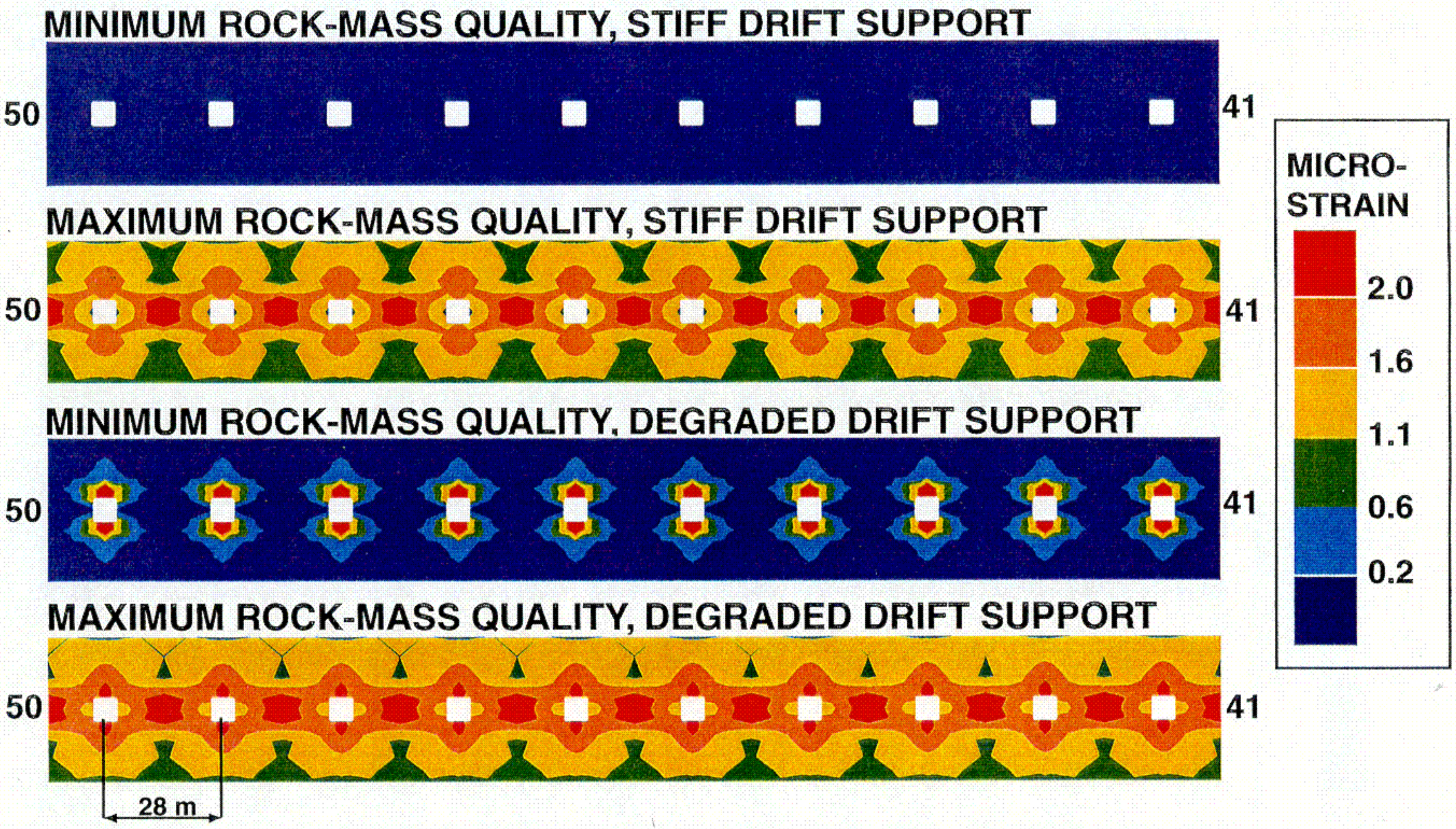


Figure 8. Inelastic strain distributions between drifts #41 and #50 at 150 years, from homogeneous models. Analyses were performed using the parameter values that correspond with the minimum and maximum *Q* values on curves Y1, F2, and C2 in Figure 4.

C04

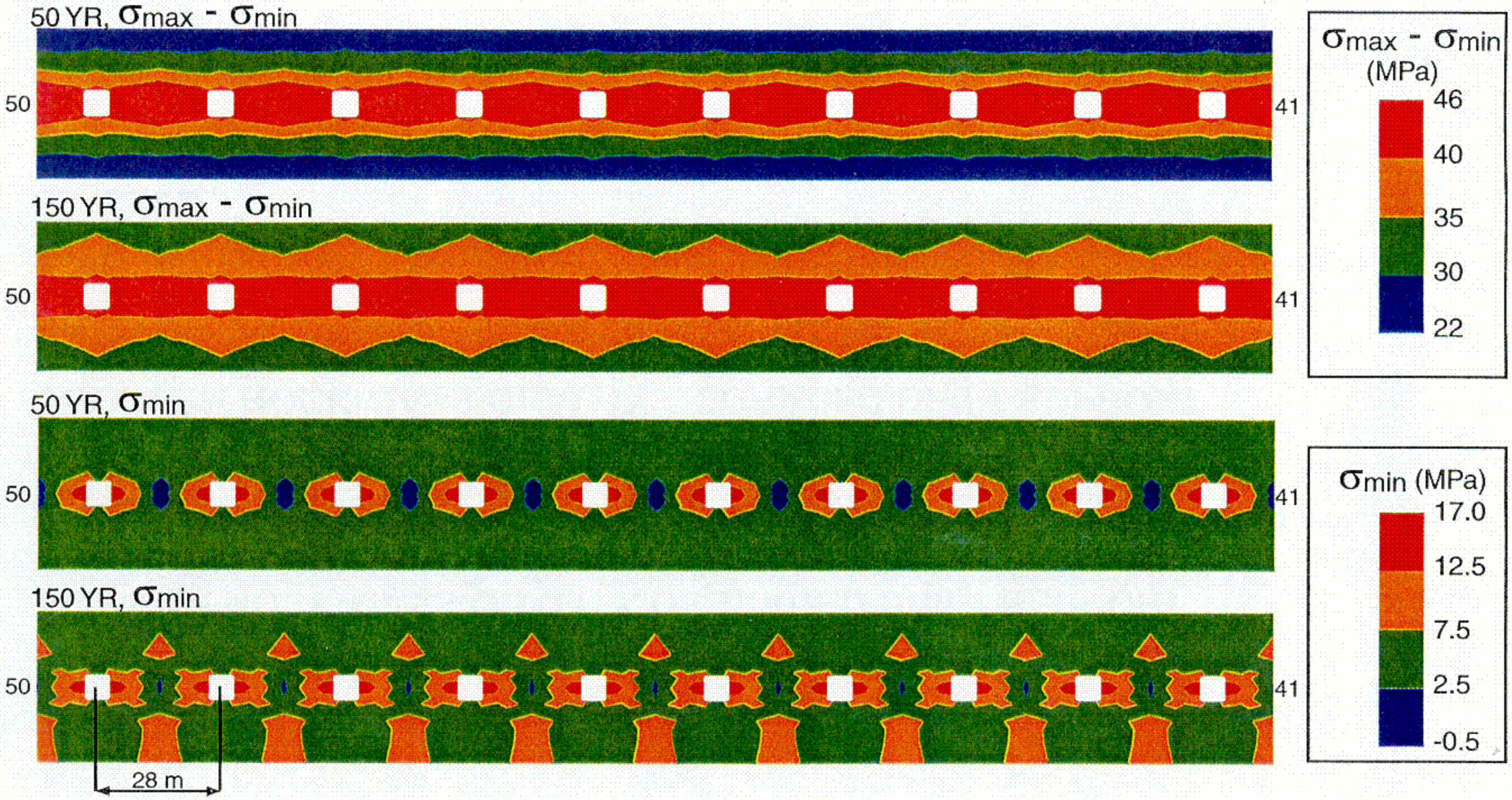


Figure 9. Distribution of principal stress difference ($\sigma_{max} - \sigma_{min}$) and minimum principal stress (σ_{min}) from a homogeneous, linear-elastic model with stiff drift support and Young's modulus corresponding to the maximum Q value on curve Y1 of Figure 4.

C05

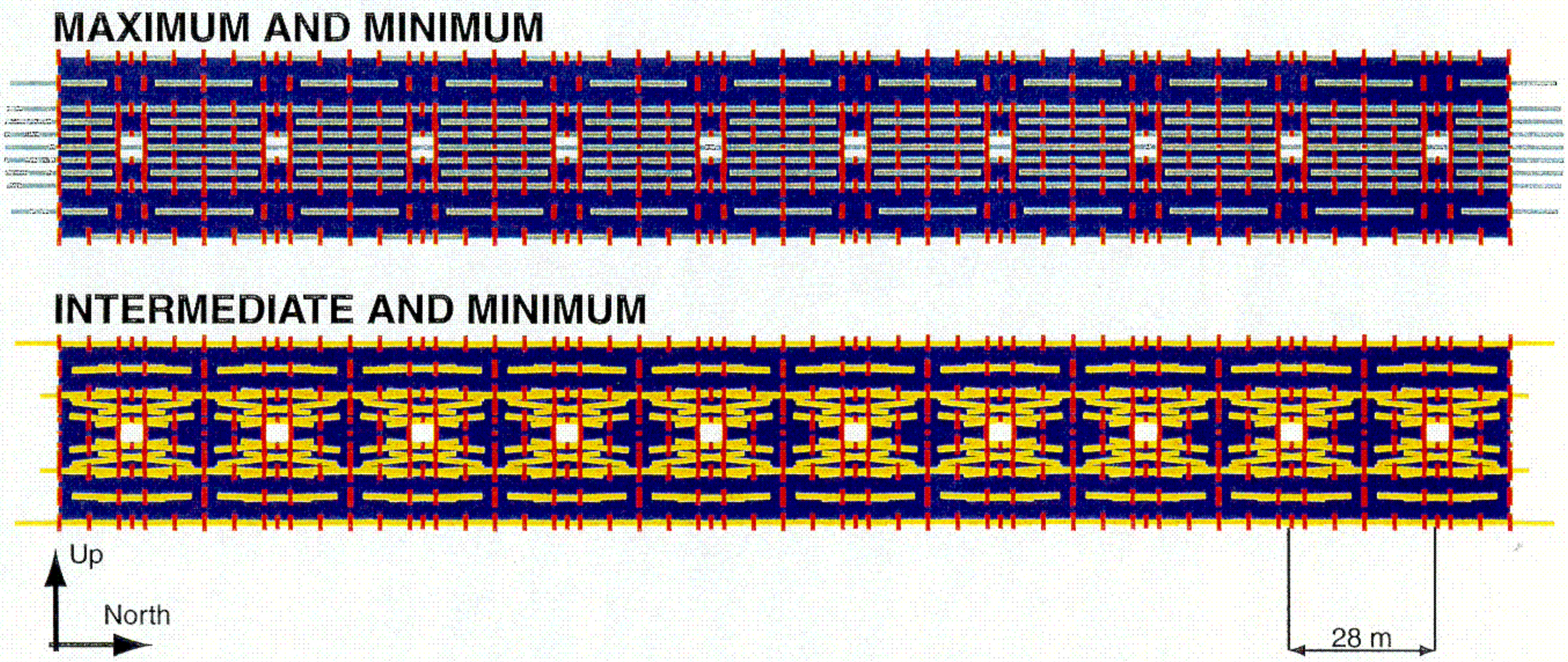


Figure 10. Principal stress orientations from a homogeneous, linear-elastic model with stiff drift support. Each plot shows the orientations of the in-plane principal stress components only, so the plots demonstrate that the maximum principal stress is in-plane (~north-south) in the pillars and out-of-plane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

