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DEC 12 1985

B. M. Crowe, Los Alamos, NM
D. O. Emerson, LLNL, Livermore, CA
J. T. Neal, SNL, Albuquerque, NM
W. B. Myers, USGS, Denver, CO
M. D. Voegele, SAIC, Las Vegas, NV

NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS (NNWSI) PROJECT SEISMIC TECTONIC MEETING MINUTES: NOVEMBER 14, 1985 (ACTION ITEM #86-394)

A draft set of meeting minutes of the NNWSI Project Working Group meeting that was held November 14, 1985, at the Science Applications International Corporation (SAIC) facility in Las Vegas is enclosed for your review and comment. You are requested to review the draft minutes and verify the accuracy of the information contained therein. Any comments or corrections should be brought to the attention of either J. S. Szymanski of this office or M. D. Voegele of SAIC. Such information should be provided no later than December 6, 1985. At that time, the meeting minutes will be finalized and distributed to all participants at the meeting.

This draft set of minutes is being furnished only to the designated lead individual of each participant organization. It is requested that that person ensure that other individuals representing his organization at the meeting review the material as appropriate. It is further requested that the designated lead individual coordinate and provide any comments that the organization's representatives may care to make.

Donald L. Vieth

Donald L. Vieth, Director
Waste Management Project Office

WMPO:JSS-335

Enclosure:
As stated

847

cc w/encl:
A. D. Youngberg, DOE/HQ (RW-24)
V. J. Cassella, DOE/HQ (RW-22)
Bruce Hurley, DOE/RL, Richland, WA
Mike Ferrigan, DOE/SRPO, Columbus, OH
Scott Hinchberger, DOE/CRPO, Argonne, IL
P. T. Prestholt, NRC, Las Vegas, NV
M. B. Blanchard, WMPO, DOE/NV
J. S. Szymanski, WMPO, DOE/NV

cc w/o encl:
W. W. Dudley, Jr., USGS, Denver, CO
T. E. Goebel, F&S, Las Vegas, NV
Vincent Gong, REECo, Mercury, NV
T. O. Hunter, SNL, 6310, Albuquerque, NM
D. T. Oakley, Los Alamos, NM
L. D. Ramspott, LLNL, Livermore, CA
M. E. Spaeth, SAIC, Las Vegas, NV
J. A. Tegtmeier, H&N, Las Vegas, NV
J. B. Wright, W, NTS
W. R. Dixon, WMPO, DOE/NV
M. P. Kunich, WMPO, DOE/NV

rec'd 12/27/85 with ltr.
dtd. 12/12/85 - Action Item
#86-394

102

Meeting Minutes
NNWSI Project Seismic Tectonic Position Paper Working Group
November 14, 1985

The NNWSI Project Seismic Tectonic Position Paper Working Group convened a meeting on November 14, 1985. This meeting was originally to have been a continuation of a DOE/HQ meeting on the same subject that was held on November 13, 1985. DOE/HQ staff concluded that a one-day meeting would be adequate for their purposes; consequently, the NNWSI Project staff utilized the second day to discuss items from the November 13, 1985, meeting and to plan for specific NNWSI Project responsibilities for the NRC presentation on December 3-4. There was no formal agenda for the meeting; an attendance list is attached (Attachment 1). In addition to the NNWSI Project staff, DOE/RL and the NRC OR attended.

Steve Bratt reviewed the presentation on seismic tectonic consequence and position assessment that he had given at the November 13, 1985 (Attachment 2) HQ meeting on the seismic tectonic position paper AO. This presentation was essentially a status report on the development of relationships between tectonic processes and the operation and performance of a repository in accordance with regulatory guidelines. The presentation covered the current state of work as well as suggested format changes such as treating each process separately in an appendix to the position paper. The paper could then be somewhat reduced in volume leading to an easier document to comprehend.

The next topic of discussion was the NNWSI Project proposed exclusionary siting criteria regarding Holocene displacements. At the November 13 meeting DOE/HQ had requested that this criteria not be presented to NRC as DOE/HQ viewed it as overly conservative. It was noted by the NNWSI Project staff that faults with possible Holocene displacements are not common in the immediate Yucca Mountain vicinity. The youngest faults identified to date are the southern extension of Windy Wash fault (40,000 yr - U trend, 6,000 yr provisional - thermoluminescence) and the Bare Mountain range front fault (possible Holocene). The suggestion was made that even if the position were not expounded, it could be beneficial to the Project ultimately to have avoided areas of recognized Holocene displacement. The NRC OR noted that, to his knowledge, there was no NRC position to include Quaternary movement in the definition of active fault. The group agreed that avoidance of faults with Holocene movement could help in the resolution of future questions about active faults.

