Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office
P.O. Box 364629
North Las Vegas, NV 89036-8629

QA: N/A

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OVERNIGHT MAIL

C. William Reamer, Chief
High-Level Waste Branch
Division of Waste Management
Office of Nuclear Materials Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Two White Flint North
Rockville, MD 20852

TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUES (KTI) STRUCTURAL DEFORMATION AND SEISMICITY (SDS)

Enclosed is a report that fulfills KTI agreements SDS 1.02 and SDS 2.03, which addresses the use of the mean vs. median in seismic analysis. The U.S. Department of Energy (DOE) agreed to either provide technical justification for use of median fault displacement and ground motion hazard curves as the basis for screening seismic Features, Events, and Processes for the Total System Performance Assessment for License Application, or to adopt and justify another statistic, such as the mean, or to evaluate and implement an alternative approach. The DOE intends to implement an approach for postclosure seismic analysis that uses mean hazard results. This approach is described in the enclosed report *Approach to Postclosure Seismic Analyses for a Potential Geologic Repository at Yucca Mountain, Nevada.*

Please direct any questions concerning this letter and its enclosure to Timothy C. Gunter at (702) 794-1343.

for Stephan Brocoum
Assistant Manager, Office of
Licensing and Regulatory Compliance

OL&RC:TCG-0140

Enclosure:
Approach to Postclosure Seismic Analyses for a Potential Geologic Repository at Yucca Mountain, Nevada

YMP-5

cc w/encl:
J. W. Andersen, NRC, Rockville, MD
M. M. Comar, NRC, Rockville, MD
D. D. Chamberlain, NRC, Arlington, TX
R. M. Latta, NRC, Las Vegas, NV
S. H. Hanauer, DOE/HQ (RW-2) FORS
B. J. Garrick, ACNW, Rockville, MD
Richard Major, ACNW, Rockville, MD
W. D. Barnard, NWTRB, Arlington, VA
Budhi Sagar, CNWRA, San Antonio, TX
W. C. Patrick, CNWRA, San Antonio, TX
Steve Kraft, NEI, Washington, DC
J. H. Kessler, EPRI, Palo Alto, CA
J. R. Curtiss, Winston & Strawn, Washington, DC
J. R. Egan, Egan & Associates, McLean, VA
R. R. Loux, State of Nevada, Carson City, NV
John Meder, State of Nevada, Carson City, NV
Alan Kalt, Churchill County, Fallon, NV
Irene Navis, Clark County, Las Vegas, NV
Harriet Ealey, Esmeralda County, Goldfield, NV
Leonard Fiorenzi, Eureka County, Eureka, NV
Andrew Remus, Inyo County, Independence, CA
Michael King, Inyo County, Edmonds, WA
Mickey Yarbro, Lander County, Battle Mountain, NV
Jason Pitts, Lincoln County, Caliente, NV
L. W. Bradshaw, Nye County, Pahrump, NV
Geneva Hollis, Nye County, Tonopah, NV
Josie Larson, White Pine County, Ely, NV
Judy Shankle, Mineral County, Hawthorne, NV
R. I. Holden, National Congress of American Indians, Washington, DC
Allen Ambler, Nevada Indian Environmental Coalition, Fallon, NV
CMS Coordinator, BSC, Las Vegas, NV
R. N. Wells, DOE/YMSCO (RW-60) Las Vegas, NV

cc w/o encl:
N. K. Stablein, NRC, Rockville, MD
W. L. Belke, NRC, Las Vegas, NV
L. H. Barrett, DOE/HQ (RW-1) FORS
A. B. Brownstein, DOE/HQ (RW-52) FORS
R. A. Milner, DOE/HQ (RW-2) FORS

cc w/o encl: (continued)
C. E. Einberg, DOE/HQ (RW-52) FORS
N. H. Slater, DOE/HQ (RW-52) FORS
S. J. Cereghino, BSC, Las Vegas, NV
N. H. Williams, BSC, Las Vegas, NV
Donald Beckman, BSC, Las Vegas, NV
K. M. Cline, MTS, Las Vegas, NV
R. B. Bradbury, MTS, Las Vegas, NV
R. P. Gamble, MTS, Las Vegas, NV
R. C. Murray, MTS, Las Vegas, NV
R. D. Rogers, MTS, Las Vegas, NV
Richard Goffi, BAH, Washington, DC
G. W. Hellstrom, DOE/YMSCO, Las Vegas, NV
S. P. Mellington, DOE/YMSCO, Las Vegas, NV
R. E. Spence, DOE/YMSCO, Las Vegas, NV
V. F. Iorii, DOE/YMSCO, Las Vegas, NV
Stephan Brocoum, DOE/YMSCO, Las Vegas, NV
D. R. Williams, DOE/YMSCO, Las Vegas, NV
A. V. Gil, DOE/YMSCO, Las Vegas, NV
T. C. Gunter, DOE/YMSCO, Las Vegas, NV
C. L. Hanlon, DOE/YMSCO, Las Vegas, NV
P. G. Harrington, DOE/YMSCO, Las Vegas, NV
S. A. Morris, DOE/YMSCO, Las Vegas, NV
M. C. Tynan, DOE/YMSCO, Las Vegas, NV
K. D. Lachman, DOE/YMSCO, Las Vegas, NV
D. H. Coleman, DOE/YMSCO, Las Vegas, NV
C. M. Newbury, DOE/YMSCO, Las Vegas, NV
J. T. Sullivan, DOE/YMSCO, Las Vegas, NV
C. A. Kouts, DOE/YMSCO (RW-2) FORS
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Letter Report