C06

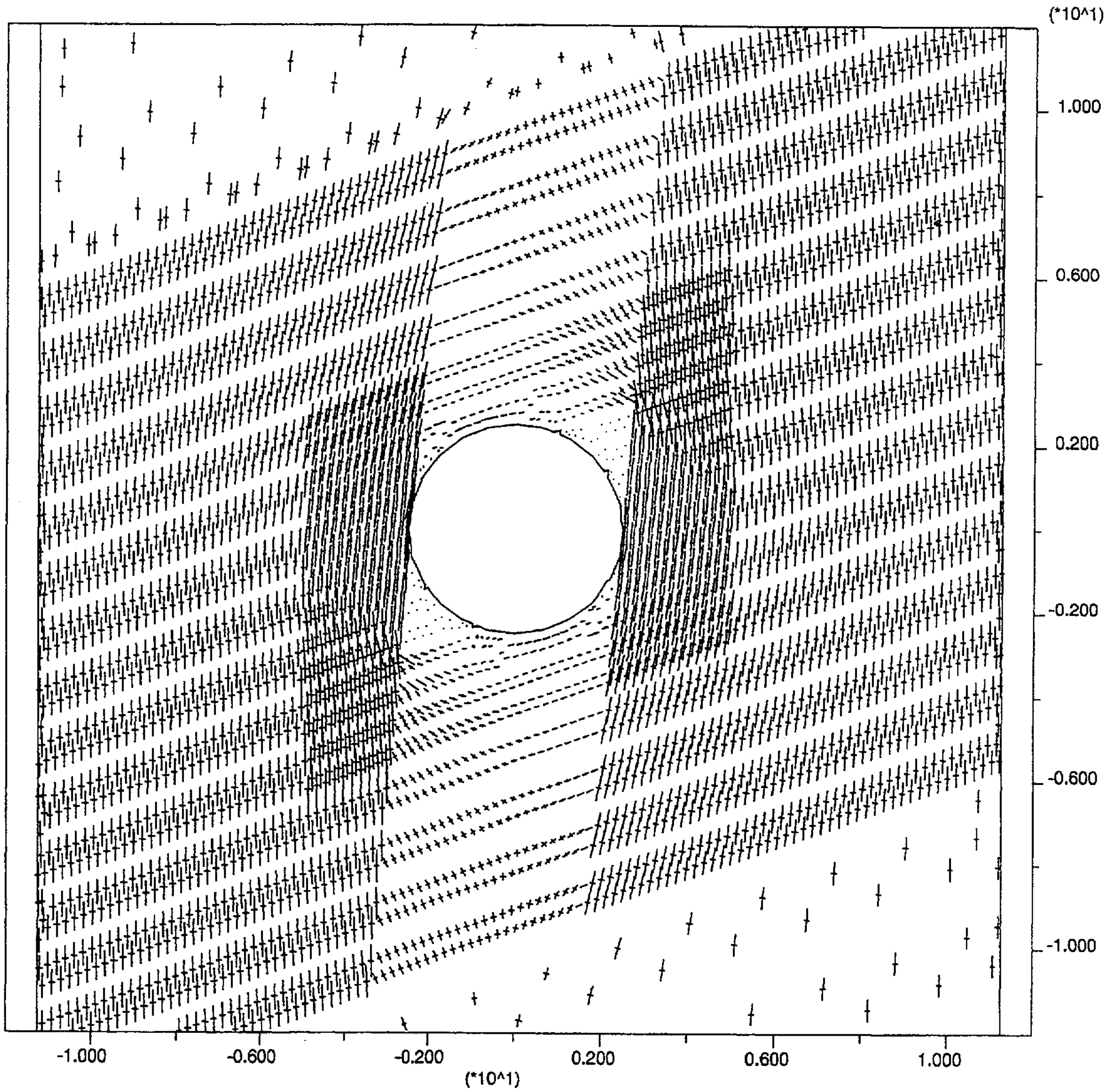


Figure 11. Distribution of principal stresses after drift excavation

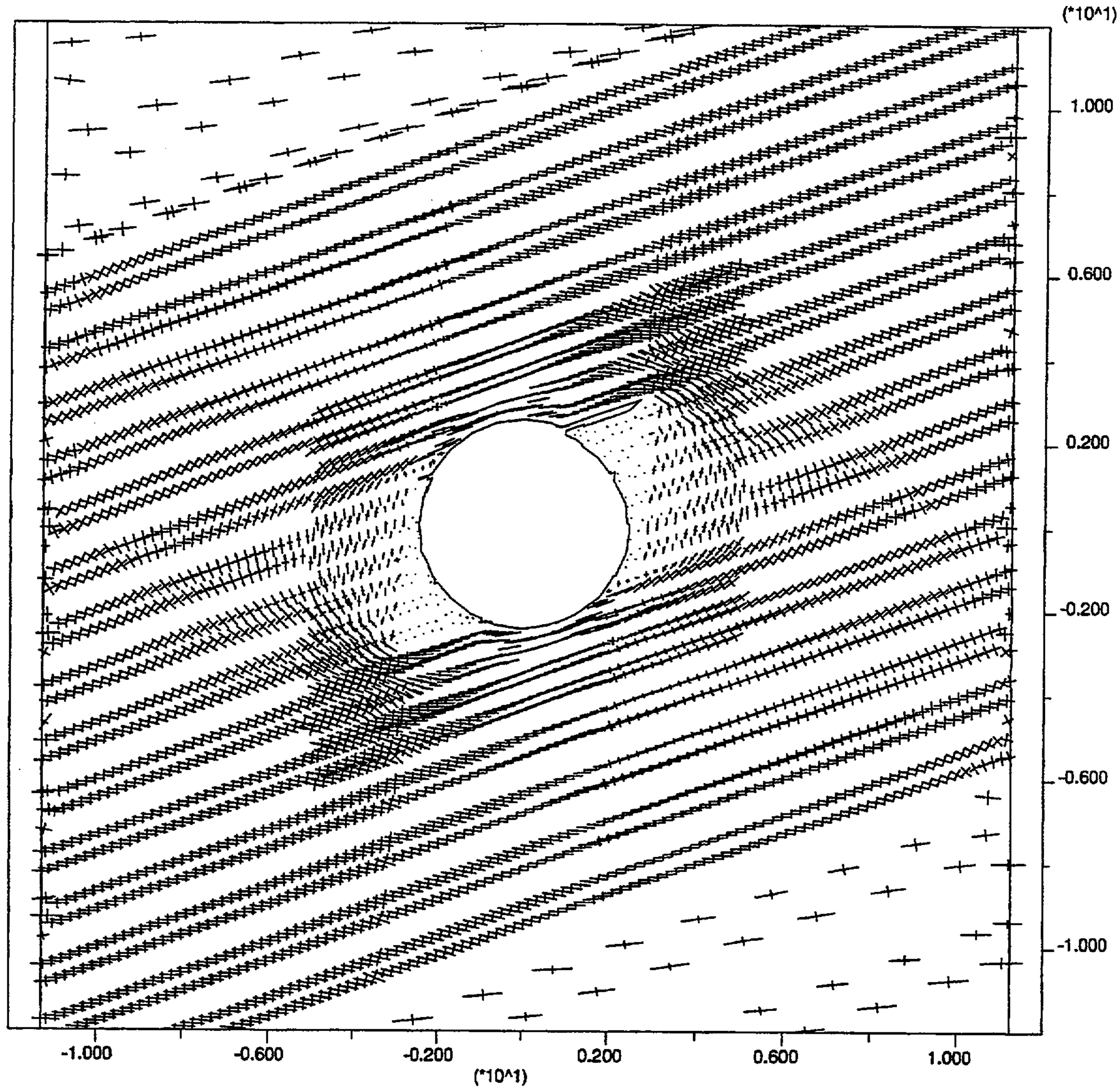
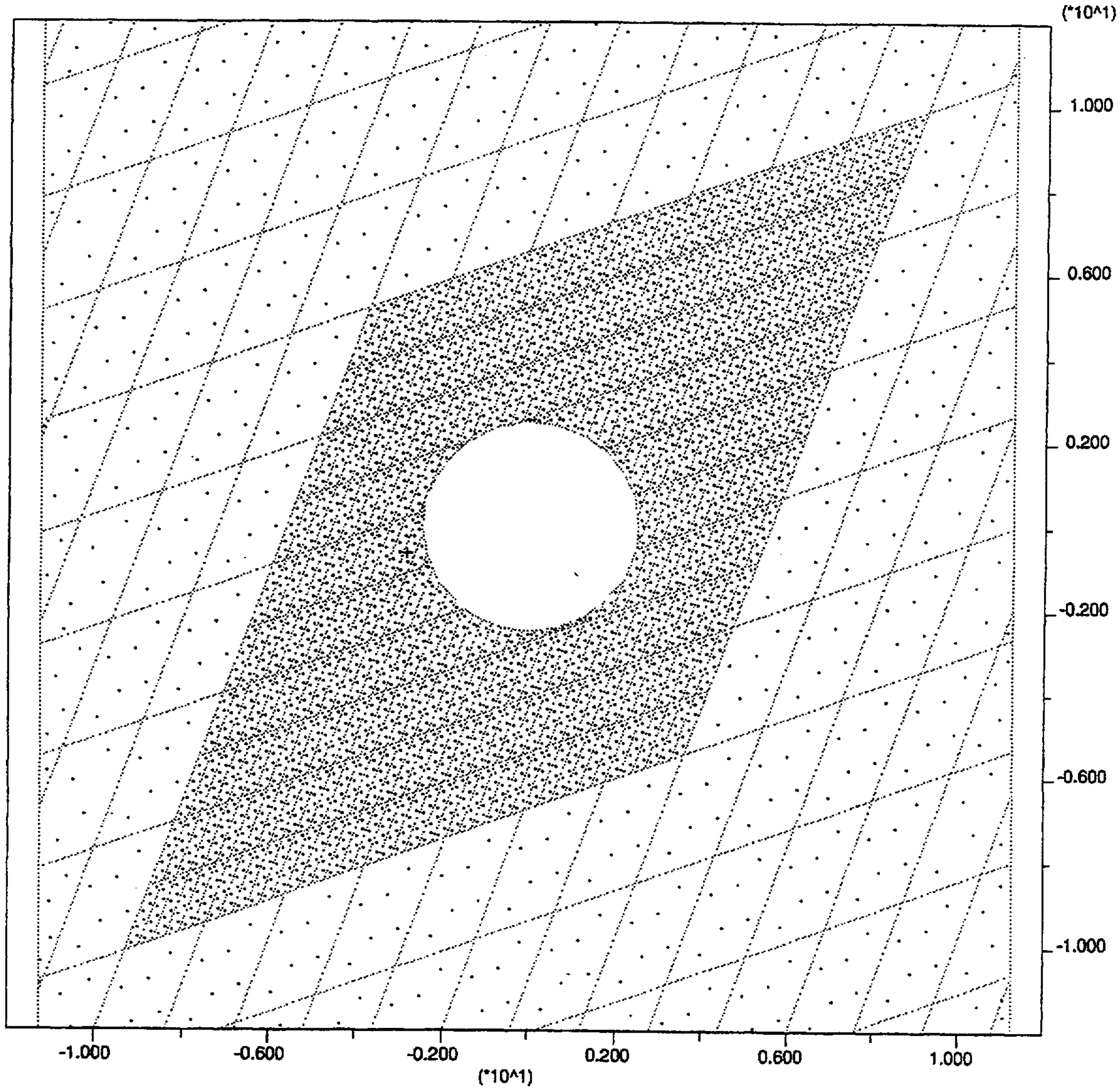
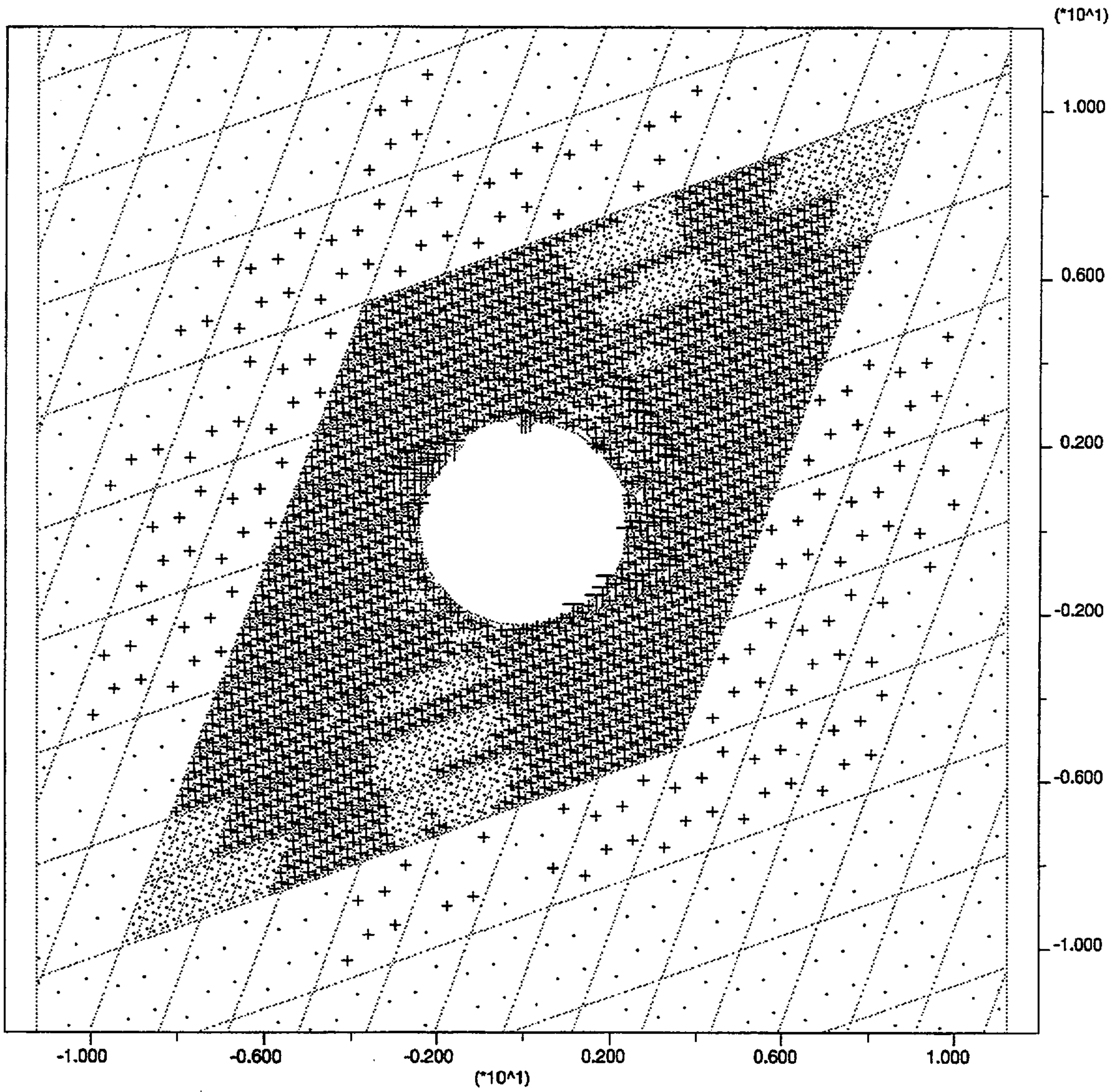


Figure 12. Distribution of principal stresses after 100 years of heating



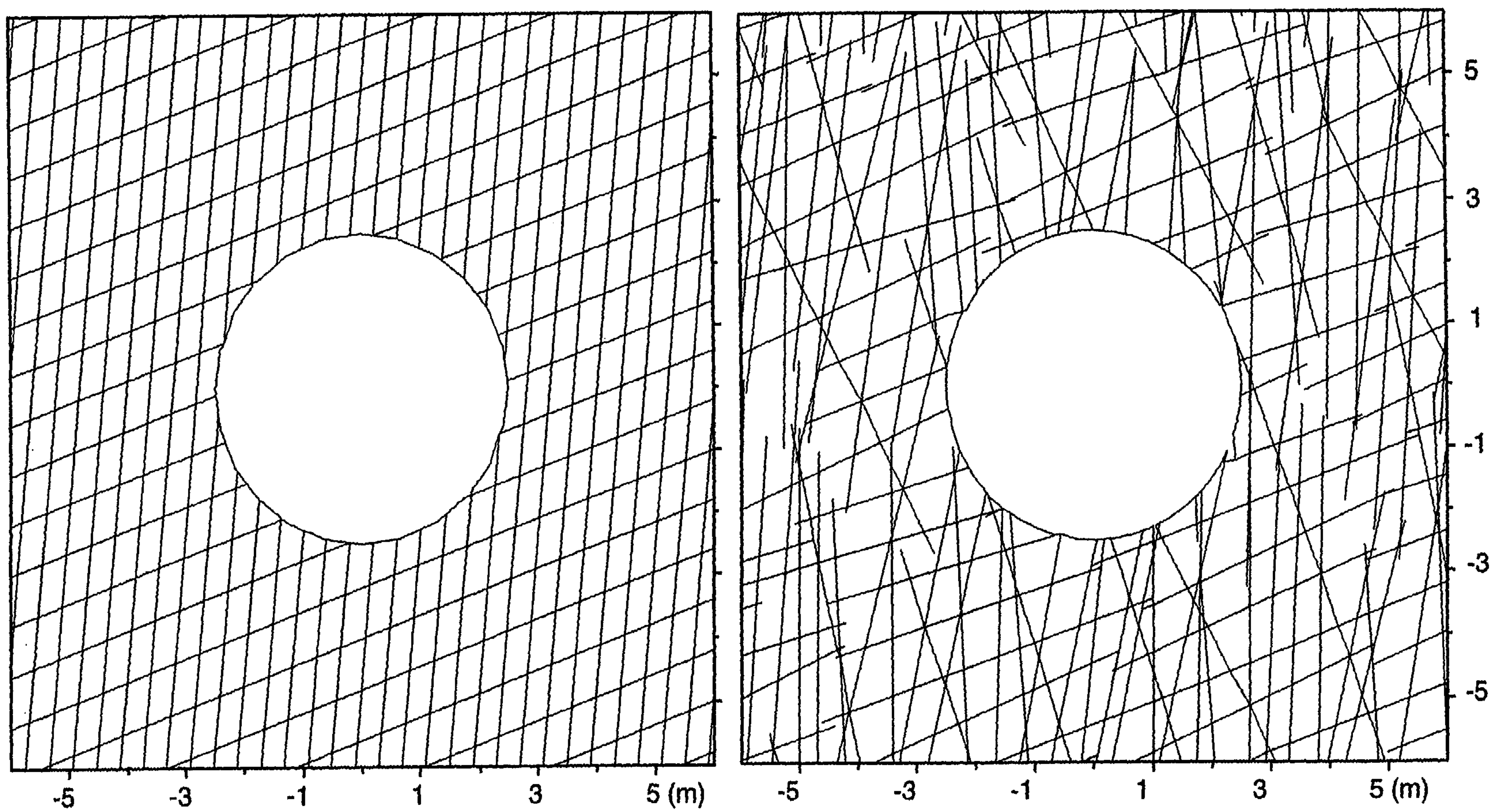
Note: Dots represent elastic state. Crosses represent yield zones. Dash lines represent joints.

Figure 13. Distribution of yielding after drift excavation



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

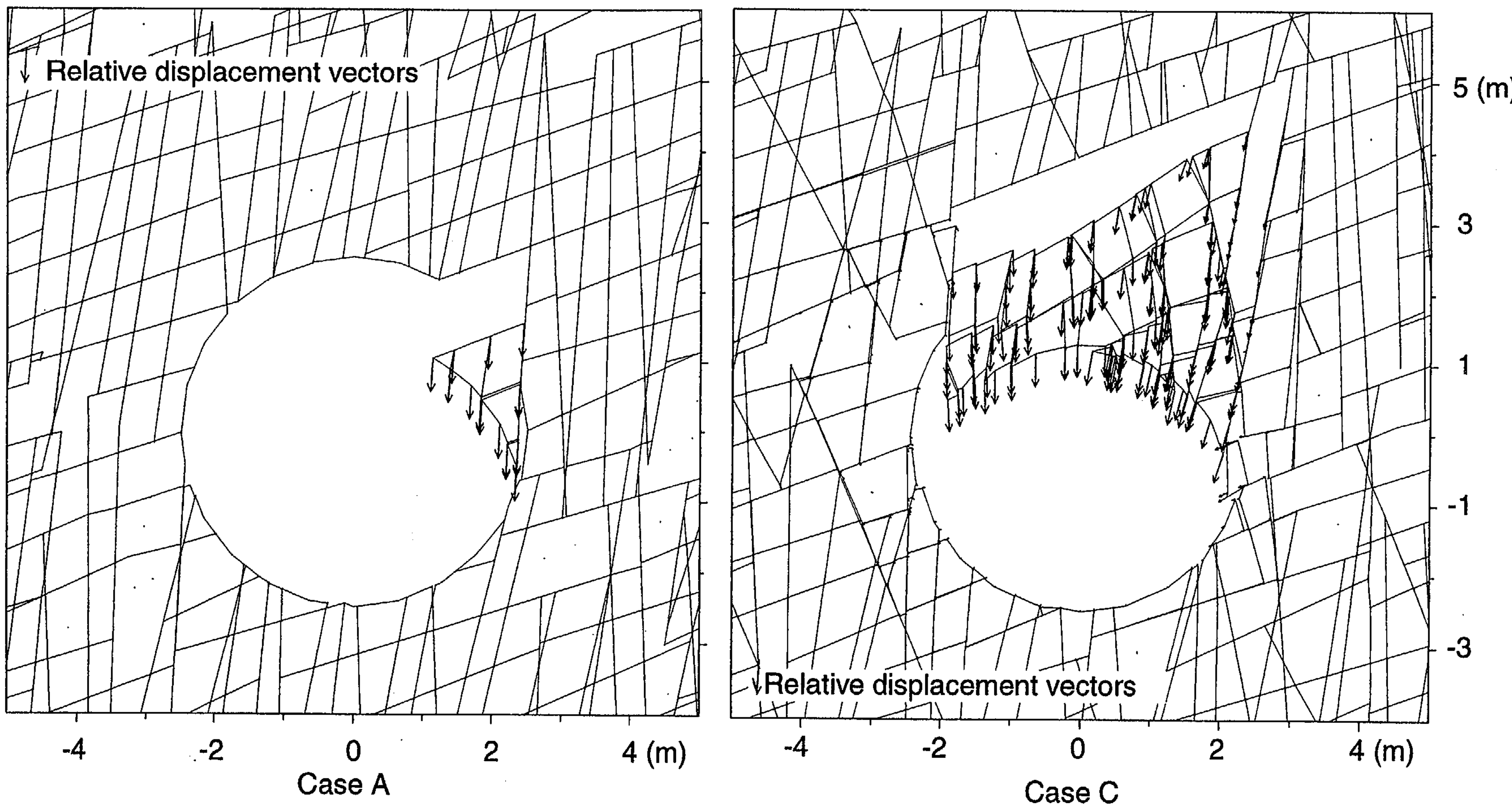


Figure 16. Simulated rockfall after 100 years of thermal loading and one episode of dynamic ground motion for two slightly different fracture patterns

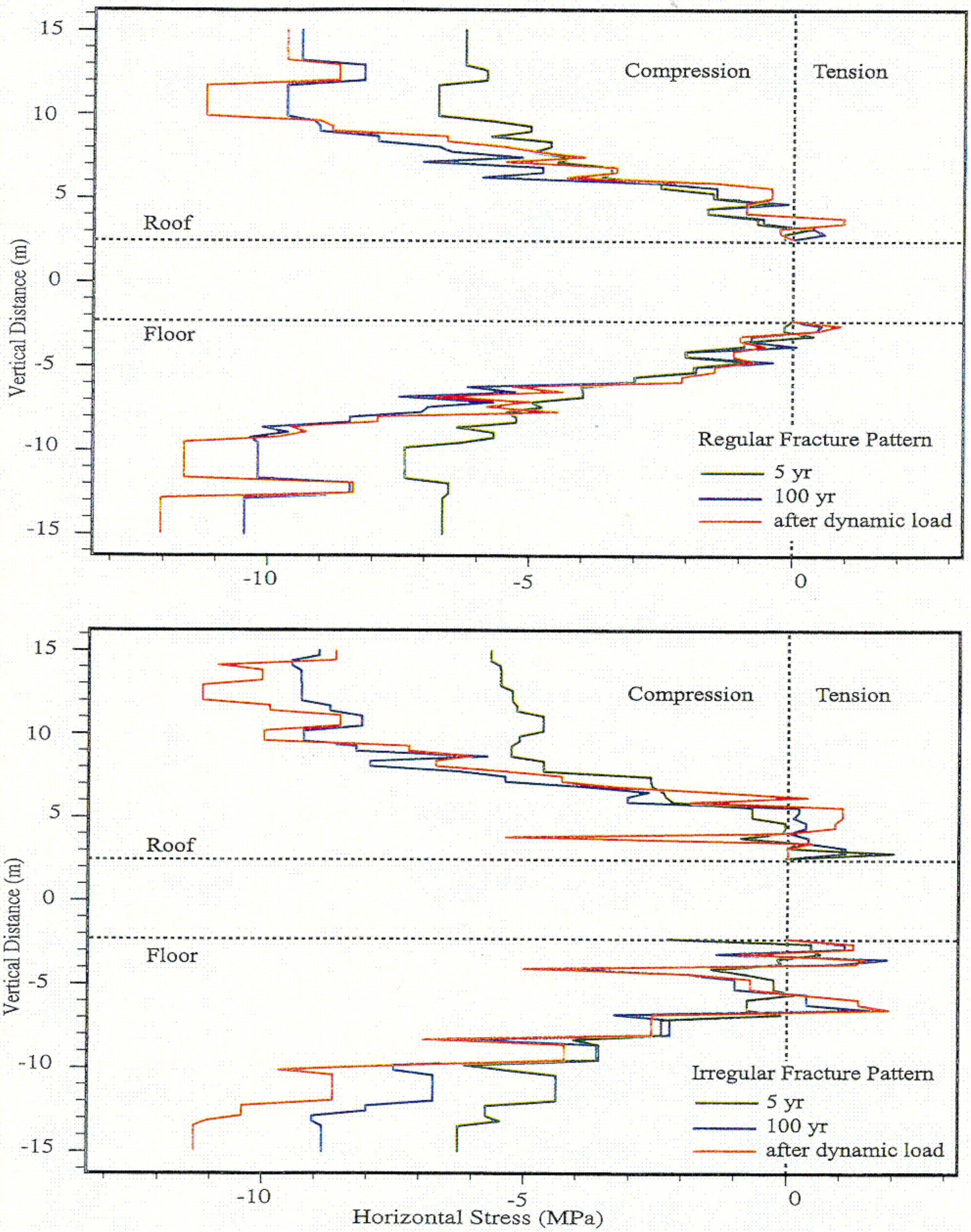


Figure 17. Comparison of vertical profile of minimum principal stresses for irregular and regular fracture patterns after 5 and 100 years of thermal and dynamic load