The discussion about exclusionary criteria also led to a discussion about the type of field evidence that would lead to a discussion that a surface facility site was inadequate or less than desirable. The Bechtel representatives suggested that the best discriminating evidence at this time would be Holocene displacement. They further proposed examining four sites at this time: 1) the present site; 2) east of the present site; 3) on the flank of Exile Hill; and 4) north of the present site. They further noted that if a fault were discovered at one of these sites, it would still be possible to design around it by changing the shape of the waste handling building. This could lead to a more costly structure and would be less efficient but would still be viable. Their proposal was to trench these sites to ensure a 500 ft x 500 ft region free of Holocene displacement. A goal would be to finalize the Waste Handling Building location as soon as possible. A final point was noted in support of adopting an exclusionary criteria: the NRC draft GTP on Seismic Tectonic questions notes that the surface facility should avoid areas of surface rupture. The group agreed that it was an appropriate topic for the site specific position paper to indicate how this would be done (i.e., through the use of an exclusionary criteria).

The next topic of discussion was to ascertain the group's reaction to the DOE/HQ reaction to the proposed definitions for anticipated and unanticipated events. It was acknowledged that the time for Project review of this information had been limited and that DOE/WMPO appreciated the preliminary nature of the review. The discussion that followed suggested that members of the group had received the material favorably. The SNL-PA representative (Peters) stated that he likes the structure and wasn't too concerned about the absolute value of the numbers. The NRC-OR (Prestholt) noted that agreement on these definitions would be beneficial to all parties; he further noted that he was slightly surprized by the presentation, but pleasantly so.

It was agreed to disseminate this information among the project participant staff not represented at the meeting and to advise DOE/WMPO of any concerns.

The group next reviewed the 15 points for discussion provided by the NRC staff to DOE/HQ in a letter to Allan Jelacic on November 6, 1985 (Attachment 3). The following assignments were made for preparation and responsibility for presentation.

1. The logic and rationale of the AO (discussion point 1) will be prepared and given by M. D. Voegele. This presentation will also address other discussion topics requested by NRC including the following: Point 5, clarification of the terms processes, phenomena and events; Point 6, inclusion of ground water travel time in preclosure issues; Point 8, the difference between remnant and residual stress; Point 9, consideration of thermal effects on tectonic processes; and Point 10, the role of consensus opinion in reducing uncertainty.

2. The intended application of terms identified in the provisional list of definitions (discussion Point 2) will be prepared by Neil Norman. It is anticipated that this topic could serve as an introduction to the discussion on the list of definitions. That discussion could be moderated by DOE/HQ although NNWSI Project will be prepared to take the lead if requested.

3. The criteria to be used to identify significant (anticipated and unanticipated) seismic/tectonic processes (discussion topic 3) will be prepared by C. G. Pflum. The material will be abstracted from his presentation that was given to DOE/HQ on November 13, 1985, and will not include numerical values for the criteria as requested by DOE/HQ.

4. The methodology for evaluating impact of processes on performance objectives (discussion topic 4) will be prepared by Steve Bratt. It is not known at this time how this topic will be treated at the workshop. It could be postponed until the site specific workshops.

The remainder of the discussion topics are the responsibility of DOE/HQ and Weston. The NNWSI Project will be prepared to support these presentations. The topic of the list of definitions for discussion with NRC was briefly reviewed BWIP (J. Kovacs) noted that BWIP is not yet ready to agree to definitions because they have not yet been widely reviewed by their project. DOE/WMPO (Szymanski) noted that no definitions to which BWIP took exception would be provided to NRC.

The final topic of discussion was concerned with three draft documents provided by Bechtel (Attachment 4), Blume (Attachment 5), and Sandia (Attachment 6), respectively. Bechtel (Norman) presented a proposed revision to the AO that they felt would be an easier outline to write to. It was observed that the proposed outline adequately dealt with preclosure topics but paid little attention to the significance of postclosure topics. It was also suggested that the proposed outline might more readily serve as an outline for the appropriate section of the SCP. The material presented by Blume (Owen) represented an early draft of the section of the position paper for which they had responsibility (Section 5.2). The material presented by Sandia (Peters) represented an example of material they had prepared to support the EA that treated the topic of postclosure performance assessment relative to seismic tectonic considerations.