October 2001

Approach to Postclosure Seismic Analyses for a Potential Geologic Repository at Yucca Mountain, Nevada

By
J. Carl Stepp and C. Allin Cornell

Prepared for:
U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Prepared by:
Bechtel SAIC Company, LLC
1180 Town Center Drive
Las Vegas, Nevada 89144

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ENCLOSURE

CONTENTS

ACRONYMS AND ABBREVIATIONS

CFR	Code of Federal Regulations
CRWMS M&O	Civilian Radioactive Waste Management System, Management and Operating Contractor
DIRS	Document Input Reference System
DOE	U.S. Department of Energy
EBS	Engineered Barrier System
LA	License Application
NRC	U.S. Nuclear Regulatory Commission
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PRA	Probabilistic Risk Assessment
PSHA	Probabilistic Seismic Hazard Analysis
SDS	Structural Deformation and Seismicity [Key Technical Issue]
SSC	Structure, System, and Component
STR	Seismic Topical Report
TSPA	Total System Performance Assessment
YMP	Yucca Mountain Site Characterization Project
YMSCO	Yucca Mountain Site Characterization Office

1. INTRODUCTION

The purpose of this document is to describe the Department of Energy's (DOE's) postclosure seismic analysis approach for the potential Yucca Mountain repository engineered barrier system (EBS). The document responds to agreements (described more completely in Section 1.3) reached between the Nuclear Regulatory Commission's (NRC's) review team and the DOE during the NRC/DOE Technical Exchange and Management Meeting on the Key Technical Issue of Structural Deformation and Seismicity (SDS), October 11–12, 2000 (Reamer and Williams 2000 [DIRS 154287]). Specifically, the DOE agreed to either provide technical justification for use of median fault displacement and ground motion hazard curves as the basis for screening seismic features, events, and processes (FEPs) for the total system performance assessment for license application (TSPA-LA) or to adopt and justify another statistic such as the mean, or to evaluate and implement an alternative approach.

The DOE will implement approaches for postclosure seismic analysis that use mean hazard results. As described in Sections 2 and 3 of this document, the DOE will implement complementary approaches, as follows:

1. For ground shaking hazard, the approach will be to perform a probabilistic risk assessment for the EBS implementing standard seismic risk assessment methods and guidelines established by the NRC (NRC 1983 [DIRS 106591] Chapters 10, 11). The EBS components that will be analyzed will include the waste package, waste emplacement pallet, and drip shield and will include the affects of rockfall.

2. For fault displacement hazard, the approach involves screening out the faulting conditions that have negligible effect on the EBS and emplacement drifts and performing a probabilistic risk assessment for those faulting conditions that are found to have non-negligible effects. For the nine locations and fifteen faulting conditions identified in the vicinity of the potential repository (Wong and Stepp 1998 [DIRS 103731] Sections 4.3.2 and 8; CRWMS M&O 2000 [DIRS 142321], Sections 6.3.4 and 6.6.3), screening will be performed using mean fault displacement hazard results. It is anticipated that some of these faulting conditions will be screened out as having negligible probability. For the subset of intrablock faulting conditions that are not screened out on the basis of probability, engineering analysis will be performed using fault displacements at 10^{-8} mean annual probability to determine the effects of these direct displacements on the engineered barrier system (EBS) and emplacement drifts. For the primary block-bounding faults (i.e., the Solitario Canyon and Bow Ridge faults), for which set backs will be implemented to meet preclosure design requirements (YMP 1997 [DIRS 100521]), direct faulting is not a concern. However, analyses using the fault displacements at 10^{-8} mean annual probability will be performed to determine point strains within the potential repository emplacement area at locations away from discrete displacements. Engineering analysis then will be performed to determine the effects of these point strains on the EBS and emplacement drifts. If the effects of direct displacements or point strains are determined to be non-negligible, a fault displacement probabilistic risk assessment will be performed to develop inputs for TSPA-LA.

A seismic probabilistic risk assessment is an analytical method for integrating different aspects of seismic hazard and seismic design of a facility to quantify the risk (annual probability) of

component damage states (unacceptable performance), system (e.g., the EBS) damage state sequences, and failure of the system to perform its intended function (e.g., release of nuclides) (see for example, NRC 1983 [DIRS 106591] Vol. 1, page 1-5). The intended purpose of the probabilistic risk assessment of the potential repository EBS is to quantify the annual probability of seismic hazard-initiated events and event sequences (i.e., component damage states and damage state sequences) and to provide appropriate inputs to the TSPA-LA. The TSPA-LA will calculate the annual dose risk. The seismic risk assessment results will be presented in a format that is compatible with input to the TSPA-LA.

The probabilistic seismic risk assessment results could also serve as the basis for determining seismic design of EBS components for the postclosure period, if such design was desired, as discussed in *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca, Mountain* (YMP, 1997 [DIRS 100521], Appendix A) (Seismic Topical Report #2 [STR #2]). The DOE has committed in STR #2, which has been reviewed by the NRC, to a single seismic design of the potential repository EBS that meets both preclosure and postclosure performance requirements.