C07

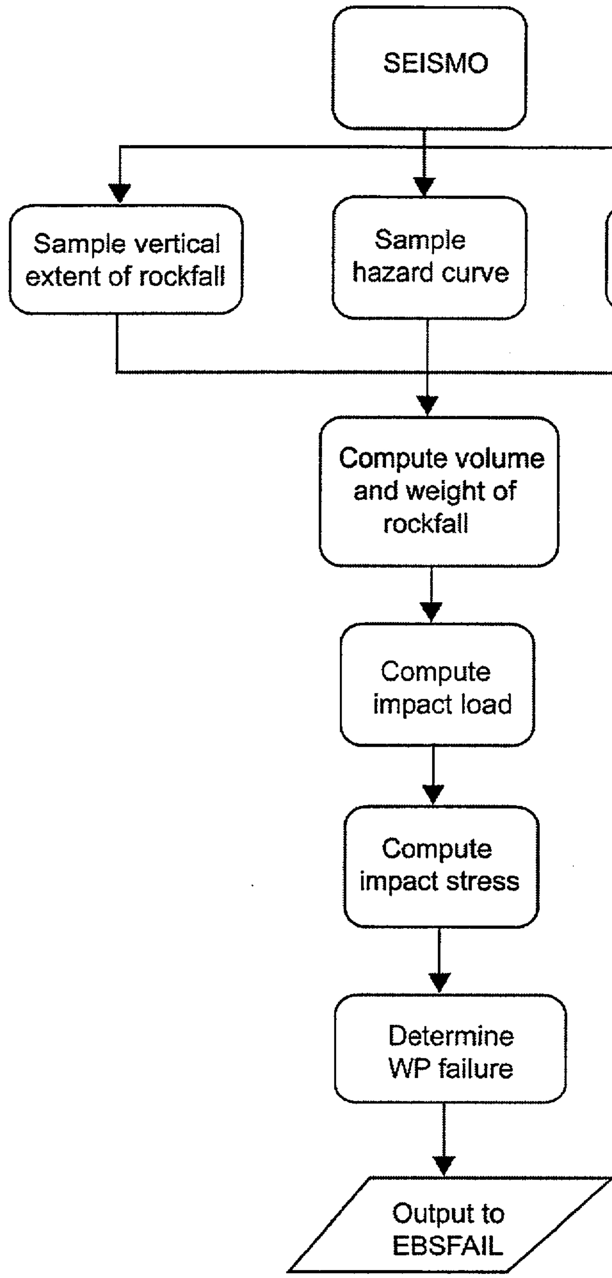


Figure 18. Flowchart highlights SEISMO calculation

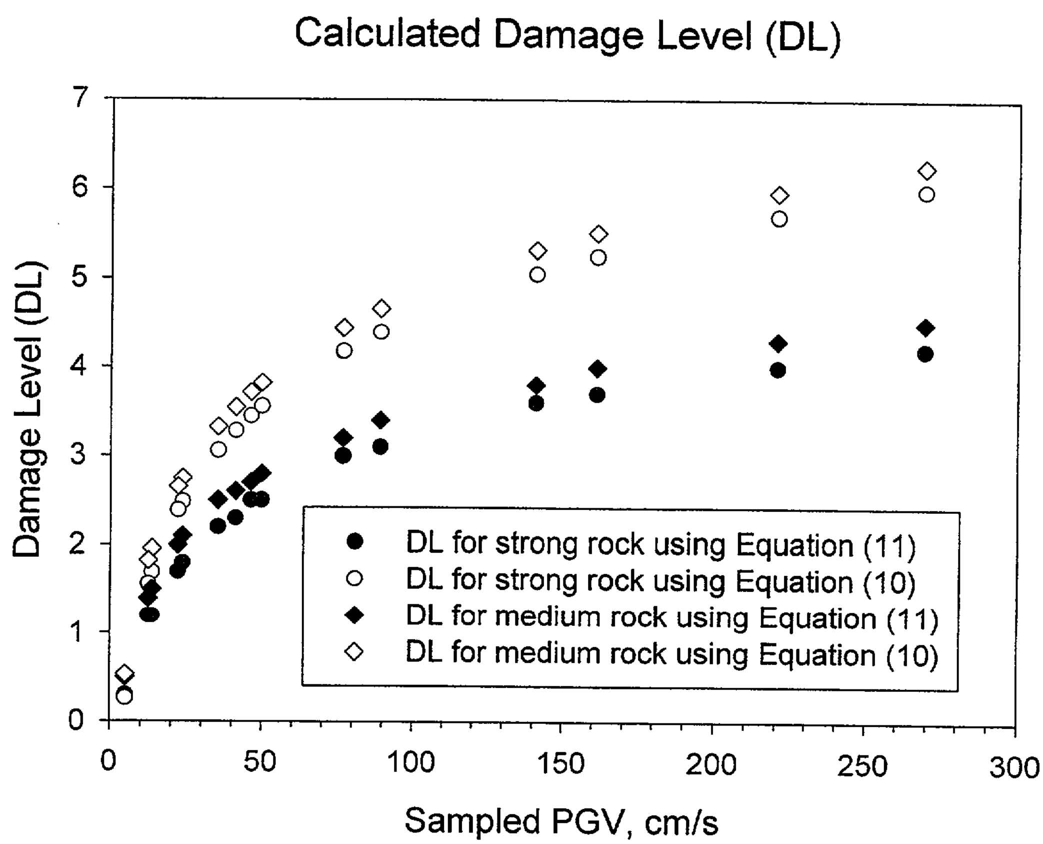


Figure 19. Damage level versus peak ground velocity

5 STATUS OF ISSUE RESOLUTION AT THE STAFF LEVEL

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

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

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

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

Exploratory Studies Facility

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

Table 2. Summary of Subissue Resolution Status

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

Geologic Repository Operations Area

During FY1998, the staff conducted a limited evaluation of the effectiveness of DOE's implementation of the design control process as a generic matter for all the SSCs that comprise the GROA. Specifically, the staff selected six systems of the GROA (three surface and three subsurface systems) for a detailed assessment on ~~of DOE's compliance/noncompliance with the 12 AC (in Section 4.1.3 of Revision 2 of this IRSR) that the staff developed to measure~~ the effectiveness of DOE's design control process. While the staff recognizes that the six systems represent only a small part of DOE's design activities for the entire GROA, the staff concludes that, with one exception, DOE has an effective design control program for the GROA, based on this limited review. The one area in this program in need of improvement is in relation to control of design changes relative to an original design and proper documentation of such changes (Section 4.1.1.3 ~~4.1.5.2~~). As mentioned previously, the staff will continue to monitor the effectiveness of DOE's design control process, including any identified areas of weakness.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.1.1.3 Status of Open Items from In-Field Verifications

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

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

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

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

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

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

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

5.1.2.1 Status of Topical Report-1

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

5.1.2.2 Status of Topical Report-2

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

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

5.1.2.3 Status of Topical Report-3

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

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

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

5.1.3.1 U.S. Department of Energy Approach

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

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

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

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

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

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

5.1.3.2 U.S. Nuclear Regulatory Commission Staff Evaluation

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

Site Description

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- Information on the geochemical composition of subsurface water held within the rock matrix, perched water zone, or from episodic flows through fractures is sufficient to determine corrosivity.
- The geochemical composition of the rock strata within which and above the repository horizon is adequately defined to identify minerals that might add to the corrosivity of water flowing through the strata.
- Potential geochemical alterations to the rock fractures and the rock matrix through heating or other processes that might significantly alter geomechanical rock mass properties are adequately characterized.

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

Structures, System, and Components Descriptions

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

- The LA has a description of surface facilities that includes their location and arrangement at the site and their distance from the site boundary. This description includes drawings of sufficient detail and appropriate scale.
- The discussion of the design of the surface facilities is adequate to permit an evaluation of the PCSA.
- The descriptions of the functional requirements for the facilities are adequate to provide an understanding of GROA operational activities, sequences, and locations sufficient for evaluation of the PCSA and GROA design.
- The descriptions of the capabilities of the equipment, training, level of the operators, and testing/maintenance plan are sufficient for evaluation of the PCSA.

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

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

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

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

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

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

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

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

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

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

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

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

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

- The LA adequately characterizes the properties of the HLW.

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

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

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

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

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

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

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

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

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

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

Identification of Hazards (Natural and Manmade)

Methods for Identifying Hazards

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

- Methods used for hazard and initiating event identification are consistent with standard industry practices.
- If standard industry practices are not used, the DOE basis and justification for choosing a particular hazard and initiating event identification method(s) are defensible.
- Methods selected for hazard and initiating event identification are appropriate for the available data on the site and GROA.
- Assumptions used to identify naturally occurring and human-induced hazards and initiating events are well-defined, have adequate technical basis, and are supported by information on the site and its SSCs and operational processes.

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

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

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

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

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

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

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

Data Consistency and Technical Basis for Inclusion and Exclusion

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- Information of number and type of aircraft that use the military training routes including information on all "live" or "dummy" ordnance.
- A map showing the land boundaries of different Military Operations Areas (MOAs) and restricted airspace with respect to the proposed facility.
- Anticipated increase in civilian and military aircraft traffic in the future near the proposed facility.

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

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

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

- The technical bases are technical defensible and consistent with site and system information.
- The technical bases include adequate consideration of uncertainties associated with frequency or probability of the hazards and initiating events.

STATUS: Open. See discussion in AC2 and AC3.

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

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

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

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

Identification of Event Sequences

Methods and Data for Identifying Event Sequences

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

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

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

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

Technical Basis for Inclusion and Exclusion

AC2 Category 1 and 2 event sequences are adequately identified.

- DOE properly applies methods for identification of event sequences.

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

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

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

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

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

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

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

Identification of SSCs Important to Safety

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Meeting 10 CFR 63.112(b)(2)

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

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

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

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

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

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

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

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

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

- The type, quantity, and concentration of airborne radionuclides that could be released during Category 2 event sequences are supported by appropriate data and analyses or are estimated in accordance with NRC guidance documents.

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

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

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

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

- The time that a member of the public is assumed to be exposed to elevated levels of radiation from Category 2 event sequences is reasonable. The time is based on the amount of time required for the facility to recover from the event sequence; and

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

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

- Credit taken for the use of ventilation and filtration systems in mitigating the release of airborne radioactive materials is appropriate. The analyses consider credible damage to the ventilation system that may result from event sequences,

- Airborne transport modeling uses an acceptable method,

- DOE considers appropriate exposure pathways,

- The time that a member of the public is assumed to be exposed to airborne radioactive materials from Category 2 event sequences is reasonable and is based on the time that radioactive effluents are released from the facility, and

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

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

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

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

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

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

Meeting 10 CFR Part 20 As Low As Reasonably Achievable Criteria

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

The management commitment includes provisions for ensuring that:

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

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

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

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

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

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

AC2 ALARA principles are adequately considered in GROA design.

The design of the GROA adequately considers the ALARA philosophy.

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

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

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

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

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

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

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

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

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

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

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

AC3 Proposed operations at the GROA adequately incorporate ALARA principles.

Operational procedures follow the ALARA philosophy.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Technical Bases for and Completeness of SSCs Important to Safety

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

- The analysis and classification of SSCs for the GROA uses results of the consequence analyses as a basis to identify those SSCs that are important to safety.

- The analyses used to identify SSCs important to safety, safety controls, and measures to ensure the availability of the safety systems include adequate consideration of:

— Means to limit concentration of radioactive material in air;

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

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

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

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

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

Risk Basis for the Categorization of SSCs Important to Safety

To be developed.

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

5.1.4 ACCEPTABILITY OF GROA DESIGN TO MEET THE PRECLOSURE PERFORMANCE OBJECTIVES

5.1.4.1 U.S. Department of Energy Approach

Design Criteria and Design Bases

To be developed.

GROA Design Methodologies

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

Design of Surface Facilities

To be developed.

Design of Subsurface Facilities

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

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

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

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

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

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

5.1.4.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Design Criteria and Design Bases

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

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

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

- Thermal design criteria and bases are consistent with relevant regulatory guidance.
- Ventilation design criteria and bases are consistent with relevant regulatory guidance.
- Design criteria and bases for shielding and confinement systems utilize appropriate guidance.
- Design criteria for normal operating conditions are adequately developed so that designs do not result in any degradation of the capabilities of the GROA to protect radiological health and safety. Design criteria for Category 1 event sequences do not permit degradation of the performance of GROA SSCs important to safety.
- Designs for fixed-area radiation monitors and continuous airborne monitoring instrumentation are consistent with relevant regulatory guidance.
- Design criteria for Category 1 and 2 event sequences are sufficiently developed and adequately consider PCSA results to ensure that SSCs important to safety will continue to prevent unacceptable consequences.
- Criticality design criteria are developed based on consequence analysis results from the PCSA and are consistent with relevant regulatory guidance. Design criteria are adequately factored into the models and assumptions used for criticality analysis.
- Design bases and criteria are clearly identified for thermal, structural, shielding, criticality, and other operating limits for the GROA facilities.

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

GROA Design Methodologies

AC1 GROA design methodologies are adequate.

- Proposed design methodologies are supported by adequate technical bases.
- Proposed design methodologies are consistent with established industry practice.
- Uncertainties associated with the proposed methodologies are adequately addressed.
- If the design methodologies depend on site-specific test data, such data are available.
- Any analytical or numerical models used to support the design methodologies are verified, calibrated, and validated.
- Any assumptions or limitations relating to the proposed methodologies are identified and their implications for the design are adequately analyzed and documented.
- Seismic design methodologies use ground-motion information that is consistent with proposed DOE methodologies for hazard assessment and, taken together, they provide adequate input for seismic design and for PA.

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

Design of Surface Facilities

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

- Applicable design codes and standards are specified for structural, thermal, shielding and confinement, criticality, and decommissioning designs.
- If other methods are used for design, the LA provides adequate technical bases for those methods.

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

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

- Materials used for SSCs important to safety related to surface facility design are consistent with either the accepted design criteria, codes, standards, and specifications or with those specifically developed by DOE.
- Materials are adequate, considering the material properties and allowable stresses and strains associated with the design.
- Materials and their properties are appropriate for the expected design loading conditions. In addition, anticipated stress limits for each material are based on maximum temperatures as established in the thermal analysis evaluation presented in the LA.
- The potential for creep or brittle fracture of materials is adequately assessed to ensure that SSCs important to safety will perform their safety functions.

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

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

- The loads used in the DOE design analyses are consistent with those normal and Category 1 and 2 event sequence loadings of radiological importance.
- The load combinations used in the design analyses are consistent with those used and accepted by the NRC for the design of similar types of nuclear facilities and for steel and reinforced concrete structures.

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

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

AC4 Design analyses are properly performed and documented.

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

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

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

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

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

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

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

Design of Subsurface Facilities

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

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

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

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

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

AC2 The design of subsurface operating systems is adequate.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

AC7 The subsurface ventilation systems are adequately designed.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5.1.5 PRESERVATION OF RETRIEVABILITY OPTION

5.1.5.1 U.S. Department of Energy Approach

To be developed.

5.1.5.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Stability of Underground Openings and Maintainability

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

Feasibility and Acceptability of Retrieval Plan

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

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

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

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

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

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

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

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

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

AC4 A reasonable schedule for potential retrieval operations is provided.

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

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

Temporary/Permanent Storage Considerations

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

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

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

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

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

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

5.1.6.1 U.S. Department of Energy Approach

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

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

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

5.1.6.2 U.S. Nuclear Regulatory Commission Staff Evaluation

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The WP PMR (CRWMS M&O, 2000a) describes the closure welding process to be used in the EDA II design. The approach used for estimating the initial failure rate of the container is also detailed (CRWMS M&O, 2000a). This approach assumes a certain probability of initial failures and the ability to detect initially defective WP. The radiological consequences during the preclosure period to workers and the public due to initial defects needs to be examined.

The postclosure PA of the EBS (CRWMS M&O, 2000c) includes the effect of microbiological colonies and water seepage on steel components (rock bolts, steel sets, and WP support system). The assumption is that, during the preclosure period, ventilation will dry out the system and therefore aqueous corrosion processes are insignificant. However, the effectiveness of ventilation system in drying out a significant portion of the drift wall and the effect of an accidental malfunction, of the ventilation system during the preclosure period needs to be examined. Degradation of the steel support system may adversely affect waste retrieval.

The methodologies used by DOE for identifying the FEPs and the consequences are similar to those methods used in the PCSA required in 10 CFR 63.112. However, this analysis has not been performed by DOE for the current design of the EBS, WP, and WF. The mechanical property data for these components as functions of temperature is lacking. During the preclosure period, corrosion of support structures in the drift, on waste retrievability, and its effect needs to be examined.