The Working Group members were requested to review this material and provide comments to DOE/WMPO.

Seismic Tectonic Working Group
Nov 14, 1985

11/14 Attachment 1

Name	ORG	Phone #
M. GLORA	SAIC/NNWSI	FTS 575-1463
Steve Bratt	SAIC/San Diego	619-458-2575
Chris Pflum	SAIC/NNWSI	FTS -575-1464
Neil Norman	Bechtel	415-768-4035
C.V. Subramanian	SNLA	FTS 846-0158
Norman Owen	URS/Blume	415-957-5360
SZYMANSKI	DOE/NV	FTS 885-1503
Don Emerson	LLNL	(415) 422-6504
JOE LITEHISER	Bechtel	(415) 768-7145
Brad Myers	USGS	FTS 776-1274
Ralph Peters	SNLA	844-4001 (FTS)
M.D Voegele	SAIC/NNWSI	FTS 575-1460
Paul Prestholt	NRC-OR	FTS 598-6125
TERRY GRANT	SAIC/NNWSI	
BRUCE HURLEY	DOE/RL - BWID	FTS 444-7059
JOHN KOVACS	"	" -1291

Attachment 2

PROPOSED REFINEMENTS TO CONSEQUENCE AND POSITION ASSESSMENT

1. EMPHASIZE PERFORMANCE OBJECTIVES.

   Discuss directly, the impact of given geologic effect on each of the performance objectives outlined in 10CFR60.

2. COVER TECHNICAL BACKGROUND MORE THOROUGHLY.

   Place detailed observations, theory, probability calculations, etc., in appendices, perhaps one appendix for each geologic effect. The contents of final table would include summaries of the conclusions of appendices.

3. ELIMINATE REDUNDANCY.

   For example, inclusion of vibratory ground motion under faulting would eliminate overlapping geologic effects sections.

4. UTILIZE ACCEPTED DEFINITIONS.

   For instance, stated positions on the importance of geologic effects at site could be given in terms of "anticipated" or "unanticipated".

* proposed *

TECTONIC PROCESS	GEOLOGIC EFFECT	CONSEQUENCE AT GENERIC SITE	POSITION ASSESSMENT FOR YUCCA MOUNTAIN
Identify tectonic processes. FAULTING STRAIN VOLCANISM	In appendices: -Identify secondary effects of tectonic processes. -Compile observations. -Develop understanding of physics. -Develop understanding of conditions necessary for occurrence. Conclusions in table. examples: OFFSET ALTER GEOHYDROLOGY EXTRUSION	Identify possible impact of given geological effect on compliance with the following performance objectives: RETRIEVABILITY OPERATIONAL RELEASES LIFE OF WASTE PACKAGE POSTCLOSURE RELEASES RELEASE RATES TRAVEL TIMES	In appendices: -Examine for presence of conditions necessary to foster given consequence. -Compile observations, recurrence intervals, probabilities. In table: -State conclusions from appendices. -State position on potential for occurrence of consequence at Yucca Mountain. NOT IMPORTANT NOT ANTICIPATED NOT LIKELY ETC.

PROPOSED ASSESSMENT FORMAT

I. FAULTING

- A. Dislocation
  - 1. retrievability
  - 2. operational releases
  - 3. life of waste package
  - 4. postclosure releases
  - 5. release rates
  - 6. travel times
- B. Vibratory ground motion
- C. Strain outside fault zone
- D. Alter geohydrology (permeability, strain, ground motion, temporary, permanent)
- E. Induce other faulting
- F. Induce landslides, debris flows, or liqification
- G. Alter patterns and rates of erosion
- H. Alter gaseous diffusion rates
- I. Alter dissolution rates
- J. Man-induced (explosions, water loading, mining)