1.1 BACKGROUND

The DOE is implementing a seismic evaluation strategy for the potential geologic repository that uses a number of mutually supporting seismic analyses that begin with a probabilistic seismic hazard analysis (PSHA) for the potential repository site. In the PSHA the DOE has developed ground motion hazard curves for the Yucca Mountain site together with fault displacement hazard curves for fifteen faulting conditions mapped within the immediate vicinity of the potential repository (Wong and Stepp 1998 [DIRS 103731], Sections 7 and 8; CRWMS M&O 2000 [DIRS 14321], Sections 6.5.3 and 6.6.3). These seismic hazard results, described in Section 2.1, are being used as basic inputs for several additional seismic analyses. They have been used as input for screening of features, events, and processes (FEPs) to determine seismic FEPs that could be excluded from the TSPA for site recommendation (SR) (CRWMS M&O 2000 [DIRS 151553]). Currently the PSHA results are being used to derive seismic design ground motions and to establish fault displacements for layout and design of the facility structures, systems, and components (SSCs) for the preclosure period (YMP, 1997 [DIRS 100521]). The hazard curves will be used, as described in Section 2.2 of this report, for analysis of seismic FEPs for the TSPA-LA. Finally, if seismic FEPs are not screened out, the seismic hazard curves will be used, as described in Section 3 of this report, for performing a probabilistic risk assessment of the EBS for input to the TSPA-LA.

1.2 REGULATORY REQUIREMENTS

Expected regulatory requirements for the Yucca Mountain facility are described in the NRC's proposed rule, 10 CFR Part 63 (64 FR 8640 [DIRS 10680]). The DOE's proposed implementation of the preclosure regulatory requirements is described in STR #2 (YMP 1997 [DIRS 100521]). STR #2 commits the DOE to a single seismic design of facility SSCs that meets both the preclosure performance objectives specified in proposed Part 63.111 and postclosure performance objectives specified in proposed Part 63.113(b). Any postclosure seismic design of facility SSCs will be established as provided in STR #2 (YMP 1997 [DIRS 100521], Appendix A).

Expected requirements for postclosure performance assessment are described in proposed Part 63.114. Of particular importance for postclosure seismic analysis are proposed Parts 63.114(b) through (f). Proposed Part 63.114(b) specifies the performance assessment to account for uncertainties and variabilities in parameter values and to provide the technical basis for parameter ranges, probability distributions, or bounding values used. Proposed Part 63.114(c) specifies that the performance assessment consider alternative conceptual models of features and processes that are consistent with available data and current scientific understanding, and evaluate the effects that alternative conceptual models have on the performance of the geologic repository. Proposed Part 63.114(d) specifies that only events that have at least one chance in 10,000 of occurring over 10,000 years be considered in the performance assessment. Proposed Part 63.114(e) specifies that the technical basis for either inclusion or exclusion of specific features, events, and processes of the geologic setting in the performance assessment be provided. Proposed Part 63.114(f) specifies that the technical basis for either inclusion or exclusion of degradation, deterioration, or alteration processes of engineered barriers in the performance assessment, including those processes that would adversely affect the performance of natural barriers, be provided.

As stated in Section 1.1, the DOE is implementing a seismic evaluation approach that uses mutually supporting seismic analyses, starting with the PSHA, to comply with these proposed regulatory requirements. The results of the probabilistic risk assessment for the EBS described in this document, when input to the TSPA-LA, will satisfy the expected requirements of the proposed Regulation with respect to seismic hazard. Proposed Part 63.114(d) specifies the screening criterion for determining events that must be included in the TSPA-LA and those that may be excluded. For regulatory documentation and review this screening criterion is implemented as a 10^{-8} mean annual event frequency. The DOE's approach for addressing this expected requirement with respect to seismic events is described in Section 2 of this report. The proposed Regulation emphasizes that reasonable assurance, taking account of uncertainty, is the general standard that will be applied to judge performance of the proposed repository, and Staff have emphasized that they will implement the Commission's Risk-Informed Approach (NRC 2000 [DIRS 156063]) in their review of the license application. The DOE's approaches for seismic event screening and for the seismic probabilistic risk assessment directly respond to both of these review and decision-making emphases.

In this report we use event and event sequence(s) in their regular usage established in nuclear power plant probabilistic risk assessment guidance (NRC 1983 [DIRS 106591], Vol. 2, Chapters 10, 11), to mean effects of ground shaking or fault displacement on the EBS components and system. This usage appropriately ensures consistency of usage across regulations and guidelines and, accordingly, is considered to be consistent with the intended meanings of the terms as they are used in proposed Parts 63.111(a)(2), 63.111(b)(2), and 63.114(d). Screening of seismic events, as specified in proposed Part 63.114(e), is discussed in Section 2.