5.1.7 ACCEPTABILITY OF THE PERFORMANCE CONFIRMATION PROGRAM

5.1.7.1 U.S. Department of Energy Approach

To be developed.

5.1.7.2 U.S. Nuclear Regulatory Commission Staff Evaluation

Feasibility of the Performance Confirmation Program

To be developed. Some ACs in Section 5.1.4 may be applicable.

Design and Performance Verification During Construction and Operation

To be developed.

5.1.8 REPOSITORY OPERATIONS

5.1.8.1 U.S. Department of Energy Approach

To be developed.

5.1.8.2 U.S. Nuclear Regulatory Commission Staff Evaluation

To be developed.

5.1.9 Permanent Closure, Decontamination, and Decommissioning

5.1.9.1 U.S. Department of Energy Approach

To be developed.

5.1.9.2 U.S. Nuclear Regulatory Commission Staff Evaluation

To be developed.

5.2 POSTCLOSURE ISSUES RESOLUTION STATUS

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

Consideration of repeated seismic loading for the (postclosure) design of the WP and TSPAs is as discussed previously, this subissue includes two components: ~~(i) TM effects on design of the underground facility;~~ (ii) effects of seismically induced rockfall on WP performance and (iii) TM effects on flow into emplacement drifts. The status of resolution for each component is presented in separate subsections.

~~**5.2.2 Status of Thermal-Mechanical Effects on Design of Underground Facility**~~
~~This component of the Subissue on TM Effects on Repository Design and Performance relates to the sufficiency of DOE's underground facility design program. Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.3.1 of this IRSR.~~

~~**5.2.2.1 Acceptance Criterion 1**~~
~~**Approved QA control procedures and standards were applied to collection and documentation of data, methods, models, and codes.**~~ ~~The DOE and M&O Contractor periodically conducts performance-based audits and surveillances on the activities related to data collection and repository design. NRC staff participates as observers in these audits and surveillance. In the future, NRC staff will continue to participate in these audit activities to ensure that proper QA procedures have been implemented in the area of TM aspect of repository design.~~

~~Recent DOE audits identified deficiencies in data traceability, management, and qualification (e.g., U.S. Department of Energy, 1998e,f,g,h,i). Corrective actions are being taken to address these deficiencies. NRC staff will monitor the progress of the corrective actions.~~

~~**5.2.1.2 Acceptance Criterion 2**~~

~~**If used, expert elicitations are conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable guidelines.**~~ ~~Expert elicitations have been used in developing probabilistic seismic hazard data and, perhaps, the seismic and fault displacement input data for repository design and PA. The report for the former is currently available, and the latter will be available in FY2000. The RDTME KTI will review the process of the expert elicitations implemented in FY2000, in conjunction with the Structural Deformation and Seismicity KTI, to determine if acceptable guidelines have been followed.~~

~~**5.2.1.3 Acceptance Criterion 3**~~

~~**TM analyses of the repository design are based on site-specific thermal and mechanical properties, the spatial variation of such properties, and temporal variations caused by post-emplacement TMHC processes, as appropriate, including the consideration of seismic effects relevant to the YM site within the rock mass.**~~ ~~Appropriate data, including variations in the spatial and temporal domains, are important to support underground facility design analyses. In its VA report (U.S. Department of Energy, 1998j), DOE commits to continue characterization of the rock mass in the lower lithophysal zone of TSw2 unit where about 75 percent of the WPs will be emplaced. The VA report also discusses plans for testing TM properties of the proposed host rock at YM~~

(U.S. Department of Energy, 1998j, Section 3.1.1.8), convergence monitoring at the ESF and the cross drift to characterize the rock mass support intersection (U.S. Department of Energy, 1998j, Section 3.1.1.7), TM deformation and associated permeability changes in the cross drift thermal test (U.S. Department of Energy, 1998j, Section 3.1.4.4), and evaluation of long-term mechanical stability of the host rock and candidate ground support materials based on laboratory test results and natural or manmade analogs (U.S. Department of Energy, 1998j, Section 3.1.5.3). However, details of the proposed testing plans are sketchy. Furthermore, review of a number of DOE design-related reports (see discussion in Section 4.3.3.2) indicates a need for an Appendix 7 meeting for NRC staff to better understand DOE's approach to data collection and utilization in design. An Appendix 7 meeting is proposed for FY2000. As a part of the meeting, Acceptance Criterion 3 is expected to be discussed in detail.

In its Repository Ground Support Analysis for Viability Assessment (CRWMS M&O, 1998e), DOE evaluated effects of seismic loads on rock-mass behavior surrounding emplacement drifts and ground support systems. The ground support systems under consideration include concrete lining and steel set lining. DOE is reevaluating concrete lining ground support because of a number of concerns (e.g., effectiveness of concrete lining under prolonged heated conditions and potentially adverse effects on postclosure performance). A combination of rock bolts and steel sets may be used in the emplacement drifts. Accordingly, the effect of seismic loads on rock bolts needs to be evaluated. The relevancy of the seismic signal used in the analyses will be determined once the DOE seismic design TR–3 is reviewed.

5.2.1.4 Acceptance Criterion 4

The process to develop inputs to TM design includes consideration of associated uncertainties and documents the potential impacts on design. The data reduction methods proposed in the DOE seismic design methodology to develop input for TM design analyses are empirical equations proposed by the industry. The equations for both mechanical and strength properties have considerable uncertainties. In its seismic design methodology, DOE also recognizes this fact and has committed to update these empirical equations. Although plans are included in the VA report for updating these empirical equations (U.S. Department of Energy, 1998j, Section 3.1.1.8), no specifics regarding how these empirical relationships will be validated have been provided. Validation of the empirical equations will be a subject of the proposed Appendix 7 meeting discussed in Section 5.3.1.3.

5.2.1.5 Acceptance Criterion 5

The seismic and fault-displacement data inputs for design are consistent with those established in seismic design TR–3. This acceptance criterion will be adequately addressed when the seismic design TR–3 is reviewed and found to be acceptable, and the seismic and fault-displacement data proposed in TR–3 are used in the design and analyses. Review of seismic design TR–3 is currently scheduled for FY2000, pending its issuance by DOE.

5.2.1.6 Acceptance Criterion 6

The methodologies used for the TM design and analyses are consistent with those established in DOE Seismic TR–2. The resolution of this acceptance criterion will await design details to be provided in the SR and LA.

5.2.1.7 Acceptance Criterion 7

The TM design and analyses make use of appropriate constitutive models that represent jointed rock mass behavior under prolonged heated conditions. The models are tested as appropriate (verified, validated, and calibrated) before the submittal of the LA. The current approach adopted by DOE for the TM design and analyses calls for the use of both continuum and discontinuum analyses to investigate the rock mass behavior and stability of the emplacement drifts under thermal and seismic loads. This approach is found to be acceptable. However, appropriate constitutive models representing reduction of mechanical and strength properties with time as a result of degradation of the rock mass induced by appropriate TMHC processes [e.g., progressive fracturing caused by sustained TM loading, alteration of fracture-wall rock from extended exposure to heat and moisture, and longevity (long-term effectiveness under high temperature and thermally induced stress) or degradation of ground support systems] should be used in the design analyses for both continuum and discontinuum approaches. Alternatively, these two aspects can be properly bounded in the analyses. To the staff's understanding, long-term deterioration of rock material properties and ground support effectiveness is not currently factored into DOE's repository design and analyses. The staff will begin review of relevant documents and engage in discussions with DOE to resolve concerns regarding this acceptance criterion during FY2000. For those aspects of the models for which long-term experimental data are needed, continued verification and validation during performance confirmation may be acceptable as long as detailed plans and procedures for such continued activities are presented in the LA or supporting documentation. This acceptance criterion will be addressed at the proposed Appendix 7 meeting.

5.2.1.8 Acceptance Criterion 8

Both drift- and repository-scale models of the underground facility are used in TM analyses to establish the intensity and distribution of ground movement (rock deformations, collapse, and other changes that may affect the integrity or geometrical configuration of openings within the underground facility). The number and variety of models permit the examination of conditions along drift-parallel and drift-normal directions. DOE has not conducted repository-scale design calculations to establish the intensity and distribution of ground movement and synergistic effect on stability of the emplacement drifts in the area of high to low rock quality transition. Nor have bounding calculations been performed to account for the potential effects. This acceptance criterion may be discussed at the proposed Appendix 7 meeting. The staff will continue to follow DOE's progress in this area.

5.2.1.9 Acceptance Criterion 9

The principles formulating the TM analytical methodology, underlying assumptions, resulting limitations, and various steps involved in the design procedures are clearly explained and justified. The staff will review DOE's design and analyses related documents during FY2000 to determine progress on this acceptance criterion.

5.2.1.10 Acceptance Criterion 10

Time sequences of thermal loading used in TM design and analyses are clearly defined. The DOE is currently considering adoption of Enhanced Design Alterative No. 2, which was proposed by the M&O Contractor as a design baseline for the LA (CRWMS M&O, 1999). The new design alternative features a 60-MTU/acre thermal load and a 0.1-m gap between adjacent WPs as compared with an 85-MTU/acre thermal load and an average 5.75-m gap for the VA design. Consequently, the thermal loading used for the TM design and analyses will need to be redefined if a decision is made in favor of the new design. The staff will continue to follow the developments in this area.

5.2.1.11 Acceptance Criterion 11

The TM design and analyses consider the presence of roof supports (bolts, shotcrete, concrete, and steel liners, as applicable), consider the interaction between rock and roof supports, and address the degradation of supports with time under high temperature and moisture conditions as they affect the maintainability of stable openings during the extended preclosure period. DOE repository designs and analyses (e.g., CRWMS M&O, 1998e) considered the presence of ground supports. However, as stated in Section 5.3.1.11, the ground support systems included only concrete lining and steel set lining. Given that rock bolts may eventually become the major support system in the underground facility, their effectiveness will need to be evaluated in DOE's design and analyses. Furthermore, potential deterioration of ground support effectiveness over the period of preclosure performance needs to be factored into the repository design and analyses. This acceptance criterion will be addressed at the proposed Appendix 7 meeting.

5.2.1.12 Acceptance Criterion 12

Results of the TM analyses, including the consideration of ground support (e.g., liners), are accounted in the determination of maintenance requirements for the underground facility. The staff will review DOE's maintenance requirements for the underground facility when they become available to determine if the TM analysis results are used to develop the requirements.

5.2.1.13 Acceptance Criterion 13

The design discusses maintenance plans for keeping the underground openings stable, with particular attention to maintaining the option for retrieval. (If the details of retrieval operations/plans are found in other sections of the LA, a reference to such sections would be acceptable.) The staff will review pertinent sections of the LA to evaluate how this acceptance criterion is addressed.

5.2.1.1 Status of Effects of Seismically Induced Rockfall on the Engineered Barrier System Waste Package Performance

This component of the Subissue on TM Effects on Repository Design and Performance relates to the assessment of rockfall effect on WP integrity. Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.4.1 of this IRSR. Two aspects of the rockfall event that are addressed are: (i) the status of the DOE efforts to establish the probability of this event and (ii) the subsequent consequences to the EB components.

The following model abstraction applies to this subissue:

- Mechanical Disruption of EBS

U.S. Department of Energy Approach

DOE disruptive events FEPs screening analysis (CRWMS M&O, 2000e) has concluded that mechanical disruption of the WP due to rockfall will not be considered in the TSPA because of the presence of the drip shield and/or backfill. According to the *Engineered Barrier System Degradation, Flow, and Transport Process Model Report* (CRWMS M&O, 2000c), Table 3-47, however,

> "...a design change prompted by thermal considerations, was initiated to remove backfill and change the drift orientation to minimize the size of key blocks. Revision or ICN of the AMR and the EBS PMR will assess consequences of this change."

DOE used key block analysis to assess drift degradation due to seismicity, thermal load, and long-term rock mass degradation for the 10,000-year performance period (CRWMS&O, 2000n). DOE has concluded in its analysis (CRWMS M&O, 1999h) that about 1 percent of the total length of emplacement drifts to be located in the Topopah Spring Tuff (TSw2) Lower Lithophysal unit is expected to experience rockfall during the 10,000-year performance period and about 16 percent of the TSw2 nonlithophysal unit. About 75 percent to 80 percent of the WP will be emplaced in the TSw2 lower lithophysal unit.

The consequences of rockfall on various components of the EBS continue to be considered by DOE. Specifically, DOE is using FE based numerical analysis methods to assess the structural response of the drip shield and WP to rock block impacts. For example, a recent report pertaining to rockfall describes the current drip shield design and the FE modeling methodology used to perform the rock block impact simulation. Areas of interest addressed in this report include: (i) the assumed sizes and shapes of the impacting rock blocks, (ii) modeling of the drip shield and rock block material behavior, (iii) the individual FE types used to model the drip shield and rock block, (iv) the load and displacement boundary conditions employed within the analysis, and (v) the failure criterion used to assess the ability of the drip shield to withstand rock block impacts.

The rock block sizes and shapes used to impact the drip shield in the FE analysis were derived from fracture geometry data obtained from tunnel mapping in the ESF located at YM (CRWMS M&O, 2000f). Using the software program entitled UNWEDGE (Version 2.3), the rock block geometry is calculated using input data representing three fracture sets. The fracture set data were defined in the context of an assumed repository tunnel azimuth of 75 degrees.

Only a 3-m length section of the drip shield was modeled in the FE analysis. The justification given for modeling the drip shield in this manner was that the largest partial volume of the rock block occurs over a 3-m length. The report further states that:

> "For sizes of rock up to 4 MT, entire rock volume is located above the 3-m partial length of the drip shield. ... the increase in rock mass is by increase in length of the rock geometry along the emplacement drift rather than any increase in the rock block apex height. For approximately the same apex height (1.3 m) ... a 4 MT rock" will have "a total length of 4 m along the emplacement drift whereas ... a 52 MT rock mass" will have "a length of 40 m. ... Using the concept of effective rock mass over a 3-m partial-

length of drip shield, maximum rock mass is determined to be 10 MT per 3-m partial length of drip shield. In other words, an estimated maximum rock of 52 MT will load a 3-m partial-length of drip shield the same as a 10-MT rock, and for any rock mass over 52 MT a 3-m partial-length of drip shield will experience the same load as 10 MT."

The following table delineates the relationship of the actual rock mass with the effective partial-volume rock mass for the different rock sizes addressed in the DOE analysis of rockfall on the drip shield.

Table 3. Relationship between actual rock mass and effective rock mass

Actual Rock Mass (MT)	Effective Rock Mass Over a 3-m Length of Drip Shield (MT)
2.0	2.0
4.0	4.0
6.0	5.7
8.0	6.7
52.0	10.0

In expectation of the drip shield experiencing loads from the rock block impact that would cause plastic deformations, the drip shield materials (i.e., Titanium Grades 7 and 24) were modeled using bi-linear stress-strain curves. The material properties required to construct a bi-linear stress-strain curve are the yield stress, ultimate strength, Young's modulus, and minimum elongation. The actual material properties used for the two materials to construct these curves were derived from empirical data obtained at room temperature (i.e., approximately 20 °C).

The rock block material was assumed to respond to the impact load in a purely elastic manner. The rationale for this assumption was that the stresses experienced by the drip shield would be bounded if potential energy dissipation mechanisms of the rock block were not accounted for.

Shell and solid element formulations were used to model the drip shield and rock block, respectively.

Even though the drip shield is intended to be a free-standing structure (i.e., the base of the drip shield is not mechanically attached to the invert), the FE model employed boundary conditions that fixed the base of the drip shield to the invert. In other words, the base of the drip shield was not allowed to translate in any direction. No definitive information was provided regarding the constraints, if any, that were applied to the rotational degrees-of-freedom of the nodes at the base of the drip shield. The justification given for fixing the translational degrees-of-freedom was that the stresses experienced by the drip shield as a result of the rock block impact would be larger than the case of no constraints at all. No information was provided concerning the displacement boundary conditions applied at the ends of the 3-m section of the drip shield model.

The fall height of the rock block was estimated to be 2.3 m. Assuming no initial downward velocity for the rock block at the time it becomes dislodged, the velocity of the rock block at the time of impact with the drip shield was calculated to be 6.72 m/second.

A strain-based criterion was used to establish the structural failure of the drip shield. Specifically, "The failure of the drip shield is defined as the condition when the strain in the drip shield exceeds the failure strain (ductility), which results in rupturing of the material." No further information on the implementation of this failure criterion was provided.

Two different rock block and drip shield impact scenarios were investigated. In the first scenario, the rock block was centrally positioned above the drip shield such that impact would occur at the crest of the drip shield crown. The second scenario addressed the rock block impacting the side of the drip shield. Additional analyses considered the effects of increasing the drip shield side wall height by 0.2 m.

It was reported that:

> "The results of the finite element solutions indicate that no crack develops in the drip shield due to the dynamic impact of a rock on the drip shield for any of the rock sizes .... This is based on the steady-state drip shield configuration after the impact. The failure of drip shield structural components were specified by failure strain values equal to the material elongation values .... When the failure strain value is reached during the simulation, the corresponding elements are automatically removed from the FER. Since none of the elements were removed throughout the simulation, the failure strain is not exceeded in any of the components, and the drip shield is deemed to remain intact after the rockfall event."

No discussion was provided in the report detailing which components or types of strain measure were used in making this assessment.

The FE analysis results were also used to assess the potential for the initiation of SCC arising from the residual stresses developed as a consequence of the rock block impact. The results indicated that the drip shield may be susceptible to SCC. No discussion was provided in the report detailing which components or types of stress were used in making this assessment.

U.S. Nuclear Regulatory Commission Staff Evaluation

AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of mechanical disruption of EB components (MDEB) and other related abstractions in the TSPA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of MDEB that are important to waste isolation and includes the technical bases for these descriptions.

- DOE identifies the EB components (e.g., backfill, drip shield) that may: (i) mitigate the effects of mechanically disruptive events on WP performance or (ii) adversely affect WP performance. DOE sufficiently describes these influences and the technical bases provided for their inclusion or exclusion in the MDEB abstraction.

- DOE identifies the materials used in the construction of the WP and other relevant EB components. DOE defends the technical basis for including or excluding various behavioral characteristics and properties (e.g., corrosion, SCC, hydrogen embrittlement, fracture toughness, ultimate strength, etc.) of these materials in the MDEB abstraction in the DOE LA.

- DOE justifies the environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) included or excluded in the MDEB abstraction.

- DOE identifies pertinent design features and dimensions of the relevant EB components accounted for in the MDEB abstraction.

- DOE justifies the mechanically disruptive events considered in the development of the MDEB. DOE considers, at a minimum, seismicity, seismically induced rock fall, faulting, transient criticality, and igneous intrusion.