* proposed *

II. STRAIN (non-dislocational)

A. Alter strain energy

B. Alter geohydrology

C. Alter patterns and rates of erosion

* proposed*

III. VOLCANISM

A. Extrusive

B. Intrusive

C. Explosive

D. Alter geohydrology

E. Alter patterns and rates of erosion

F. Increase heat flow

G. Induce strain changes

H. Induce dislocations

I. Induce vibratory ground motion

****

PRIORITIES FOR COMPLETING SEISMIC/TECTONIC CONSEQUENCE AND POSITION ASSESSMENT

****

1. AGREE ON FORMAT OF PACKAGE.
   - table or outline
   - appendices
   - sections and contents

2. COMPILE BACKGROUND INFORMATION ON GEOLOGIC EFFECTS OF TECTONIC PROCESSES (APPENDICES).
   - observations
   - theory
   - occurrence conditions

3. DETERMINE OPTIMUM MEANS OF RELATING GEOLOGIC EFFECTS TO BOTH PERFORMANCE OBJECTIVES AND SPECIFIC CONSEQUENCES AT A GENERIC SITE.
   - risk to components of repository
   - risk to compliance with performance objectives

FLOW DIAGRAM

IDENTIFY TECTONIC PROCESSES

IDENTIFY GEOLOGIC EFFECTS

UNDERSTAND EFFECTS

IDENTIFY CONSEQUENCES OF EFFECTS
AT GENERIC REPOSITORY

RELATE TO REGULATORY GUIDELINES

UNDERSTAND EFFECTS AT SPECIFIC SITE

ASSESS LIKELIHOOD AND CONSEQUENCES
OF OCCURRENCE OF EFFECTS AT SPECIFIC SITE

PARAMETERS

REGULATORY GUIDELINES

SAFETY

DISRUPTION OF REPOSITORY

TECTONICS

SECONDARY PROCESSES

GENERIC SITE

SPECIFIC SITE

INFORMATION NEEDS

FUTURE WORK

ETC.

Voegele

SEISMIC/TECTONIC CONSEQUENCE AND POSITION ASSESSMENT

MOTIVATION:

Relationships between tectonic processes and the safe operation and performance of a high-level nuclear waste repository tend to be ill-defined.

IMMEDIATE OBJECTIVE:

Develop a framework for use in the SCP within which tectonic issues and their possible impacts on repository operation and performance can be identified, understood, and related both to each other and to regulatory guidelines.

NNWSI ULTIMATE OBJECTIVES:

Assess the importance of all pertinent tectonically-induced consequences at the Yucca Mountain site.

Prioritize consequences in order of importance.

Focus further study on anticipated consequences and causative tectonic processes.

4. ASSESS LIKELIHOOD OF EACH CONSEQUENCE AT GENERIC REPOSITORY.
   - is further information necessary to make assessment?

5. ELIMINATE CONSEQUENCES THAT ARE IMPOSSIBLE OR HIGHLY UNLIKELY AT GENERIC SITE.

6. COMPILE INFORMATION NECESSARY TO ASSESS IMPORTANCE OF CONSEQUENCES AT YUCCA MOUNTAIN (APPENDICES).
   - observations
   - occurrence conditions
   - recurrence intervals
   - deterministic/probabilistic assessments
   - severity of consequence

7. DEVELOP POSITION IN LIGHT OF REGULATORY FRAMEWORK AND SEISMIC/TECTONIC SETTING OF SITE.
   - is further information necessary to develop position?

8. ELIMINATE CONSEQUENCE THAT ARE IMPOSSIBLE OR HIGHLY UNLIKELY AT YUCCA MOUNTAIN.

9. FOCUS FURTHER STUDY ON ANTICIPATED AND UNANTICIPATED GEOLOGIC EFFECTS AND CONSEQUENCES.

* current state of assessment *

PROCESS	GEOLOGIC EFFECT	CONSEQUENCE AT GENERIC SITE	POSITION ASSESSMENT FOR YUCCA MOUNTAIN
Identify tectonic processes.	Identify secondary effects of tectonic processes.	Identify possible impact of given geologic effect on operation and performance of generic nuclear waste repository.	Examine for presence of conditions necessary to foster given consequence.
FAULTING VIBRATORY GROUND MOTION STRAIN VOLCANISM	Compile observations. Develop understanding of physics behind the effect and conditions necessary for its occurrence.		Compilation of observations, recurrence intervals, and probabilities. Statement of position on potential for occurrence of consequence at Yucca Mountain.
	examples: OFFSET SHAKING STRESS AND STRAIN EXTRUSION ALTERATION OF GEOHYDROLOGY	examples: PRECLOSURE DAMAGE TO WASTE PACKAGE PRECLOSURE DAMAGE TO SURFACE FACILITIES POSTCLOSURE FLOODING OF REPOSITORY LEVEL EXTRUSION THROUGH REPOSITORY LEVEL	NOT IMPORTANT (i.e., to repository performance) IMPORTANT PROBABLY NOT IMPORTANT. FURTHER INFORMATION REQUIRED. ETC.