1.3 DEPARTMENT OF ENERGY-NUCLEAR REGULATORY COMMISSION AGREEMENTS

The DOE's approach for postclosure seismic analysis responds to agreements reached in the NRC/DOE Technical Exchange and Management Meeting on the Key Technical Issue of Structural Deformation and Seismicity (SDS), October 11-12, 2000 (Reamer and Williams 2000

[DIRS 154287]). In that meeting the NRC reviewers stated that the DOE's use of median hazard statistics for screening seismic (fault displacement and ground motion) hazard-initiated events for postclosure performance assessment, failed to comply with established NRC practice of using mean hazard. The reviewers also indicated that use of the median hazard for screening was inconsistent with the Staff's understanding of the intent of the proposed Regulation. In response to these concerns for SDS Subissue #1 – Faulting, the DOE committed in Agreement #2, to either provide technical justification for use of median fault displacement hazard for fault displacement-initiated event screening or to adopt and justify another statistic such as the mean, or to evaluate and implement an alternative approach. Similarly, for SDS Subissue #2 – Seismicity, the DOE committed in Agreement #3 to either provide technical justification for use of median ground motion hazard for the purpose of screening ground motion-initiated events or to adopt and justify another statistic such as the mean, or to evaluate and implement an alternative approach.

These agreements address the use of hazard for screening of seismic-related FEPs for TSPA-LA. As described in Section 2.1 of this report, the PSHA incorporates evaluations of seismic-related features and processes that include assessments of the epistemic (knowledge) uncertainty in the features and processes and the epistemic and aleatory (random) uncertainty in the seismic probabilistic hazard modeling parameters (parameters of the components of the seismic hazard computational model [McGuire 1995 (DIRS 107483)]) as well as uncertainty due to limitations of data. The seismic hazard curves are, consequently, considered appropriate for screening seismic hazard-initiated events for postclosure performance assessment.

For the TSPA supporting a site recommendation decision, the DOE elected to use median hazard curves to screen seismic FEPs, considering the median to be representative of the central tendency of the hazard at annual exceedance frequencies lower than about 10^{-6}. The mean hazard curves exceed the median hazard curves for all annual exceedance frequencies and the distance between the median and the mean increases with decreasing annual exceedance frequency, increasingly for annual exceedance frequencies lower than approximately 10^{-6}. This behavior is a result of the mean hazard being increasingly controlled by the upper tails of the source characterization experts' uncertainty distributions combined with the upper tails of the ground motion experts' uncertainty distributions. At annual exceedance frequencies lower than 10^{-7} the mean hazard curves, therefore, are often at or above the 85th fractile and for some hazard measures approach the 90th fractile of the epistemic uncertainty distribution. Moreover, mean hazard ground motion and fault displacement values at these very low annual exceedance frequencies are significantly larger than is reasonable based on experience and physically reasonable maximum values. However, NRC reviewers rejected the use of median hazard for FEPs screening as being inconsistent with established NRC practice for use of PSHA. Established NRC practice and guidance use the mean as the appropriate representation of hazard uncertainty. Consequently, the DOE will implement an alternative approach that uses the mean in support of a potential license application.

Section 2 of this report describes the DOE's approach for screening seismic FEPs, which uses mean seismic hazard curves. The purpose of the screening approach described in Section 2 will be to identify seismic hazard-initiated events (i.e., the effects of seismic hazard on EBS component performance) that must be included in the TSPA-LA. The DOE believes this

approach properly addresses the DOE-NRC agreements (Reamer and Williams 2000 [DIRS 154287]).

In addition, the DOE has committed (Brocoum 1994 [DIRS 155835]) to document in a topical report (Seismic Topical Report #3) the design ground motions and fault displacements for preclosure design. This topical report will also describe the approaches that will use the PSHA results for analysis and quantification of seismic hazard-initiated events and event sequences in the postclosure period (DOE 1998 [DIRS 131432]).

1.4 SCOPE

This report describes approaches for screening postclosure seismic hazard-initiated events to determine those that will be included in the TSPA-LA. It also describes a probabilistic risk assessment approach for the potential Yucca Mountain repository EBS for the postclosure period. Section 2 describes approaches for screening seismic hazard-initiated events that must be included in the TSPA-LA. Section 3 describes the approach for performing a probabilistic risk assessment of the EBS for ground motion-initiated events, which may also be applied for fault displacement-initiated events. Section 4 describes the use of the probabilistic risk assessment results. Section 5 lists references.

2. SEISMIC EVENT SCREENING FOR TOTAL SYSTEM PERFORMANCE ASSESSMENT

This section describes the PSHA results and the approaches that will use these results to screen seismic events for the postclosure period. As described in Section 1.2, proposed 10 CFR Part 63.114(e) specifies that the technical basis be provided for either inclusion or exclusion in the performance assessment of specific features, events, and processes of the geologic setting. The approach for screening ground motion-initiated events uses the ground motion hazard curves at the site control location (described in the following Section), which apply to the entire waste emplacement area, and simplified component fragility curves to identify ground motion-initiated events and event sequences that are important for TSPA-LA. The approach for screening fault displacement-initiated events uses mean fault displacement hazard results and analyses of the effects of direct fault displacement, and the possibility of fault displacement-induced strains at locations away from direct fault displacement, to identify fault displacement-initiated events.