- DOE identifies the mechanical failure processes and concomitant failure criteria used for the individual EB components included in the MDEB abstraction. DOE defends the technical bases used to demonstrate that the failure processes and criteria are consistent with the material behavioral characteristics and anticipated loading conditions derived from the disruptive events.

- DOE justifies the TSPA models of seismicity, seismically induced rock fall, faulting, and igneous intrusion relies on consistent and appropriate assumptions throughout the TSPA abstraction process.

- DOE demonstrates the impact of internal pressure and temperature build-up on the integrity of the WP.

- DOE justifies the earthquake vibration effect on the EB and in particular the WP and its support (the invert).

- DOE considers appropriate components such as WP internal structures and WF (i.e., SNF matrix, cladding, structural support) that effect mechanical integrity under disruptive events.

STATUS: Open. DOE disruptive events FEPs screening analysis (CRWMS M&O, 2000e) has concluded that mechanical disruption of the WP due to rockfall will not be considered in the TSPA because of the presence of the drip shield and/or backfill. According to the *Engineered Barrier System Degradation, Flow, and Transport* PMR (CRWMS M&O, 2000c), Table 3-47, however, "...a design change prompted by thermal considerations, was initiated to remove backfill ...." Consequently, backfill needs to be removed from the screening arguments used by DOE as an EB component that will mitigate the effects of rockfall on the WP. In addition, backfill should no longer be used as justification for excluding rockfall effects as they pertain to the drip shield. The NRC staff does recognize that the presence of the drip shield will play a significant role in protecting the WP from rockfall. In the absence of backfill, however, the drip shield will be susceptible to extensive damage potential because of rock block impacts. Of particular concern is the continued ability of the drip shield to act as a water infiltration barrier once it has been damaged by falling rock blocks.

The NRC staff is also concerned that the use of the *Drift Degradation Analysis* (CRWMS M&O, 1999h) as a screening argument for excluding seismically induced rockfall from the TSPA code is premature and misrepresents the significance of the analysis results presented. For example, the areal coverage and sizes of the key blocks are reportedly quite small when the emplacements drifts are oriented at an azimuth of 75 degrees. This result is being independently verified by the NRC staff. The preliminary results indicated that the key block trace area (projected on the emplacement drift wall) to the emplacement drift surface area is about 1.4 to 2.2 percent for the TSw2 lower lithophysal unit. Although the drift length affected by rockfall was not specifically calculated, the trace plots of the key blocks show a much higher percentage than the 1.0 percent reported in the DOE *Drift Degradation Analysis* report (e.g., Figure 21). Consequently, the 1.0 percent value does not appear to be appropriate or conservative. Furthermore, in determining block sizes, the *Drift Degradation Analysis* report assumes that a joint surface is represented by a circular disc with a radius equal to twice the mapped trace length. This assumption may potentially underestimate the block size. Shorter joint length indicates less persistency; thus, the rock blocks will be bigger and their shapes will become more irregular, as shown in Goodman and Shi (1985). Consequently, the pyramid shape will be much less dominant as suggested in the DOE *Possible Rock Block Geometry, Dimension, Orientation, Probability, and Masses* report (CRWMS M&O, 2000f). A preliminary analysis indicates that a reduction of joint length to half could cause the maximum rock block size to increase by as much as 30 to 40 percent. In the *Drift Degradation Analysis* report, Monte Carlo simulations were used to model a 24.4-m-long tunnel in 3D space to generate rock blocks for conducting key block analysis. The use of a 24.4-m-long tunnel for analysis is not justified in the report. The complete dimension of the model domain is not given. The potential "boundary effect" is not discussed, either.

The effects of thermal load and long-term degradation of rock-mass was considered in the *Drift Degradation Analysis* report by reducing joint cohesion. The report indicates that time-dependent and thermal effects have a minor impact on rockfall. This finding is intuitive since the value used to represent joint cohesion is very small to start with. The report neglected the potential effects of reduction in joint friction angle.

Furthermore, the thermal stress induced in the rock-mass surrounding the emplacements drift could potentially fracture the intact rock and consequently cause additional rockfalls due to rock fracturing and subsequently increase the possibility for other rock blocks to fall. The *Drift Degradation Analysis* report does not take this aspect into consideration. The rock block size and potential emplacement drift affected by rockfall could increase if mapped trace length is used, and long-term and thermal effects on joint friction angle and intact rocks are factored into consideration. The concern regarding use of a pseudostatic approach to address seismic effect on rockfall using the key block analysis is discussed in Section 5.2.1.2 (*Change in Emplacement-Drift Geometry*, U.S. Department of Energy Approach subsection).

It does not appear that the *Drift Degradation Analysis* report considered potential joint sampling biases. Accurate characterization of fracture networks at YM requires that several important sampling biases common to fracture analyses be accounted for. If left uncorrected, these sampling biases could potentially lead to under-representation of fracture intensity, porosity, permeability, and connectivity and an incorrect statistical determination of dominant and subordinate fracture distributions. A detailed examination of sampling biases in the YM fracture data sets is given in the SDS IRSR Revision 2.0 (U.S. Nuclear Regulatory Commission, 1999). Some of the pertinent points are summarized in the following paragraph.

First, the lengths of the longest fractures in a population are often unconstrained because the ends of the fracture are obscured (blind). This bias can lead to underestimation of fracture connectivity. Second, the orientation of a one-dimensional sampling line (e.g., borehole or detailed line survey scan line) or two-dimensional sampling surface (e.g., pavement or road cut) inherently biases sampling against discontinuities parallel to the sampling line or surface, and in favor of sampling discontinuities at a high angle to the sampling line or surface. Mathematical corrections (e.g., Terzaghi, 1965) can partially compensate for this sampling bias. Third, because measuring every fracture from microscale to megascale is impractical or impossible for large sample areas, fracture studies usually have a size (e.g., length) cutoff. Fractures smaller than a given dimension are not counted. Consequently, small fractures are under-represented in fracture characterization. Exclusion of fractures less than 1-m from the ESF data set may lead to an incorrect interpretation of fracture intensity. For example, interpretations near faults such as the Ghost Dance fault in the ESF, where the1-m cutoff for trace length was used, leads to extremely variable fracture intensity estimates over a wide zone (Sweetkind, et al., 1997a,b).

DOE has indicated that the drip shield will be fabricated using Titanium Grades 7 and 24. The WP, according to the EDA-II design, will employ Alloy 22 for the outer barrier and stainless steel 316NG for the inner barrier of the WP.

In anticipation of loads that would cause the drip shield materials to exceed their respective yield stress limits, the drip shield materials were modeled using bi-linear stress-strain curves in the preliminary DOE analysis of rockfall on the drip shield (CRWMS M&O, 2000n). The material properties required to construct a bi-linear stress-strain curve are the yield stress, ultimate strength, Young's modulus, and minimum elongation. The actual material properties used for the two materials to construct these curves were derived from empirical data obtained at room temperature (i.e., approximately 20 °C). As tables 4 and 5 indicate, however, the mechanical material properties for Titanium Grade 7 are strongly dependent on temperature. In addition, note that the yield stress values for Titanium Grade 7 published in the 1995 and 1998 versions of the ASME Boiler and Pressure Vessel (B&PV) Code, Section II, Part D– Properties (American Society of Mechanical Engineers, 1995; 1998) are not in agreement.

The temperature-dependent values for the yield stress, ultimate strength, and Young's modulus of Titanium Grades 5 or 24 are not provided in the ASME B&PV Code. Note that the composition of Titanium Grades 5 and 24 are the same except that Grade 24 contains 0.04 to 0.08 percent palladium. As a result, it is expected that these two grades will exhibit similar mechanical behavior (i.e., mechanical properties). The *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures* (U.S. Department of Defense, 1998) and *Material Properties Handbook: Titanium Alloys* (American Society for Metals International, 1994) provide extensive material data for Titanium Grade 5. As Table 6 illustrates, the values for the yield stress, ultimate strength, and Young's modulus that were extracted from graphical data provided in the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures* (U.S. Department of Defense, 1998) are also strongly dependent on temperature. Even though Titanium Grade 5 exhibits much higher strengths than Titanium Grade 7, the relative effects of temperature are still significant and must be considered when assessing the ability of the drip shield to withstand rock block impacts.

Table 4. Relevant mechanical properties of Titanium/Grade 7 as a function of temperature according to the 1995 American Society of Mechanical Engineers Boiler and Pressure Vessel Code

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength† ksi (MPa)	Modulus of Elasticity‡ ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	—	15.5×10^3 (106.9)
200 (93)	32.2 (222.0)	—	15.0×10^3 (103.4)
300 (149)	25.2 (173.8)	—	14.6×10^3 (100.7)
400 (204)	18.6 (128.2)	—	14.0×10^3 (96.5)
500 (260)	14.1 (97.2)	—	13.3×10^3 (91.7)
600 (316)	11.4 (78.6)	—	12.6×10^3 (86.9)

* – 1995 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table Y-1.
† – No values published.
‡ – 1995 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table TM- 5.

Table 5. Relevant mechanical properties of Titanium/Grade 7 as a function of temperature according to the 1998 American Society of Mechanical Engineers Boiler and Pressure Vessel Code

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength† ksi (MPa)	Modulus of Elasticity‡ ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	50.0 (344.8)	15.5×10^3 (106.9)
200 (93)	40.0 (275.8)	43.6 (300.6)	15.0×10^3 (103.4)
300 (149)	40.0 (275.8)	36.2 (249.6)	14.6×10^3 (100.7)
400 (204)	40.0 (275.8)	30.9 (213.1)	14.0×10^3 (96.5)
500 (260)	40.0 (275.8)	26.6 (183.4)	13.3×10^3 (91.7)
600 (316)	40.0 (275.8)	22.8 (157.2)	12.6×10^3 (86.9)

* - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table Y-1.
† - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table U.
‡ - 1998 American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section II, Part D, Table TM-5.

Table 6. Relevant mechanical properties of Titanium/Grade 5 as a function of temperature.

Temperature °F (°C)	Yield Stress* ksi (MPa)	Ultimate Tensile Strength* ksi (MPa)	Modulus of Elasticity† ksi (GPa)
Room Temperature	120.0 (828.0)	130.0 (895.0)	16.9×10^3 (116.5)
200 (93)	105.6 (728.6)	118.3 (814.5)	16.2×10^3 (111.8)
300 (149)	94.8 (654.1)	109.2 (751.8)	15.5×10^3 (107.2)
400 (204)	85.2 (587.9)	101.4 (698.1)	14.9×10^3 (102.5)
500 (260)	78.0 (538.2)	96.2 (662.3)	14.4×10^3 (99.0)
600 (316)	74.4 (513.4)	93.6 (644.4)	13.7×10^3 (94.4)

* Room temperature reference value obtained from American Society for Testing and Materials B 265-98. Temperature correction factor extracted from Figure 5.4.1.1.1 of the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures.*
† Room temperature reference value obtained from Table 5.4.1.0(c_1) and the temperature correction factor extracted from Figure 5.4.1.1.4 of the *Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures.*

Because the potential reductions in yield stress and ultimate strength for Titanium Grades 7 and 24 as a result of elevated emplacement drift temperatures are significant, there is some concern by the NRC staff that these materials will also be susceptible to creep related failures arising from the support of dead loads (e.g., backfill and/or fallen rock blocks). Further justification for the staff concerns pertaining to creep failure of the drip shield materials can be found in *Fracture Mechanism Maps for Titanium and its Alloys* (Krishnamohanrao et al., 1986) and *Material Properties Handbook: Titanium Alloys* (American Society for Metals International, 1994). Consequently, DOE should provide the technical basis for excluding creep as a potential failure mechanism from the MDEB abstraction within its TSPA code.

No DOE analyses pertaining to the assessment of the new EDA II design for the WP when subjected to rockfall were available at the time this report was prepared. Specific aspects of the new WP design of interest to the NRC staff are (i) the potential loss of material ductility in the immediate area of the closure lid welds; (ii) the design provisions made to account for the significant difference in thermal expansion between the inner and outer barriers of the WP; and (iii) the failure criteria used to assess the structural integrity of the WP. Potential failure mechanisms related to rockfall include breaching of the WP barriers and SCC potential arising from the residual stresses attributable to rock block impacts.

AC2 Sufficient data (e.g., field, laboratory, and natural analog data) pertaining to the EB materials, mechanical failure processes, and the characterization of potential disruptive events are available to adequately define relevant parameters and conceptual models necessary for developing the MDEB abstraction in the TSPA. The data are also sufficient to assess the degree to which FEPs related to MDEB and which affect compliance with 10 CFR 63.113(b) have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these FEPs are adequate.

- DOE demonstrates that the data for mechanical failure models of the EB are based on laboratory measurements and tests designed to simulate or appropriately bound conditions that can be expected during a given mechanically disruptive event.

- DOE considers the effects of prolonged exposure to the expected emplacement drift environment (e.g., the effects of temperature, corrosion degradation, hydrogen embrittlement, radiation exposure, etc) in the constitutive models and their concomitant properties and failure criteria for the different EB component materials.

- DOE justifies that the use of material test results not specifically designed or performed for the YM repository program incorporates or appropriately bounds environmental conditions expected to prevail in the emplacement drift at the proposed YM repository.

- DOE demonstrates that sufficient data are presented to support the conceptual models, process-level models, and alternative conceptual models of mechanical disruption of MDEB.

- DOE identifies the data that support the technical bases for FEPs related to MDEB that have been included or excluded in the DOE LA.

- DOE demonstrates the effects design features and/or fabrication methods for the WP and other relevant EB components have on mechanical stresses and material properties. These effects may include, but are not limited to, residual stresses and/or structural flaws introduced during fabrication, stresses induced by differential thermal expansion, and material strain hardening.

- DOE adequately evaluates seismic source characterization, recurrence, and ground-motion attenuation. For example, DOE justifies seismic source data, including: (i) the geologic and tectonic settings of the site and region; (ii) local and regional faults (Type I faults); (iii) areal sources; (iv) the historic earthquake record; (v) fault slip rates, (vi) recurrence activity rates; (vii) clustered events; and (viii) earthquake and strong motion data used to develop ground-motion attenuation models, are geologically consistent and reasonable, compatible with current understanding of the YM tectonic framework, and adequate to support the TSPA abstraction of MDEB, such that reasonable projections can be made of future YM seismic activity.

- DOE adequately evaluates rock block sizes, contact surface geometry of the rock, and relative impact velocities between the rock block and EB components. For example, DOE's interpretations of rock block size from surficial and underground mapping and geophysical or analog investigations are geologically consistent and reasonable, are compatible with current understanding of the YM joint spacing and orientation framework, and are adequate to support conceptual models, attendant assumptions, and boundary conditions such that reasonable projections can be made on how future rock fall within the emplacement drifts will affect EB integrity.

STATUS: Open. The mechanical properties of Titanium Grades 7 and 24 have a significant influence on the overall structural behavior of the drip shield. Specific mechanical properties of interest include yield stress, ultimate strength, Young's modulus, minimum elongation, and creep rate. These same mechanical properties are dependent on temperature and these temperature effects should be accounted for in the design analyses. Given the lack of consistency and/or absence of published data for Titanium Grades 7 and 24, independently qualified tests may have to be conducted to establish the variability of these mechanical properties over the temperature range expected to exist within the proposed repository emplacement drifts.

No discussion was provided in the *Rock Fall on Drip Shield* report detailing which components or types of strain measure were used in concluding that "... no crack develops in the drip shield due to the dynamic impact of a rock on the drip shield for any of the rock sizes ...." For generalized three-dimensional stress states, failure criteria are typically based on maximum shear stress, octahedral shear stress, Von Mises stress, or strain-energy density. These measures are used because they can be readily employed to discern failure when complex stress states exist using data derived from simple tension tests.

FE analysis results were used to assess the potential for the initiation of SCC in the drip shield arising from the residual stresses developed as a consequence of the rock block impact. The results indicated that the drip shield may be susceptible to SCC. No discussion was provided in the report detailing which components or types of stress were used in making this assessment. As pointed out in the *Threshold Stress Level for Initiation of Stress Corrosion Cracking (SCC) in Alloy 22, Ti Gr7 and Ti Gr24* (CRWMS, M&O, 2000g),

> "...no experimental test results on SCC initiation stress threshold (IST) values are available for any of the corrosion-resistant alloys selected for the drip shield (Ti Gr7 and Ti Gr 24) and for the waste package (Alloy 22 and 316NG) under expected bounding waste package/drip shield surface environments and temperatures. ...However, a review of the literature indicates that SCC IST evaluation test results obtained in boiling magnesium chloride solutions performed in accordance with ASTM G36 or similar test procedures are very likely lower bound values as compared to the range of IST values expected in bounding waste package/drip shield surface environments. Consequently, the lower bound IST values obtained in boiling magnesium chloride tests reported in the literature for similar classes of alloys should be conservatively used for design and PA [Performance Assessment] purposes until directly measured alloy/environment relevant IST values are generated in currently planned test programs. In particular, IST values of 20 to 30 percent of room temperature yield stress (reported for stainless steels Types 304, 304L, and 316) will be used for the subject drip shield alloys (Ti Grade 7 and Ti Gr24) and waste package alloys (Alloy 22, 316NG) for design and PA purposes. This lower bound ITS range is assumed to be uniformly distributed between 20 and 30 percent of room temperature yield stress"

Although a literature search pertaining to IST values for SCC was apparently conducted, no supporting references were cited in the report to justify the assumption that the lower bound IST range is uniformly distributed between 20 and 30 percent of room temperature yield stress. Moreover, there was no information provided that addresses the recommended procedure for how generalized 3D stress states obtained from engineering analyses should be interpreted to properly determine whether the 20 to 30 percent of yield stress criterion for IST has been exceeded. In other words, should the Von Mises or first principle stress be used for comparison with the 20 to 30 percent of yield stress criterion. In addition, given the significant reduction in yield stress for Titanium Grades 7 and 24 at emplacement drift temperatures relative to the values at room temperature, the assumed IST criterion does not appear to be conservative or technically defendable.

AC3 Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of MDEB are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the TSPA abstraction are provided.