CURRENT STATE OF CONSEQUENCE AND POSITION ASSESSMENT

I. FAULTING (PROCESS)

A. Offset (GEOLOGIC EFFECT)

(CONSEQUENCES AT GENERIC SITE)

1. preclosure damage to waste package
2. postclosure damage to waste package
3. preclosure damage to emplacement holes
4. preclosure damage to subsurface structures
5. preclosure damage to surface facilities

B. Stress and strain outside fault zone

C. Alter patterns and rates of erosion

D. Alter surface and subsurface geohydrology by fault offset

E. Alter surface and subsurface geohydrology by post-seismic strain

F. Induce other faulting

G. Altered geochemistry due to changes in geohydrology or stresses

H. Enhanced dissolution due to changes in geohydrology

I. Change gaseous diffusion rates due to fracture and faulting

J. Induced by explosion testing

K. Induced by water loading

L. Induced by mining activity

* current *

II. VIBRATORY GROUND MOTION

A. Shaking

B. Alter surface or subsurface geohydrology

C. Altered geochemistry due to changes in geohydrology

D. Enhanced dissolution due to changes in geohydrology

E. Change gaseous diffusion rates due to induced fracture

F. Induce other faulting

G. Induce landslides, debris flows, liquification

H. Induced by explosion testing

I. Induced by water loading

J. Induced by mining activity

* current *

III. STRAIN (non-dislocational)

A. Stress and strain changes

B. Alter patterns and rates of erosion

C. Alter surface and subsurface geohydrology

* current *

IV. VOLCANISM

A. Extrusion

B. Intrusion

C. Explosion

D. Stress and strain changes

E. Alter surface and subsurface geohydrology

F. Increase heat flow

G. Induce faulting

H. Induce vibratory ground motion

Attachment 3

Voegele

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 06 1985

Dr. Allan Jelacic
Geosciences & Technology Division
Office of Civilian Radioactive
  Waste Management
Department of Energy
Washington, DC 20585

Dear Dr. Jelacic,

Enclosed are points for discussion with your staff at the December 3-4, 1985 meeting regarding the rationale for seismic/tectonic investigations for licensing a nuclear waste repository. The list of points should be considered in developing an agenda.

Please contact me (FTS 427-4728) if you have any questions.

Sincerely,

Pauline P. Brooks for

Seth M. Coplan, Section Leader
Repository Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
  and Safeguards

Enclosure:
Points for Discussion

~~8511120362~~

NOV 0 6 1985

Points for Discussion with
DOE on "Rationale for Seismic/Tectonic
Investigations for Licensing a
Nuclear Waste Repository"

Voegele 1. ✓ The logic flow in the Table of Contents.

Norman 2. Section II B: the intended application of terms identified in the provisional list of definitions.

Def A/U pflow 3. Section III A: criteria to be used to identify significant seismic/tectonic processes.

[illegible] 4. Section III A: methods for evaluating potential impact of seismic/tectonic processes on pre-closure and post-closure performance objectives.

brief [illegible] 5. ✓ Section III A and C: clarification of the terms processes, phenomena, and events.

MRV 6. ✓ Section III C: inclusion of groundwater travel time in pre-closure as well as post-closure issues. eg broken can ? [illegible] not [illegible]! get [illegible] from [illegible]

NO clarify ✓7. Section IV B: limitations of the ground motion models and the distribution functions.

MRV [illegible] 8. ✓ Section IV B: the difference between remnant and residual stress. applied in past; [illegible]

[illegible] 9. ✓ Section IV C: the consideration of thermal effects on tectonic processes. [illegible] is analogous to man induced seismicity - eg "sorry we forgot"

MRV 10. ✓ Section IV D: the role of consensus opinion in reducing conceptual and numerical uncertainties. all answers will not be fully quantifiable, we need judgments; understand, characterize, alleviate [illegible]

W 11. Section V B: what is meant by complementary earthquake approaches acceptable for other nuclear facilities.

W 12. Section V B: the specific structures, systems and components important to safety that would be vulnerable to the process.