2.1 SEISMIC HAZARD

The DOE has developed ground motion hazard curves for the Yucca Mountain site together with fault displacement hazard curves for nine locations with fifteen faulting conditions mapped within the immediate vicinity of the potential repository (Wong and Stepp 1998 [DIRS 103731] Sections 7 and 8; CRWMS M&O 2000 [DIRS 14321], Sections 6.5.3, 6.6.3). The ground motion hazard curves define the annual frequency of exceedance versus ground motion levels for a specified ground motion measure (e.g., peak ground acceleration [PGA], peak ground velocity [PGV] or response spectrum amplitude at given structural frequencies). Ground motion hazard curves have been computed at a specific control location – UTM 547.953 km easting, 4077.750 km northing – between the Solitario Canyon and Ghost Dance faults (Wong and Stepp 1998 [DIRS 103731], Section 7). The control location has geotechnical properties defined to represent the general properties of the site at the repository drift level (-300m). The hazard curves, therefore, can be applied at any location within the potential geologic repository operations area. Fault displacement hazard curves have been obtained at nine locations encompassing fifteen conditions within the geologic repository operations area that represent the range of faulting conditions known in the vicinity of the potential repository (Wong and Stepp 1998 [DIRS 103731], Section 4.3.2; CRWMS M&O 2000 [DIRS 142321], Section 6.3.4)

The PSHA was conducted as part of the DOE strategy to obtain early NRC approval of seismic design parameters for the proposed Yucca Mountain facility. Performance of the PSHA implemented *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain* (Seismic Topical Report #1) (YMP 1997 [DIRS 105522]) with a Senior Seismic Hazard Analysis Committee Level 4 site-specific PSHA (Budnitz, et al. 1997 [DIRS 103635]) and generally followed NRC's expert elicitation guidelines (Kotra et al.1997 [DIRS 100909]). The major emphasis of the assessment was on capturing the scientific community's epistemic (knowledge) uncertainties about tectonic and earthquake processes and models (e.g., tectonic models), earthquake sources, earthquake recurrence, modeling of fault displacement potential, and ground motion estimation, and properly quantifying these uncertainties in the hazard results. The seismic hazard results consequently, specifically incorporate assessments of

uncertainties about relevant processes and features as well as data-related uncertainties. The stated purpose of the PSHA was to provide hazard results for determining preclosure design ground motions and fault displacements and for analyzing seismic hazard-initiated events for use in postclosure analyses input to TSPA. The extensive effort expended to capture uncertainties and to properly represent them in the PSHA results provides reasonable assurance that hazard uncertainties are properly represented in the preclosure design of the potential facility as well as in postclosure analyses that provide input to the TSPA-LA.

As stated above, for the purpose of assessing ground motion hazard, geotechnical parameters for the control location were defined based on those found at the depth of waste emplacement drifts and hazard was computed for free surface conditions (i.e., assuming no overlying material). This definition of the properties of the waste emplacement level at a specific control location permits the ground shaking hazard results to be used, taking proper account of the distribution of geotechnical properties, to compute ground shaking hazard at any other location within the geologic repository operations area. The effect of taking account of geotechnical parameters of the materials between the waste emplacement level and the free ground surface is to lower the hazard at the waste emplacement level relative to the PSHA results. The hazard at the free surface control location is consequently, higher relative to that at the waste emplacement level.

Calculation of ground shaking hazard for the control location is based on multiple alternative seismic source and earthquake recurrence evaluations made by each of six teams of earth scientists and on alternative ground motion attenuation evaluations made by each of seven ground motion estimation experts. These evaluations resulted in a very large number of seismic source, earthquake recurrence, and ground motion model scenarios together with associated weights representing the experts' assessed epistemic uncertainties (Wong and Stepp 1998 [DIRS 103731], Section 7; CRWMS M&O 2000 [DIRS 42321], Section 6.5). Together, the scenarios and weights express the scientific community's epistemic uncertainty in tectonic processes, models, features, and data; in earthquake processes, sources, models, and data; and in ground motion estimation processes, models, and data. For each source evaluation team, ground motion hazard calculations were carried out for each alternative source and earthquake recurrence scenario using each ground motion expert's alternative ground motion evaluation. The combination of one of the source characterization team's scenarios for seismic sources and earthquake recurrence parameters with one of the ground motion expert's scenarios for the ground motion attenuation model represents one possible model for earthquake hazard at the site. The parameters of this combined hazard model scenario express the aleatory uncertainty (randomness) in the process of earthquake generation and ground motion propagation. The result of calculations with the combined hazard model scenario is a seismic hazard curve that integrates these aleatory uncertainties to express the frequency of exceeding a range of ground motion levels at the site. Together, the set of aleatory hazard curves for a team's weighted alternative scenarios express the team's epistemic uncertainty in processes, models (e.g., tectonic models), features, and data as well as the ground motion experts' epistemic uncertainty in ground motion estimation processes, models (e.g., of median ground motion attenuation), and data. The combined set of aleatory hazard curves across all of the experts expresses the teams' assessments of the scientific community's epistemic uncertainty in processes, models, features, and data together with the ground motion experts' assessments of the scientific community's epistemic uncertainty in ground motion estimation processes, models, and data. These hazard results were

then aggregated giving each team equal weight and each ground motion expert equal weight. The aggregated hazard results consequently properly incorporate alternative conceptual models of ground motion and tectonic features and processes weighted by the experts' assessments of consistency with available data and current scientific understanding. These evaluations express the epistemic uncertainty in the integrated hazard results. Fault displacement hazard curves similarly reflect uncertainties in faulting sources, earthquake recurrence, and fault displacement processes. Therefore, the PSHA results specifically respond to and satisfy the expected requirements of proposed Parts 63.114(b) and (c) with respect to seismic evaluations.