- DOE justifies the process-level models used to determine corrosion-dependent parameter values that define the relevant behavioral characteristics and properties (e.g., SCC, hydrogen embrittlement, fracture toughness, ultimate tensile strength, etc.) of the materials of the EB components considered important to waste isolation and susceptible to mechanical disruptions. DOE adequately defines a range of variations for these parameter values that accounts for the effects of and uncertainties associated with fabrication flaws, accumulated damage caused by multiple disruptive events, and the temporal and spatial changes in the emplacement drift environment (e.g., temperature, redox conditions, pH, chemical composition of water contacting the relevant EBs, etc.). These variations: (i) have been incorporated into the MDEB abstraction such that the model will not underestimate the failure of the relevant EB components subjected to mechanically disruptive events and (ii) are consistent with the requirements of the CLST KTI IRSR (U.S. Nuclear Regulatory Commission, 2000).

- DOE justifies, through appropriate methods for nondestructive examination of fabricated EB, the type, size, and location of fabrication defects that may lead to premature failure as a result of rapidly initiated EB degradation. The parameter values used in the analysis are consistent with the results of the nondestructive examination. DOE considers these defect when evaluating rock fall.

- DOE addresses, through appropriate sensitivity analyses or conservatively chosen bounds, uncertainty and variability in the relevant EB component corrosion models and their effects on the response of the EB component to mechanically disruptive events.

- DOE justifies the process-level models used to represent seismic conditions within the emplacement drifts at the proposed YM repository. DOE parameter values are adequately constrained by YM seismicity data such that the effects of seismicity on EB integrity are not underestimated. DOE identifies parameters within conceptual models for seismicity are consistent with the range of seismicity characteristics observed at YM.

- DOE's seismicity model parameters account for variability in data precision and accuracy. For example, DOE adequately accounts for uncertainty and verified parameter distributions of (i) maximum magnitude, (ii) depth of seismogenic crust, (iii) earthquake recurrence or activity rates, (iv) fault recurrence and dip, (v) wave propagation characteristics between earthquake sources and the YM site, and (vi) empirical and theoretical factors controlling directivity and other near-field effects.

- DOE identifies the seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the repository design criteria and TSPA.

- DOE demonstrates with adequate consideration of associated uncertainties that the size distribution of rocks that may potentially fall on the WP and other relevant EB components is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions).

- DOE appropriately establishes that possible correlations between parameters are included in the TSPA abstraction.

- Where sufficient data do not exist, the definition of parameter values and conceptual models are based on appropriate use of other sources such as expert elicitation conducted in accordance with appropriate guidance such as NUREG–1563.

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

AC4 Alternative modeling approaches consistent with available data and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of MDEB. DOE has provided sufficient evidence that ACMs of FEPs have been considered, that the models are consistent with available data (e.g., field, laboratory, and natural analog) and current scientific understanding, and that the effect of these ACMs on TSPA has been evaluated.

- DOE adequately considers the temporal and spatial variations of parameters relevant to the response of the EBs to mechanically disruptive events (e.g., fracture toughness, dimensional changes, residual stresses, and SCC).

- DOE investigates alternative modeling approaches for seismicity, such as recurrence relationships or ground-motion attenuation relationships. For example, DOE models adequately considers uncertainties in: (i) geologic and tectonic conditions, (ii) seismic activity of independent and clustered events, (iii) recurrence-magnitude models, or (iv) ground-motion attenuation models.

- DOE identifies alternative conceptual models for seismically induced rockfall on theWP and other relevant EBs. DOE demonstrates that the analytical models used in the estimation of impact load due to rock fall on the WP and other relevant EB components are: (i) based on reasonable assumptions and site data, (ii) consistent with the underground facility (e.g., emplacement drift geometry and backfill) and EB component designs, and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses. DOE considers the rock fall analyses, as functions of ground-motions: (i) the possibility of multiple blocks falling onto the EBs simultaneously and (ii) the extent of the potential rock-fall area around the individual emplacement drifts and the entire repository. Within the rockfall dynamic analyses, DOE considers the TM effect and time-dependent jointed rock behavior and provides the background conditions on which seismic loads are superimposed.

STATUS: Not reviewed at this time. Materials related to this AC will be reviewed and the results documented in subsequent revisions. For evaluation of the last item of this AC, refer to the discussion provided for AC1.

AC5 Output from the TSPA abstraction of the degradation of EB is justified through comparison with output from detailed process-level models and empirical observations arising from laboratory tests and field measurements.

- DOE defends modeling results for MDEB by seismicity by comparison to output from detailed process-level models, empirical observations, or both. DOE demonstrates that results of assessments of the seismic disruption of the WP and other relevant EB components used in TSPA models were verified against results from empirical observations (including appropriate analogs). DOE appropriately adopts acceptable and documented procedures to construct and test empirical and physical models used to estimate the seismic hazard. DOE defends the effectiveness of proposed models in quantifying ground-motion at YM as it relates to earthquake-induced rock fall and repository performance.

- DOE justifies the output from the abstraction of the effect of seismically induced rock fall on the WP and other relevant EB components, and compares the results with a combination of corrosion degradation, rock block size and shape, impact velocities, and temperature adjusted EB component material characterizations. DOE identifies detailed models of mechanical failure to evaluate the PA abstractions of MDEBs.

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

5.2.1.1.1 Acceptance Criterion 1

Approved QA and control procedures and standards were applied to collection, development and documentation of data, methods, models, and codes. The M&O Contractor periodically conducts performance-based audits and surveillance on various activities related to repository PA. NRC staff will defer the determination of compliance with this acceptance criterion until the relevant audit is conducted.

5.2.1.1.2 Acceptance Criterion 2

If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable approaches. Expert elicitations have been used in developing probabilistic seismic hazard data. These data have been used in the TBD for determining damage level (see also Section 3.3.3.1). The report for developing the probabilistic seismic hazard data is available. In FY2000, the RDTME KTI will review the process the expert elicitation implemented, in conjunction with the Structural Deformation and Seismicity KTI to determine if acceptable guidelines have been followed.

5.2.1.1.3 Acceptance Criterion 3

The seismic hazard inputs used to estimate rockfall potential are consistent with the inputs used in the design and PAs as established in DOE's TR–3 reviewed and accepted by NRC. As discussed in Section 3.3.3.1 of this IRSR, M&O used the annual probability of exceedence curve for horizontal *PGV* from the Probability Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada, Final Report, Volume 1, Text, based on the June 15, 1998, version in its TBD for rockfall assessment. This report has been subsequently revised and published on September 23, 1998. As a result, the annual probability of exceedence curve for horizontal *PGV* is substantially different in shape and annual probability. The new curve appears to produce higher *PGVs* than the one used in the TBD. The effect of the revised curve on WP damage needs to be evaluated.

5.2.1.1.4 Acceptance Criterion 4

Size distribution of rocks that may potentially fall on the WPs is estimated from site-specific data (e.g., distribution of joint patterns, spacing, and orientation in three dimensions) with adequate consideration of associated uncertainties. The distribution of rock block sizes determined in a CRWMS M&O report (1997i), based on the joint spacings obtained from the scanline mapping in the ESF, was used in the TBD to assess rockfall effects on WP disturbance. The rock block size was estimated using the approach suggested by Palmstrøm (1996). This approach has not been verified by the M&O.

In a TSPA Disruptive Events Workshop held February 9–11, 1999, in Albuquerque, New Mexico, it was proposed to refine the rockfall model in two areas: (i) determination of rock size distribution and relationship between seismicity and size of rockfall using the Key Block theory; and (ii) reassessment of rockfall effects on WP damage. The first proposed work item will attempt to determine available rock block size using a probabilistic Key Block theory. The NRC staff will continue to evaluate the approach adopted for rock size determination and the results generated as these become available.

5.2.1.1.5 Acceptance Criterion 5

The analytical model used in the estimation of impact load due to rockfall on the WP is: (i) based on reasonable assumptions and site data; (ii) consistent with the underground facility (emplacement drift geometry and backfill) and WP designs; and (iii) defensible with respect to providing realistic or bounding estimates of impact loads and stresses. The M&O rockfall model uses a WP damage criterion that links it to the rock size necessary to cause damages. This rock size was estimated by dynamically modeling the rockfall impact on WPs considering various stages of WP corrosion (CRWMS M&O, 1996a,b). In general, this approach is acceptable. However, there are a few concerns (Section 4.3.4.2) that need to be addressed.

The DOE model implicitly includes the possibility of repeated rockfalls at the same location by assuming that rockfalls will not cover up the WPs to protect them from further direct rockfall impact (CRWMS M&O, 1998d, Section 10.5.1). In its report, the M&O (1998d, Section 10.5.1) concluded that because of this implicit assumption, the DOE model encompasses the worst case condition. This assumption does not represent the worst case, however, because the distance the rocks fall is set to be from the drift ceiling to the WP (fall height)—approximately 3.5 m based on the reference design—for all the rockfalls that may occur at the same location (U.S. Department of Energy, 1998g, Section 4.4.3.1, Volume 3). The fall height for the first rockfall is 3.5 m based on the reference design; however, the fall height for the subsequent rockfalls at the same location should be greater than 3.5 m. For a given block size, the greater the fall height the more damage to the WP because the energy associated with the rock is higher. If the extent of the first rockfall is not sufficient to cover the WP, the potential effect of the second rockfall at the same location on WP damage needs to be assessed. In this regard, the critical rock size developed from the dynamic analysis as presented in the two M&O reports (CRWMS M&O, 1996a,b) is not appropriate for this assessment. Assuming the fall height is the same for subsequent rockfalls at the same location is not conservative in assessing WP damage.

The Enhanced Alterative Design No. 2 is currently under consideration to replace the TSPA-VA design. The WP damage criterion for assessing the effect of seismic activity should take into account this new design. The new design includes a 2-cm thick titanium drip shield and a thinner WP. The new design for the WP involves a 2-cm Alloy 22 outer barrier and a 5-cm A316 steel inner barrier. The total thickness of the new WP is 5 cm thinner than that proposed in the TSPA-VA. If designed properly, the drip shield may be able to withstand rockfall impact and thus delay or eliminate rockfall damage on WPs.

5.2.1.1.6 Acceptance Criterion 6

The TM analyses that provide the background conditions on which seismic loads are superimposed consider time-dependent jointed rock behavior. The TSPA-VA rockfall model does not consider the potential effect of time-dependent jointed rock behavior that will likely make the rockfall scenario more plausible than the *DL* approach adopted.

As discussed in Section 5.3.2.4, M&O plans to completely rework the rockfall model. This includes: (i) determination of rock size distribution and relationship between seismicity and size of rockfall using the Key Block theory; and (ii) reassessment of rockfall effects on WP damage. The first proposed work item attempts to associate the Key Block analysis with the thermal and seismic conditions expected in the emplacement horizon. In conducting this work, staff expects that the time-dependent jointed rock behavior also should be taken into consideration by M&O. The NRC staff will review the results of this work as they become available.

5.2.1.1.7 Acceptance Criterion 7

Rockfall analyses consider, in a rational and realistic way through dynamic analyses, the possibility of multiple blocks falling onto a WP simultaneously, and the extent of the potential rockfall area around an individual emplacement drift as well as over the entire repository as functions of ground-motions. A recent study showed that variability in joint patterns (mainly joint trend and plunge) appears to have a controlling effect on the potential and amount of rockfall (Chen, 1999). For a given rock type, the potential for rockfall is the smallest for a constant joint pattern (i.e., one without variations in joint trend and plunge). When variations are considered, the likelihood and extent of the rockfall and the number of multiple coherent rock blocks that can fall increase as the variability of joint patterns increases (Chen, 1999). The potential for rock blocks located one above the other to fall in unison (as opposed to individual rocks) will increase the "effective" size of rockfalls that hit the WPs. As a result, WPs will be damaged more severely and possibly experience earlier failures—a condition that could induce earlier, higher, or both doses at receptor locations. Both DOE (CRWMS M&O, 1998d) and NRC (1998) rockfall models recognize the effect of rock size on performance. As a general rule, the larger the rock block, the more damage it will cause the WPs. Consequently, mechanisms that may increase the "effective rock size" should be considered in the model.

5.2.1.2 Thermal-Mechanical Effects on Flow into Emplacement Drifts

TM Effects on Repository Performance address three aspects of DOE's PA abstractions change in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading; and (iii) the characterization of repository thermal loading and ventilation. The following PA abstractions are affected by these three concerns:

- Degradation of EBs
- Quantity and Chemistry of Water Contacting WP and WF
- Spatial and Temporal Distribution of Flow

~~This component of the Subissue on TM Effects on Repository Design and Performance relates to the determination if TM effects have been considered properly in the PA. Resolution of this component will be through the application of the acceptance criteria defined in Section 4.3.5.1 of this IRSR.~~

U.S. Department of Energy Approach

Change in Emplacement-Drift Geometry

DOE is likely to rely on analyses documented in the *Drift Degradation Analysis* report (CRWMS M&O, 1999h) for the prediction of potential changes in emplacement-drift geometry. The AMR defined its objective as: (i) to provide a statistical description of block sizes formed by fractures around the emplacement drifts; (ii) to estimate changes in drift profiles resulting from progressive deterioration of the emplacement drifts both with and without backfill, and (iii) to provide an estimate of the time required for significant drift deterioration to occur.

The analyses reported in the AMR were conducted using a computer code DRKBA (Stone Mineral Ventures, Inc., 1998), which is based on a statistical analysis of fracture networks to determine the occurrence of key blocks (i.e., the rock blocks that would have to fall before their neighboring blocks can fall) and calculates the factor of safety against the fall of key blocks under their own weight. The only driving force in the code (i.e., the force that may cause a key block to fall) is gravity. Resistance against block fall is provided by the shear strength of the fracture surfaces that define the key block.

The DRKBA code has no mechanism for the analysis of distributed internal forces such as are associated with thermal and seismic loadings. The AMR stated that thermal and seismic loadings were incorporated in the analyses through reductions of the shear strength of fracture surfaces. The procedure of accounting for thermal and seismic loadings through fracture-strength reductions is, however, inadequate for the following reasons.

- A key characteristic of thermal and seismic loading is that they generate distributed internal forces with varying orientations and magnitudes, such that the geomechanical response of a rock mass to thermal or seismic loading depends partly on the stress-strain response of the rock blocks and partly on the response of fracture surfaces. A code such as DRKBA that is based on the kinematic modeling of rigid blocks separated by fractures is not able to account for the stress-strain response of rock blocks and, consequently, is not appropriate for modeling the geomechanical response of a rock mass to thermal or seismic loading.

- Because the only driving force in the DRKBA code is vertical, the strength-reduction approach can only affect movement on vertical and near-vertical fracture planes. Block movements that may be caused by slip on subhorizontal fractures cannot be detected by the analysis procedure. Analyses conducted by other investigators using numerical codes based on stress analysis (e.g., Chen, et al., 2000; Ofoegbu, 2000) indicate that slip on subhorizontal fractures may be a predominant aspect of geomechanical response at YM because of the anticipated horizontal orientation of the maximum principal compressive stress during the thermal regime (e.g., Section 4.1.3.1).

Consequently, the analyses presented in the *Drift Degradation Analysis* report (CRWMS M&O, 1999h) are not capable of leading to any conclusion on the second and third objectives defined in the report. The first objective of the analysis, that is, providing a statistical description of block sizes formed by fractures around the emplacement drifts, can possibly be satisfied using the DRKBA code, depending on evaluations in Section 5.2.1.1, but the code is not appropriate for estimating potential changes in emplacement-drift geometry owing to thermal and seismic loading.

CRWMS M&O (CRWMS M&O, 2000h,i) proposed a procedure for incorporating drift-geometry changes in drift-seepage abstraction, but at the same time argued that only a small percentage of the emplacement drifts would be expected to experience significant changes in geometry. The conclusion regarding the percentage of drifts that may experience significant geometry changes was taken from the *Drift Degradation Analysis* report, which, as discussed earlier, is not capable of providing a technical basis for such a conclusion.

Change in Rock-Mass Hydrological Properties

The DOE approach to evaluating TM-induced hydrological-property changes is summarized in a statement, presented at the April 2000 DOE/NRC Technical Exchange, that "thermal loading will produce negligible changes in rock hydrologic properties."[7] This conclusion is based on an analysis by Blair (in Hardin, 1998) and numerical modeling by Berge et al. (1998, 1999), from which it was concluded that: (i) slip on a single vertical-fracture set can cause the permeability of the set to increase by a factor of two or less and (ii) if slip occurs simultaneously on two orthogonal sets of vertical fractures, the permeability of the sets can increase by a factor of four or less. As argued in Ofoegbu (2000), this suggested upperbound for thermally induced permeability increase is incorrect, having been calculated from an assumption that the magnitude of thermally induced slip on a given fracture is equal to the preexisting (i.e., before thermal loading) slip on the same fracture. No justification was offered for the assumption [Blair (in Hardin, 1998); Berge et al., 1998; 1999)]. In fact, there is no reason at all to expect a relationship between preexisting slip and thermally induced slip.

In contrast to the DOE position, information presented in Ofoegbu (2000) indicates that: (i) rock-mass permeabilities near the repository horizon can be expected to increase within laterally discontinuous zones centered at the emplacement drifts and in the middle of pillars, owing to fracture dilation associated with geomechanical response to thermal loading; (ii) the magnitude of permeability increase can be expected to greatly exceed the upper bound suggested by DOE and would be greater around the drift openings than in the pillars; (iii) the magnitudes would depend on thermal loading, rock-mass mechanical properties, and time-dependent mechanical degradation; (iv) altered zones characterized by horizontal-fracture dilation in areas of high rock-mass quality and vertical-fracture dilation in areas of low rock-mass quality can be expected, but fracture closure from thermally induced stresses is likely to be small and insignificant to rock-mass permeability; and (v) lateral flow of moisture can be expected in the altered zones and would result in elevated vertical percolation flux within and at the downstream end of the altered zones.

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[7]Barr, D. *Thermal Effects on Flow. Presentation at DOE/NRC Technical Exchange on Yucca Mountain Pre-Licensing Issues.* Las Vegas, NV: U.S. Department of Energy, Yucca Mountain Site Characterization Office. April 2000.

Characterization of Repository Thermal Loading and Ventilation

This aspect of DOE's PA abstractions deals with thermal-load characterization of the emplaced nuclear waste, representation of thermal loading and ventilation in PA abstractions, and analysis to demonstrate that the ventilation design would remove the amount of heat assumed in PA abstractions.

A characterization of thermal loading for the proposed EDA II design concept is documented in a calculation report (CRWMS M&O, 2000j) that has not been reviewed by NRC.