The aggregated seismic hazard results in a large number of aleatory hazard curves, one for each alternative seismic source, earthquake recurrence, and ground motion or fault displacement scenario. The aggregate hazard curves depict the epistemic uncertainty in hazard. For purposes of visualization, the very large number of hazard curves (i.e., the range of epistemic uncertainty in hazard) are summarized by the 15^{th}, 50^{th}, and 85^{th} fractile, and mean hazard curves. The median (50^{th} fractile) and mean hazard curves convey the central tendency of the annual exceedance frequency, while the difference between the 15^{th} and 85^{th} fractile curves is a measure of the epistemic uncertainty in the exceedance probability. Because the epistemic uncertainty distribution in the hazard is skewed to the right toward higher values, the mean hazard curve exceeds the median hazard curve for all annual exceedance frequencies. The distance between the median and the mean increases with decreasing annual exceedance frequency as the mean hazard is increasingly controlled by the upper tails of the source characterization experts' epistemic uncertainty distributions combined with the upper tails of the ground motion experts' epistemic uncertainty distributions, particularly for annual exceedance frequencies lower than approximately 10^{-6}. The consequence of this behavior is that at annual exceedance frequencies lower than 10^{-7} the mean hazard curve may be above the 90^{th} fractile of the aggregate epistemic uncertainty distribution for some hazard measures.

2.2 USE OF HAZARD FOR POSTCLOSURE EVENT SCREENING

The purpose of event screening is to identify those events that can be excluded and those that must be included in the TSPA consistent with the expected requirements of proposed Part 63.114(d). The DOE will implement a staged approach for identification of ground motion-initiated events to satisfy this expected requirement. The approach will be to perform an initial assessment implementing the Simplified Hybrid Method described by Kennedy (1999 [DIRS 155940], Section 6). This assessment will use hazard curves for the control location (Point A, Wong and Stepp 1998 [DIRS 103731], Sections 1 and 7), which are expected to be higher relative to hazard curves at the waste emplacement level. The assessment also will use component fragility curves derived using the simplified method described by Kennedy (1999 [DIRS 155940]). The Simplified Hybrid Method provides a quick estimation of the seismic risk, which permits identification of those ground motion-initiated events and event sequences that provide non-negligible contributions to component damage states or the risk of nuclide release by the EBS and those that do not. Ground motion-initiated events that provide non-negligible contributions to the risk will be screened in and those that do not will be screened out. The final assessment then will incorporate these ground motion-initiated events and event sequences.

For fault displacement the approach consists of two primary components: screening on fault displacement hazard alone and screening on the effects of fault displacement on the EBS and

emplacement drifts. Screening will be performed for the fifteen faulting conditions identified in the vicinity of the potential repository emplacement area (Wong and Stepp 1998 [DIRS 103731] Sections 4.3.2 and 8; CRWMS M&O 2000 [DIRS 142321], Sections 6.3.4 and 6.6.3). The screening will use fault displacements for these faulting conditions corresponding to 10^{-8} mean annual hazard. Some of the fifteen faulting conditions may be screened out on the basis of hazard alone as having negligible effect on performance of the EBS and waste emplacement drifts. For the intrablock faulting conditions that are not screened based on low probability, engineering analysis will be performed using fault displacements for these faulting conditions at 10^{-8} mean annual probability to determine the effects of direct displacements on the engineered barrier system (EBS) and emplacement drifts. The faulting conditions that are shown by the analysis to have negligible effect on the performance of the EBS and waste emplacement drifts will be screened out. For faulting conditions that are not screened out on the basis of this analysis, a probabilistic risk assessment will be performed implementing the general steps described in Section 3 to develop inputs for the TSPA-LA.

For the primary block bounding faults (i.e., the Solitario Canyon and Bow Ridge faults) the analysis consists of two steps. Because set backs from these faults will be implemented for preclosure design requirements (YMP 1997 [DIRS 100521]), direct displacements on the block bounding faults are not a concern. Instead, the analysis will be concerned with point strains at distances away from the faults within the repository block. Analyses using the fault displacements for block-bounding faults at 10^{-8} mean annual probability will be performed to determine point strains within the potential repository emplacement area. Engineering analysis then will be performed to determine the effects of these point strains on the EBS and emplacement drifts. If the effects are determined to be non-negligible, the DOE may either establish set back distances from these faults to ensure postclosure performance, or perform a probabilistic risk assessment to develop inputs for TSPA-LA.