Process level models that develop input information for TH abstractions (CRWMS M&O, 2000k) make an assumption that 70 percent of the waste-generated heat during the first 50 year would be removed by ventilation. The process level models implement this assumption by using only 30 percent of waste-generated heat as input thermal load during the first 50 years and 100 percent of the waste-generated heat thereafter (CRWMS M&O, 2000k). The procedure of using only 30 percent of the waste-generated heat (assuming that 70 percent of the heat is removed by ventilation) would satisfy the total energy balance of the repository control volume. The calculated temperatures within the repository volume are, however, likely to be incorrect, because the temperature gradients that drive heat transfer (by conduction, convection, and radiation) cannot be represented satisfactorily by using only 30 percent of the heat source. Heat transfer by radiation from the WP to the drift wall would be represented incorrectly using this procedure, possibly resulting in underestimation of the drift-wall and pillar temperatures.

Analyses to demonstrate that the proposed ventilation design would remove 70 percent of the waste-generated heat during the ventilation period are documented in the *Ventilation Model* report (CRWMS M&O, 1999g). The analyses are based on a combination of two-dimensional finite-element modeling for heat transfer in drift-normal planes, and spreadsheet calculations for heat transfer along the drift. The spreadsheet calculations use an explicit incrementation algorithm to advance the solution process in time and spatially along the drift. The conditions for numerical stability of the incrementation algorithm, which would define allowable limits for the time and drift-length increments, were not investigated. Furthermore, the algorithm did not use a predictor-corrector scheme to ensure consistency of corresponding estimates of drift-wall, air, and WP temperatures. These omissions from the algorithm raised a concern that the calculated drift-wall, air, and WP temperatures, and, consequently the predicted amounts of heat removal by ventilation, might not be correct. The concern was heightened by the results of calculations performed by CNWRA to check the consistency of the air and drift-wall temperatures given in the *Ventilation Model* report. The two sets of temperatures were found to be inconsistent: the drift-wall temperatures were not reproduced by analyses that used the air temperatures as input.

U.S. Nuclear Regulatory Commission Staff Evaluation

Degradation of Engineered Barriers

AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of degradation of EBs and other related abstractions in the TSPA, and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes design features of the EBS and aspects of the degradation of EBs that are important to waste isolation and includes the technical bases for these descriptions.

- DOE: (i) considers the effects of TM processes and thermohydrologic processes on the EB environment, taking into account heterogeneities such as joints and faults; (ii) bounds the range of thermally driven flux; and (iii) considers the possibility of water reflux during cool-down.

- DOE considers the effects of TM processes on ground movement (including rock fall, rock deformation, and alterations to porosity and existing fractures) and changes to the drift geometry that may affect the EB chemical environment.

- DOE's thermohydrologic models used to assess the effects of evaporation, thermally driven flow, and groundwater condensation on the EB environment include significant repository design features and evaluate the following potential thermohydrologic phenomena: (i) multidrift dry-out zone coalescence, (ii) lateral movement of condensate, (iii) cold-trap effect, (iv) repository edge effects, and (v) condensate drainage through fractures.

Status: Open. Change in emplacement-drift geometry (from roof and side-wall collapse and floor heave) is screened out from the abstraction of degradation of EBs (CRWMS M&O, 2000l) based on conclusions from the *Drift Degradation Analysis* report (CRWMS M&O, 1999i). The *Drift Degradation Analysis* report is, however, incapable of drawing conclusions regarding the long-term geometry of emplacement drifts because thermal and seismic loadings are not considered satisfactorily in the analyses. Therefore, the conclusions from the report cannot be used as a basis to screen out TM processes from the abstraction of degradation of EBs.

TM-induced change in hydrological properties are included in the abstraction of degradation of EBs through changes in the drift-seepage flux. Therefore, the treatment of TM effects on hydrological properties is evaluated as part of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms (CRWMS M&O, 2000l).

The assessment of TH effects on the EB environment is documented in a CRWMS M&O report (CRWMS M&O, 1999i), which ignored the first 50 or 100 years of thermal loading in the calculations. This report did not explain how the distributions of temperature, saturation, and relative humidity at 50 or 100 years (i.e., the initial conditions used in the analyses) were obtained without considering thermal loading during the earlier period (of 50 or 100 year). The thermal-load characterization of the emplaced waste and ventilation are significant design features that need to be considered in the assessment of TH effects on the EB environment.

Quantity and Chemistry of Water Contacting WPs and WFs

AC1 Important design features, physical phenomena and couplings, and consistent and appropriate assumptions have been identified and described sufficiently for incorporation into the abstraction of the quantity and chemistry of water contacting WP and WF in the PA and other related abstractions in the TSPA, and the technical bases are provided. The features, phenomena and couplings, and assumptions used to abstract the quantity and chemistry of water contacting WP and WF have been provided. The TSPA abstraction is consistent with the identification and description of those aspects of the quantity and chemistry of water contacting WP and WF that are important to waste isolation. The TSPA abstraction is also consistent with the technical bases for these descriptions of barriers important to waste isolation. Specifically:

- DOE evaluates the potential for focusing of water flow into drifts caused by coupled THMC processes.

- DOE abstractions, including dimensionality of the abstractions, appropriately account for the various design features, site characteristics, and alternative conceptual approaches.

- DOE spatial and temporal abstractions appropriately address the physical couplings (thermal-hydrologic-mechanical-chemical).

- DOE provides the bases and justification for modeling assumptions and approximations where simplifications for modeling coupled THMC effects on seepage and flow and the WP chemical environment are used for PA.

- DOE provides adequate technical bases, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for exclusion of any THMC couplings and FEPs.

- DOE uses important design features, including WP design and material selection, backfill, drip shield, ground support, cladding, thermal loading strategy, and degradation processes, to determine the initial and boundary conditions for calculations of the quantity and chemistry of water contacting WP and WF.

Status: Open. CRWMS M&O (CRWMS M&O, 2000h,i) proposed an approach based on drift surface area for including drift-geometry changes in the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms. The long-term emplacement-drift geometry required as input to the abstraction needs to be estimated using a procedure that accounts for the rock-mass geomechanical response to thermal and seismic loading. The *Drift Degradation Analysis* report (CRWMS M&O, 1999h) is unable to provide this information because the analyses did not consider thermal and seismic loadings satisfactorily.

TM effects on hydrological properties are screened out of the abstraction of Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms for two reasons (CRWMS M&O, 2000k): First, TM effects on fracture permeability were considered to be small based on the Berge, et al. (1998) analyses (see *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach of this section). The upper bound permeability increase suggested by Berge, et al., (1998) is, however, too small and can be exceeded as discussed in Section 5.2.1.2 in *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach subsection. Second, analyses presented by CRWMS M&O (2000h) indicate that an increase in fracture permeability would result in decreased water flow into emplacement drifts. Alternative model calculations summarized in the *Change in Rock-Mass Hydrological Properties*, U.S. Department of Energy Approach subsection of this section (Ofoegbu, 2000; Ofoegbu et al., 2000), however, indicate that lateral flow of moisture can be expected within a TM-altered zone and would cause increased vertical percolation flux and, therefore, drift seepage, at the downstream end of the altered zone. One difference between the two studies that may explain the divergence in the findings relates to the change in capillarity associated with a change in fracture aperture. In the study conducted by CRWMS M&O (2000h), a two-fold increase in fracture aperture (ten-fold increase in fracture permeability) was combined with a ten-fold decrease in capillarity, which effectively caused the altered zone to function as a capillary barrier. On the other hand, a change in capillarity was not applied in the alternative study (Ofoegbu, 2000;

Ofoegbu et al., 2000) in which an increase in fracture aperture by a factor of up to 10 was applied. DOE needs to provide the technical bases for the parameter values used to assess the effects of TM-altered hydrological properties on the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms.

As discussed previously (in the *Characterization of Repository Thermal Loading and Ventilation*, U.S. Department of Energy Approach subsection of Section 5.2.1.2), process level models that develop input information for the abstraction of the Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms implement preclosure ventilation by using only 30 percent of waste-generated heat as input thermal load during the first 50 years after waste emplacement. Thereafter, the models use 100 percent of the waste-generated heat (CRWMS M&O, 2000k). To justify this representation of ventilation, DOE needs to demonstrate that: (i) the ventilation design would actually remove 70 percent of the waste-generated heat during the ventilation period, and (ii) the temperature distributions calculated using 30 percent of the heat source adequately represent the temperature distributions that would be calculated using 100 percent of the heat source with a proper representation of the ventilation design.

AC2 Sufficient data on design features (including drip shield, backfill, WP, cladding, other EB components, and thermal loading), geology, hydrology, geochemistry, and geomechanics of the unsaturated zone and drift environment (e.g., field, laboratory, and natural analog data) are available to adequately define relevant parameters and conceptual models necessary for developing the abstraction of the quantity and chemistry of water contacting WP and WF in the TSPA. The data are also sufficient to assess the degree to which FEPs related to the quantity and chemistry of water contacting WP and WF and which affect compliance with post-closure performance objectives have been characterized and to determine whether the technical bases provided for inclusion or exclusion of these FEPs are adequate. Where adequate data do not exist, other information sources such as expert elicitation have been appropriately incorporated into the abstraction process. Specifically:

- DOE demonstrates that sufficient data were collected on the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, to establish initial and boundary conditions, including temporal and spatial variations in conditions, for conceptual models and simulations of thermal-hydrologic-mechanical-chemical coupled processes that affect seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

Status: Open. There are unresolved issues regarding data used to define potential changes in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading, and (iii) the characterization of repository thermal loading and ventilation. The information needed to resolve these issues is discussed in Sections 4.1.3.1 and 5.1.4.2 (under **AC5** of *Design of Subsurface Facilities* component).

AC3 Parameter values, assumed ranges, probability distributions, and bounding assumptions used in the TSPA abstraction of quantity and chemistry of water contacting WP and WF, such as the pH, chloride concentration, and amount of water flowing in and out of the breached WP, are consistent with site characterization data, design data, laboratory experiments, field measurements, and natural analog data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the TSPA abstraction are provided. Specifically,

- DOE demonstrates that input values used in the quantity and chemistry of water contacting EBs (e.g., drip shield, WP, and cladding) calculations in TSPA are consistent with the initial and boundary conditions and the assumptions of the conceptual models and design concepts for the YM site, such as WP and EBS design (including backfill, drip shield, ground support, and cladding), WP degradation (corrosion and mechanical disruption), cladding degradation, deep percolation flux, important thermal-hydrologic-mechanical-chemical coupling effects, the thermal reflux model, the thermal loading strategy (including effects of ventilation), natural system masses and fluxes, and other design features that may affect performance.

- DOE establishes that reasonable or conservative ranges of parameters or functional relations are used to determine effects of coupled thermal-hydrologic-mechanical-chemical processes on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release.

- DOE shows that the parameters used to define initial conditions, boundary conditions, and computational domain used in sensitivity analyses involving coupled THMC effects on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release, are consistent with available data.

- DOE adequately considers the uncertainties in the characteristics of the natural system and engineered materials, such as the type, quantity, and reactivity of material, in establishing initial and boundary conditions for conceptual models and simulations of THMC coupled processes that affect seepage and flow and the WP chemical environment, as well as the chemical environment for radionuclide release.

Status: Open. There are unresolved issues regarding data used to define potential changes in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loading, and (iii) the characterization of repository thermal loading and ventilation. The information needed to resolve these issues is discussed in Sections 4.1.3.1 and 5.1.4.2 (**AC5** *of Design of Subsurface Facilities* component).

AC4 Alternative modeling approaches consistent with available data (e.g., design features, field, laboratory, and natural analog) and current scientific understanding are investigated and results and limitations are appropriately factored into the abstraction of quantity and chemistry of water contacting WP and WF. DOE has provided sufficient evidence that alternative conceptual models of FEPs have been considered, that the models are consistent with available data and current scientific understanding, and that the effect of these alternative conceptual models on TSPA has been evaluated. Specifically:

- DOE adequately considers the effects of THMC coupled processes that may occur in the natural setting or due to interactions with engineered materials or their alteration products in their assessment of alternative conceptual models. DOE considers: (i) thermohydrologic effects on gas and water chemistry; (ii) hydrothermally driven geochemical reactions such as zeolitization of volcanic glass, which could affect flow pathways, water chemistry and WP environmental conditions; (iii) dehydration of hydrous phases liberating moisture that may affect the WP chemical environment and the chemical environment for radionuclide release; (iv) effects of microbial processes on the WP chemical environment and the chemical environment for radionuclide release; (v) changes in water chemistry that may result from the release of corrosion products from the WP and interactions between engineered materials and groundwater, which, in turn, may affect-flow and the WP chemical environment, as well as the chemical environment for radionuclide release; and (vi) changes in boundary conditions (e.g., drift shape and size) and hydrologic properties relating to the response of the geomechanical system to thermal loading, in their assessment of alternative conceptual models.

Status: Open. DOE should provide adequate description of the alternative conceptual models used to assess the effects of change in: (i) emplacement-drift geometry, (ii) rock-mass hydrological properties owing to geomechanical response to thermal and seismic loadings; and (iii) ventilation on the abstraction of quantity and chemistry of water contacting WP and WF. For example, an alternative conceptual model for change in emplacement-drift geometry and hydrological properties may consist of two sets of abstractions, one set based on completely collapsed drifts and the other set based on the initial drift geometry with predictions from the two sets combined using a time-dependent weighting function. Similar alternative models may also be developed to explore the effects of ventilation, if it is determined that it is not practical to model ventilation explicitly.

AC5 Output from the TSPA abstraction of quantity and chemistry of water contacting WP and WF is justified through comparison with output from detailed process-level models and/or empirical observations (e.g., laboratory testing, field measurements, natural analogs).

- DOE demonstrates that abstracted models for coupled thermal-hydrologic-mechanical-chemical effects on seepage and flow and the WP chemical environment, as well as on the chemical environment for radionuclide release, are based on the same assumptions and approximations demonstrated to be appropriate for closely analogous natural or experimental systems.

- DOE clearly describes changes, if any, in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements, and demonstrates that the magnitudes and distributions of the changes provided are consistent with the results of TM analyses of the underground facility.

Status: Open. DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the anticipated geomechanical response to the proposed thermal loading and potential seismic loading.

Spatial and Temporal Distribution of Flow

AC1 Important design features, site-specific physical phenomena and couplings, and consistent and appropriate assumptions have been incorporated into the spatial and temporal distribution of flow abstraction in the PA and the technical bases are provided. The TSPA abstraction in the DOE LA identifies and describes aspects of spatial and temporal distribution of flow that are important to waste isolation and includes the technical bases for these descriptions. Specifically:

- DOE temporal abstractions of the spatial and temporal distribution of flow appropriately incorporate the physical couplings (THMC) or sufficient justification is provided for exclusion of these couplings. The DOE abstraction incorporates or conservatively bounds coupled THMC processes based on, for example, independent models, laboratory and field analyses, literature reviews, natural analog data, and other available information.

- DOE estimates of performance are not over optimistic, given the excluded set of phenomena and the implementation of coupled THMC processes in the TSPA.

Status: Open. TM effects on spatial and temporal distribution of flow are screened out of the DOE PA abstraction (CRWMS M&O, 2000m) using an argument that assumes that important TM effects would be reversible. The argument assumes that: (i) TM effects on hydrological properties would develop during the period of increasing temperature, (ii) drift seepage would not occur during this period because hot and dry conditions at the repository level, and (iii) the TM effects would be reversed before moisture returns to the repository level. These assumptions are not correct. Permanent TM-induced changes in hydrological properties and emplacement-drift geometry can be expected as discussed under the U.S. Department of Energy Approach subsection of this section (also, Ofoegbu, 2000; Ofoegbu et al., 2000). DOE needs to develop estimates of changes in hydrological properties and emplacement-drift geometry that account for the, anticipated geomechanical response to the proposed thermal loading and potential seismic loading; and account for such changes in the abstraction of spatial and temporal distribution of flow.

AC3 Determine that parameter values, assumed ranges, probability distributions, and/or bounding assumptions used in the spatial and temporal distribution of flow abstraction are consistent with site characterization data, are technically defensible, and reasonably account for uncertainties and variabilities. The technical bases for the parameter values used in the PA have been provided. Specifically:

- Input values used in the abstraction are consistent with the initial and boundary conditions and the assumptions of the conceptual models for the YM site. For example, estimation of the deep percolation flux into the drift is based on the infiltration rate, structural control (for flow diversion via faults), thermal loading strategy (for reflux), and other design features that may affect spatial and temporal distribution of flow.

Status: Open. The representation of repository thermal loading and ventilation in DOE's abstraction of the spatial and temporal distribution of flow is discussed under AC1 of *Quantity and Chemistry of Water Contacting Waste Packages and Waste Forms* under the U.S. Nuclear Regulatory Commission Staff Evaluation subsection of this section. There are unresolved issues, and the path to resolution of these issues is discussed in the same section.

~~5.2.2.1 Acceptance Criterion 1~~

~~**Approved QA, control procedures, and standards were applied to collection, development and documentation of data, methods, models, and codes.** The M&O Contractor periodically conducts performance-based audits and surveillances on various activities related to the repository~~

PA. NRC staff will defer the determination of compliance with this acceptance criterion until relevant audits are conducted.

5.2.1.1 Acceptance Criterion 2

If used, expert elicitation is conducted and documented in accordance with the guidance in NUREG–1563 or other acceptable approaches. DOE conducted an expert elicitation on the near-field/altered zone. This component of the Subissue on TM Effects on Repository Design and Performance is considered part of the near-field/altered zone subject area. The final report by the expert elicitation panel was published during 1998 (Geomatrix Consultants, Inc. and TRW, 1998).

To date, no questions or comments regarding the use of expert elicitation, in areas related to this component, have been raised by the staff. The expert elicitation process for the near-field/altered zone will be reviewed under the Evolution of the Near-Field Environment KTI.

5.2.1.2 Acceptance Criterion 3

Time-dependent changes in size and shape of the emplacement drifts due to thermally induced ground movements (rock deformations, collapse, and other changes that may affect the integrity and geometrical configuration of underground openings) are estimated taking into account the uncertainties in the context of their impacts on performance. Thermally and seismically induced ground movements will affect inputs to hydrological flow assessment in two ways: changes in fracture permeability and porosity associated with rock deformation and changes in geometry (size and shape) of underground openings. Both effects have been recognized within the DOE program. The assessment of the impact of thermal loading on the fracture porosity and permeability throughout the host rock, particularly near the emplacement drifts and within the intervening pillars, is one of the topics that was presented to a panel of experts assembled by DOE to examine the role and assessment of near-field/altered zone coupled effects (Geomatrix Consultants, Inc. and TRW, 1998).

Change in geometry has been recognized to have a potential effect on dripping characteristics into emplacement drifts (Hughson and Dodge, 1999). This effect was not considered in the TSPA-VA (CRWMS M&O, 1998a).