3. SEISMIC PROBABILISTIC RISK ASSESSMENT OF THE POTENTIAL REPOSITORY ENGINEERED BARRIER SYSTEM

The DOE's approach for postclosure ground motion analysis is a ground motion probabilistic risk assessment of the EBS. The probabilistic risk assessment will follow the procedures and guidelines established for conducting a seismic probabilistic risk assessment for external event initiators for nuclear power reactors (NRC 1983 [DIRS 106591], Chapters 10, 11). The products of the assessment will be identified seismically initiated events, the range of EBS component damage states, component interaction, event sequences, and probability distributions for ground motion induced component damage states for input to the TSPA-LA. To be compatible with the TSPA, the assessment will include consideration of component temperature and deterioration as a function of time due to normal aging and corrosion processes and the effects of these processes on component and system seismic capacity. The results will describe the range of damage state scenarios caused by ground motion hazard for input to TSPA-LA. While the approach described in the following sections focuses on ground motion effects, if required, a similar approach will be implemented to address the effects of fault displacement in the TSPA-LA.

3.1 ELEMENTS OF SEISMIC PROBABILISTIC RISK ASSESSMENT

The ground motion probabilistic risk assessment for the potential repository EBS will follow well-established and accepted procedures (NRC 1983 [DIRS 106591] Chapters 10, 11), which involve the following elements:

- The PSHA, which quantifies the frequency of occurrence per year of ground motions at the site
- Seismic fragility analysis, which quantifies for individual components the conditional probability of a damage state as a function of levels of ground motion and for different states of component degradation
- An engineered barrier system model that describes the types of damage states and damage state sequences that lead to significantly reduced capability or failure of the EBS to perform its intended function. This system model will be compatible with the TSPA system modeling.
- Risk quantification resulting in component damage state probabilities or the magnitudes and frequencies of component and system damage states for input to TSPA-LA.

3.2 DESCRIPTION OF GROUND MOTION HAZARD INPUT TO SEISMIC PROBABILISTIC RISK ASSESSMENT

To carry out a ground motion probabilistic risk assessment of the EBS a mean ground motion hazard curve is required. The ground motion hazard curve (e.g., PGV) establishes the annual frequency of ground motion-initiated component damage states and EBS damage state sequences. The hazard curve for any ground motion measure (PGA, PGV, response spectrum amplitude at a structural frequency) can be used as long as component fragility curves are

determined for the same ground motion measure and used in the risk assessment. The ground motion measure used should be highly correlated with failure of the system's components being considered in the probabilistic risk assessment (Kennedy 1999 [DIRS 155940], Section 2.1.1). For components of the potential repository EBS, PGV is likely to be most highly correlated with component damage (Kennedy 2001 [DIRS 155946]). As the objective of the probabilistic risk assessment will be to determine mean risk, the mean ground motion hazard curve will be used.

3.3 ANALYSIS OF COMPONENT FRAGILITIES

The purpose of the seismic fragility analysis, therefore, is to determine the conditional probability that a component will fail to perform its intended function as ground motion increases; the result is the component's fragility curve. The seismic fragility of a component is defined as the conditional probability of the component's failure to perform its intended function, given a value of a ground motion measure such as PGV (NRC 1983 [DIRS 106591]). A seismic fragility curve is often presented as the cumulative probability distribution on a component's capacity to withstand values of a ground motion measure. Component fragility curves are calculated based on an analysis of the component's capacity measures, such as strength and inelastic energy absorption, and various demand parameters – ground motion randomness, frequency and mode shapes, damping, modal combinations, and so on. A fragility curve will be determined for defined damage states of the EBS components.

Assessed median capacity and the logarithmic standard deviation of a component's resistance to failure can generally be used to describe a component fragility curve. There is epistemic uncertainty in the median fragility curve, described also by a logarithmic standard deviation. Experience with nuclear power plant probabilistic risk assessments has shown that satisfactory risk results can be obtained by combining these two standard deviations into a single "composite" logarithmic standard deviation. This together with the median capacity permits a component's fragility to be described by a single (mean) fragility curve (Kennedy, 2001 [DIRS 155946]). Development of fragility curves will use conservative or realistic (mean centered) analysis (Kennedy 2001 [DIRS 155946]; Kennedy, 1999 [DIRS 155940]; Kennedy and Reed, 1994 [DIRS 156108]).

Fragility analyses of the EBS components will use the methods described by Kennedy (2001 [DIRS 155946]) and Kennedy and Reed (1994 [DIRS 156108]). Initially a simplified conservative approach will be used. This approach will involve making conservative estimates of an EBS component's median seismic capacities and logarithmic standard deviations using simplified methods described by Kennedy (2001 [DIRS 155946]) and Kennedy and Reed (1994 [DIRS 156108]). The analysis will involve estimating the median value and composite logarithmic standard deviation for each capacity and demand parameter – component seismic strength, seismic demand for a specified ground motion input, and inelastic energy absorption factor. These parameter values are then combined to obtain the mean component fragility (Kennedy 2001 [DIRS 155946]; Kennedy and Ravindra 1984 [DIRS 102182]). For example, the total composite logarithmic standard deviation may be computed as the square root of the sum of the squares of the capacity and demand logarithmic standard deviations (Kennedy, 2001 [DIRS 155946]; Kennedy and Reed 1994 [DIRS 156108]). The analysis will take advantage of past

nuclear plant component fragility assessment experience to the extent that these components share similar ground motion response properties with components of the EBS.