5.2.1.3 Acceptance Criterion 4

Changes in hydrological properties (e.g., fracture porosity and permeability) due to thermally induced ground movements are estimated taking into account the uncertainties in the context of their impacts on performance. Thermally and seismically induced ground movements will alter the hydraulic properties of the environment immediately next to the WP. The RDTME KTI staff is working with the Thermal Effects on Flow KTI staff to evaluate the importance of such changes to PA.

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

Item ID: OSC0000001347C055 Comment 055 SCA
Title: Use of statistics in TM properties
Status: Closed
Basis: Overtaken by changing of testing program. Related concerns are being reviewed under Design of GROA subissue

Item ID: OSC0000001346C056 Comment 056 SCA
Title: Validation of models/TM properties
Status: Closed
Basis: Subsumed under Acceptance Criterion 6 of Section 4.3.3.1 listed in Revision 2. For status, see Section 5.1.4 .

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

5.2.3 Other Related Items

To be determined.

5.3 DESIGN AND LONG-TERM CONTRIBUTION OF SEALS TO PERFORMANCE

~~This subissue will be addressed in subsequent revisions of this IRSR as DOE and NRC begin to focus more attention on it.~~

STATUS: Closed. The proposed 10 CFR Part 63 is a risk-informed and performance-based regulation. This regulation offers ample flexibility for DOE to demonstrate its case that the design of GROA meets preclosure and postclosure performance. Since this regulation does not specifically provide requirements for design and performance of seals and DOE does not current include seals in its PA, the staff determines that this subissue is closed. If DOE decides to take credit on seals to demonstrate meeting postclosure performance objectives in the future, the status of this subissue will be reexamined.

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

Item ID: OSC0000001347Q042 Comment 074 SCA
Title: DOE's plan for *in-situ* testing of seal components
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSC0000001347Q025 Question 025 SCA
Title: Sealing program/gaseous transport
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSC0000001347Q028 Question 028 SCA
Title: Impacts on sealing program/calico hills penetration
Status: Closed
Basis: The current site characterization efforts have eliminated the need for penetrating the Calico Hills unit. Should DOE decide to revise its position to penetrate the Calico Hills unit, this concern may be reinstated.

Item ID: OSP0000831421Q001 Question 001 SP831421
Title: Status of borehole seal design
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

Item ID: OSP000831421Q002 Question 002 SP831421
Title: Specification for sealing boreholes
Status: Closed
Basis: The open item is related to seals. The design and long-term contribution of seals to performance subissue is closed since the proposed 10 CFR Part 63 does not specifically provide requirements for seals and DOE is not currently taking credit on seals for postclosure performance. Consequently, the open item is closed as well.

5.3.2 Other Related Items

To be determined.

5.4 OTHER OPEN ITEMS NOT INCLUDED UNDER THE FOUR SUBISSUES

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

Item ID: OSC0000001347C077 Comment 077 SCA
Title: Retrieval accidents/radiation exposure
Status: Closed
Basis: Related concerns will be reviewed under retrievability subissue.

Item ID: OSC0000001347Q042 Comment 120 SCA
Title: Comprehensive, integrated and prioritized plan for model and code validation
Status: Closed
Basis: Transferred to TSPAI KTI IRSR Revision 2.

Item ID: OSC0000001347Q042 Comment 122 SCA
Title: Criteria for determining the acceptability of dry coring method
Status: Closed
Basis: Dry coring technology has been demonstrated.

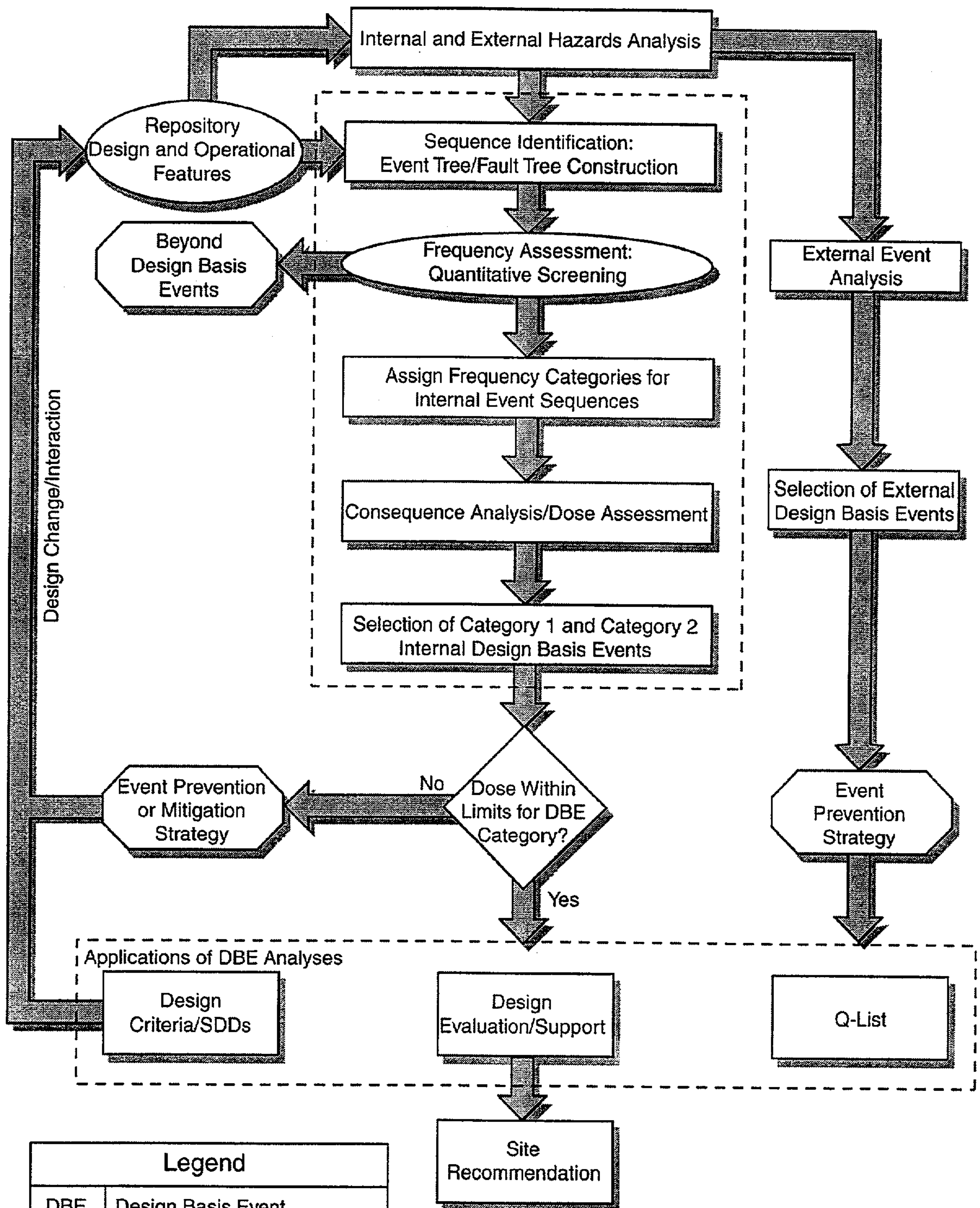
Item ID: OSC0000001347Q042 Question 055 SCA
Title: Analysis of potential test interference from water storage facilities
Status: Closed
Basis: ESF construction completed. No evidence of test interference from surface water storage facilities.

5.4.2 Status of Open Items from the Annotated Outline

Item ID: OAO030SEP1992C00 Comment 003 AO30SEP1992
Title: Planned area/controlled area
Status: Closed
Basis: DOE repository design is being revised.

Item ID: OAO030SEP1992C00 Comment 004 AO30SEP1992
Title: Legal definition of controlled area
Status: Closed
Basis: NRC has revised the definition of controlled area under DBE rule making.

Item ID: OAO030SEP1992Q00 Question 001 AO30SEP1992
Title: Figure reference/underground facility
Status: Closed
Basis: The underground facility design is being updated. The concern does not apply to the latest DOE design presented in the VA.



Legend	
DBE	Design Basis Event
SDD	System Description Document

Figure 20. Department of Energy integrated safety analysis methodology

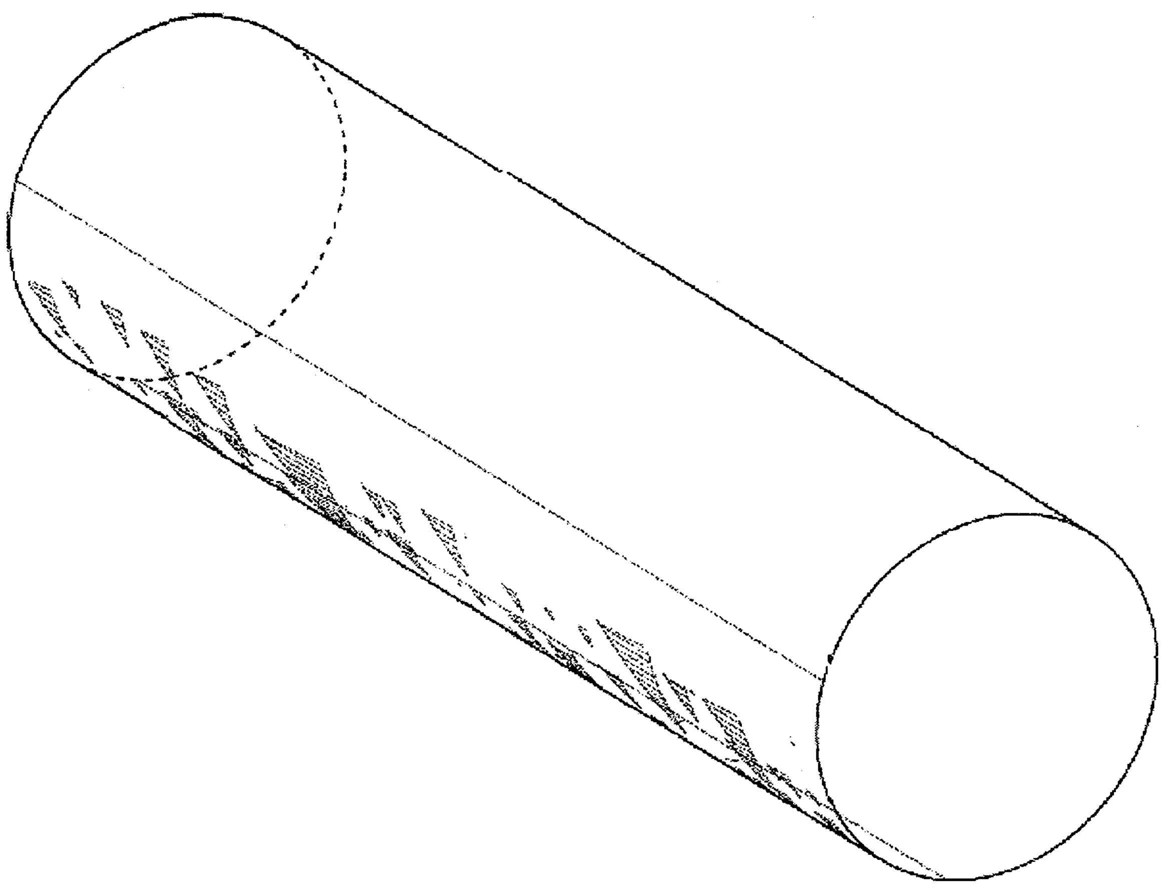


Figure 21. Traces of key blocks on emplacement surface for TSw2 lower lithophysal unit

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APPENDIX

APPENDIX

This appendix lists important correspondences and interactions between the Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) related to the subissue of exploratory studies facility (ESF) design and design control process and briefly summarizes relevant details at the end of each item:

(1) U.S. Nuclear Regulatory Commission letter from R.M. Bernero to S. Rousso of U.S. Department of Energy, [cover letter to NRC's Site Characterization Analysis (SCA)] dated July 31, 1989.

[The letter and SCA raise two objections to DOE's continued deficiencies in its overall Quality Assurance Procedures (QAP) and inadequacy of its ESF design and design control process.]

(2) U.S. Nuclear Regulatory Commission letters from R.M. Bernero to J. Bartlett of U.S. Department of Energy, dated March 2, 1992, and November 2, 1992.

[The letters lift NRC's objections 1 and 2 based in part, on DOE's demonstration that it had revised its process of controlling ESF design and implementation of such a process.]

(3) U.S. Nuclear Regulatory Commission letters from J.J. Holonich to D. Shelor of U.S. Department of Energy, dated March 24, 1993, and May 5, 1993.

[The letters express renewed concerns related to ESF design and design control process.]

(4) U.S. Nuclear Regulatory Commission letter from B.J. Youngblood to D. Shelor of U.S. Department of Energy, dated August 20, 1993.

[The letter requests specific information from DOE including an action plan for implementing an acceptable design control process before proceeding with further design activities.]

(5) U.S. Department of Energy letter from D. Shelor to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated November 1, 1993.

[This letter provides details related to the technical and regulatory design requirements and document hierarchy.]

(6) U.S. Department of Energy letter from D. Shelor to B.J. Youngblood of U.S. Nuclear Regulatory Commission, dated November 18, 1993.

[This letter provides response to specific NRC requests made in (4) above.]

(7) DOE–NRC interactions related to ESF design and design control process dated September 17, 1993, October 4–5, 1993, December 8, 1993, and January 5–7, 1994.

[The discussions held during these interactions provide additional responses and clarifications to earlier staff requests.]

(8) U.S. Nuclear Regulatory Commission letter from B.J. Youngblood to D. Shelor of U.S. Department of Energy, dated March 30, 1994.

[This letter expresses limited satisfaction at the progress made by DOE and recommends further followup, such as quality assurance (QA) audits and surveillances for additional verification of DOE actions.]

(9) U.S. Nuclear Regulatory Commission from R.M. Bernero to D. Dreyfus of U.S. Department of Energy, dated October 13, 1994.

[This letter notifies DOE of staff continued concerns with DOE and its management and operating (M&O) Contractor QAP and transmits one major comment related to DOE and M&O QAP and three specific questions related to ESF design and its interface with geologic repository operations area (GROA) conceptual design.]

(10) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated October 17, 1994.

[This letter provides a quick initial response to staff letter of October 13, 1994, and proposes a set of actions and commitments.]

(11) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated November 14, 1994.

[This letter provides a detailed response to NRC's letter of October 13, 1994, and a series of actions and commitments. The staff uses this letter to develop a checklist of 51 items to be verified during an in-field verification.]

(12) U.S. Department of Energy letter from R.A. Milner to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated January 27, 1995.

[This letter provides a list of DOE's commitments in response to staff recommendations.]

(13) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated March 9, 1995.

[This letter summarizes Phase-1 staff review of DOE's detailed response of November 14, 1994, and concludes that the responses provided by DOE are acceptable and presents a schedule for Phase-2 in-field verification.]

(14) U.S. Department of Energy letter from D. Dreyfus to R.M. Bernero of U.S. Nuclear Regulatory Commission, dated March 14, 1995.

[This letter provides continued response to staff letter of October 13, 1994, and attaches the Regulatory Compliance Review Report (RCRR) showing the allocation and traceability of 10 CFR Part 60 requirements to the ESF.]

APPENDIX (cont'd)

(15) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated March 16, 1995.

(This letter summarizes staff observations of DOE's QA audit of M&O.)

(16) U.S. Nuclear Regulatory Commission conducted in-field verification (phase-2) during April 3–6, 1995.

[See NRC (1995b), for in-field verification procedures and NRC (1995c), for the summary of findings from 6.0 List of References.]

(17) U.S. Department of Energy letter from R.A. Milner to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated May 1, 1995.

[This letter informs NRC of DOE's decision to lift a self-imposed "hold" on tunnel boring machine (TBM) progress beyond upper Paintbrush Tuff nonwelded (Ptn) contact.]

(18) U.S. Nuclear Regulatory Commission letter from J.G. Greeves to R.A. Milner of U.S. Department of Energy, dated May 12, 1995.

[This letter concludes that an "objection" level concern does not exist with respect to the "pneumatic pathway" issue and documents that establishing or lifting "hold points" for TBM progress was a matter left to DOE's discretion.]

(19) U.S. Nuclear Regulatory Commission letter from J.J. Holonich to R.A. Milner of U.S. Department of Energy, dated June 16, 1995.

[This letter transmits staff in-field verification report, along with a commendation, closing several open items from the 51 items of the checklist and making three specific recommendations and proposals for followup.]

(20) U.S. Department of Energy letter from D. Dreyfus to C.J. Paperiello of U.S. Nuclear Regulatory Commission, dated August 3, 1995.

(This letter provides the balance of responses to NRC's letter of October 13, 1994, and provides the supplement to RCRR.)

(21) U.S. Department of Energy letter from S.J. Brocoum to J.J. Holonich of U.S. Nuclear Regulatory Commission, dated October 25, 1995.

[This letter acknowledges the "cumbersome" nature of demonstrating regulatory flowdown and reports on two specific design process improvements: change to QAP–3–9 and modification to the structure and content of the Design Requirements Document.]

(22) U.S. Nuclear Regulatory Commission letter from M.J. Bell to S.J. Brocoum of U.S. Department of Energy, dated December 14, 1995.

[This letter transmits the staff review of DOE's RCRR and concludes that DOE made an acceptable demonstration of regulatory flowdown via the example of design package 2C and considered most of the applicable regulatory requirements from 10 CFR Part 60. In addition, the staff requests two specific items: a design example conducted under the new and improved design QA/design procedure and current versions of revised ESF Design Requirements Document along with DOE's latest description of "Document Hierarchy."]

(23) U.S. Department of Energy letter from S.J. Brocoum to M.J. Bell of U.S. Nuclear Regulatory Commission, dated September 1996.

[This letter responds to staff requests made in December 14, 1995, letter and provides clarifications sought by the staff.]

(24) U.S. Nuclear Regulatory Commission conducts an Appendix 7 meeting on June 12–13, 1997, at DOE/M&O Offices and at the YM site to gather data, conduct onsite reviews, and complete activities intended to be covered under phase-3 of the in-field verification, which had to be canceled because of personnel and budgetary reasons.

[The staff concludes that most of the checklist items that were not verified during phase-2 of the in-field verification conducted on April 3–6, 1995, could be closed out based on interviews with DOE/M&O staff and onsite reviews. The staff also concludes to keep two items open: (i) quality classification for the concrete inverts used for the ESF construction; and (ii) hierarchy of documents that control site characterization, design, construction, and operations activities at the YM site.]