A necessary step in developing a component's fragility curve is the definition of the damage state associated with the curve. In some cases a damage state may be complete loss of intended function and in others a degradation of the intended function. Seismic design engineers, risk analysts, and TSPA personnel working together will identify damage states that are important for TSPA-LA. Component fragilities will be used to quantify damage state probabilities of seismically initiated events and event sequences. Possible damage states due to fault displacement will be evaluated, if fault displacement is found to be a non-negligible event initiator for TSPA-LA.

3.4 DEVELOPMENT OF THE ENGINEERED BARRIER SYSTEM MODEL

For the probabilistic risk assessment, the EBS system model (the EBS components and their spatial relationships) that will be used is the existing TSPA model of the EBS. The functional effects of ground motion on the EBS will be analyzed using event and fault tree methods (NRC 1983 [DIRS 106591]), continuous state analysis, or a combination of these as discussed in Section 3.5. The analysis will describe ground motion-initiated events and event sequences that lead to degraded EBS performance and/or enhanced rates of nuclide release or loss of containment by the EBS. The results of this analysis will be integrated into the TSPA model, which describes the ambient behavior waste emplacement drifts (i.e., rockfall and drift stability) and degradation of the engineered components by general and localized corrosion.

3.5 QUANTIFICATION OF THE MAGNITUDE AND FREQUENCY OF SEISMICALLY INITIATED DAMAGE STATES

Quantification of risk (i.e., damage states and damage state sequences) may use either continuous or discrete methods. Either method starts with a continuous-state ground motion hazard curve – for example, PGV for the potential Yucca Mountain facility. The quantification will ultimately produce a continuous EBS release state curve or continuous component damage state curves. For intermediate analyses the quantification will use methods that are prudent and economical. Discrete-state analyses lend themselves best to components and multi-component systems that have binary states (fail - no fail). Discrete-state analysis will be applied for any components of the EBS that have binary damage states. Continuous state analysis may be used for multi-state or continuous-state components and sub-system outputs (e.g., rockfall tonnage, drip shield displacement, net increment in total crack aperture in the drip shield [or waste package], corrosion rate, release rate). These continuous state components can, if appropriate, be analyzed as discrete states, being modeled as a sequence of binary states (i.e., corrosion rate greater than x_i "or not", for several values of x_i). The EBS may not fall into the binary-state component and system logic that is so prominently used in nuclear power plant PRAs. (Such systems normally are modeled using event trees, fault trees, and Boolean logic.) Nuclear power plants have active systems with many components in series and/or standby parallel configurations. Each component of these systems either performs its intended function or does not (e.g., valve opens or not). Components of the EBS are, on the other hand, passive. They may fail to perform their intended function in degrees that are best quantified as states of degradation of their intended performance. Consequently continuous state analysis methods may well prove to be more

economical and result more directly in continuous system states (such as a degraded performance description, e.g., net crack aperture increment due to a ground motion-initiated event, or EBS release rate probability curves) that best interface with TSPA.

Regardless of whether continuous, discrete, or a combination of these analysis approaches is used, the structurally important aspects of the time-dependence of the fragility must be incorporated. These include corrosion effects on the thickness and temperature effects on the material behavior properties of the drip shields and waste packages. Such effects can be incorporated by breaking the analysis into a sequence of time intervals in which the inputs and outputs of the seismic assessment properties (such as corrosion state, the fragility curve, or its equivalent in a continuous model, e.g., the slope of a curve of net crack aperture increment versus PGV) are assumed effectively constant. To facilitate the TSPA interface it may be preferable instead to assess these component and system state probabilities parametrically in the drip shield and waste package thickness. At least early in the repository life, temperature may also need to be treated parametrically, as it too can affect structural properties.

4. USE OF THE ENGINEERED BARRIER SYSTEM PROBABILISTIC RISK ASSESSMENT RESULTS

This section describes the implementation of the proposed approach using seismic probabilistic risk assessment. First, use of the results in seismic design is discussed. Then, use of the results in postclosure performance assessment is described.

4.1 INPUT TO ITERATIVE SEISMIC DESIGN

The DOE has committed to a single seismic design of the potential Yucca Mountain facility that satisfies both preclosure and postclosure performance requirements (YMP 1997 [DIRS 100521], Appendix A). Seismic design specifically to meet postclosure performance requirements currently is not planned. The EBS risk analysis results will, however, provide a sufficient basis to determine any postclosure seismic design requirements, should such design ultimately be considered.

4.2 INPUT TO POSTCLOSURE TOTAL SYSTEM PERFORMANCE ASSESSMENT

The format for outputs of the ground motion probabilistic risk assessment will be determined in interaction with TSPA personnel to ensure that the results are compatible with TSPA modeling input needs. Given that a seismic probabilistic risk assessment is undeveloped and the TSPA modeling is in an advanced state of development, it seems reasonable that the seismic part could adapt to the current TSPA format needs, e.g., with respect to how TSPA is currently treating time dependent degradation effects. Pending further interaction, one possible output is a continuous curve of the annual probability of a seismically induced net crack or patch aperture increment greater than x covering an area y for possibly multiple thicknesses and temperature states (to reflect time-dependent degradation). This type of result could be used directly or modified for input to TSPA. Such curves would be necessary for both the drip shield and the waste package. The curves would integrate the total effects of all (drip shield and waste package) system damage state sequences and modes. The final form of the results for input to TSPA will be determined through future analysis and integration.

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