No clarify ✓13. Section V B: the proposed method of fragility analysis that will be used to evaluate the impact based on a pre-conceptual level of design of such structures, system and components.

W 14. Section VI C: inclusion of shaft and borehole seals in the list of items that should have effects of seismic/tectonic phenomena examined.

HQ clarify 15. Section VII B: the adequacy of the conceptual design to allow meaningful analysis.

Attachment 4

C 907

Bechtel National, Inc.
Engineers—Constructors

Fifty Beale Street
San Francisco, California
Mail Address: P.O. Box 3965, San Francisco CA 94119

November 11, 1985
BSL-163

C. V. Subramanian
Sandia National Laboratories
Division 6311
P.O. Box 5800
Albuquerque, New Mexico 87185

Attn: Jim Neal

Subject: Seismic/Tectonic Position Paper, Preliminary Re-draft

Dear Subra,

Enclosed is a re-draft of sections of the seismic position paper as was discussed at our meeting on Thursday, November 7 in San Francisco.

Very truly yours,

Neil Norman

Neil A. Norman, PE
Project Manager

NAN/LJ/jm
Attachment
cc: Mary Tang, w/enc.
6310, NNWSICF
L.W. Scully

Seismic Position Paper

Table of Contents

016①

1.0 Introduction

1.1 Purpose and Scope

The purpose of this document is to present the principal seismic and tectonic design considerations used in the design of geologic respositories for the preclosure and postclosure periods. This document presents the generic seismic design strategy that is used by all repositories, a summary of existing information on seismic-tectonic characteristics for each site, and a tabulation of the specific site characterization data needs for each site required to implement the seismic design strategy.

The seismic design strategy consists of three major elements: (1) a probabalistic seismic hazard analysis to establish ground motion parameters, (2) a common seismic design approach for a design basis earthquake for establishing the responses of structures, systems, and components, (3) the use of design response (i.e., fragility analyses) and consequence analyses to improve the margins of safety and to assure that the repository can be constructed and operated at a proposed site without undue risk to the health and safety of the public due to seismic-tectonic issues. Based on a review of existing seismic-tectonic characterizations and information for each site, a description of the nature of investigations required to obtain tectonic and seismic data necessary to carry out the processes and analyses required in the seismic design strategy is given. These latter data needs are among those presented in the SCP's for each site.

This document does not include volcanic phenomena.

2.0 Regulatory Framework

(This is 1 page and t.b.d.)

3.0 Seismic Design Strategy

3.1 Introduction

The approach to seismic design for a repository contains three main elements. First, a complete probabilistic seismic hazard analysis is performed for the proposed site in order to establish a quantitative relationship of the probability or frequency of exceeding a specific ground acceleration vs the ground acceleration. The seismic hazard analysis approach and an estimate of its required uncertainity is based on regional and site specific tectonics and ground attenuation properties and is discussed in Section 3.2. The specification of a design ground motion of the design earthquake (DE) is taken from the seismic hazard analysis. The DE is based on the acceleration expected on the average of once every 1000 years (i.e., the 10^{-3} annual acceleration hazard) at the site. This hazard or DE value corresponds to a 4% chance of exceedance of the DE at the site during the 40 year period in the operating lifetime when significant inventories of nuclear material will be in surface process and in temporary surface storage.

A second element consists of using traditional structure design methods as used for other licensed nuclear facilities for the design of all structures, systems and components containing radioactive materials and required to withstand a design earthquake, DE. This design approach is outlined in Section 3.3. The selection of items required to withstand the DE is obtained from both engineering judgment and preclosure safety analyses performed in parallel with the facilty design.

The third element consists of a probabilistic analysis of the design response of select major structures, systems, and components using seismic fragility analyses as outlined in Section 3.4.1. This selection of items for analysis is guided by the consequence analyses of the seismic PRA studies used in the preclosure safety analyses. A screening analysis is used to limit the number of items requiring detailed analyses. The results of the fragility analyses are used to develop recommendations for redesign of select portions of the facility in order

01 6②

to remove primary seismic failure mechanisms and to introduce additional margins of safety into the design of items already designed to withstand the DE per the structural design methods of Section 3.3.

3.2 Seismic Hazard Analysis

This section describes the approach to establish ground motion parameters used for design of the surface and subsurface respository facilities.

3.2.1 Surface Ground Motion

All repository sites must be evaluated for their earthquake potential. To quantify this earthquake potential and to provide basic information that, in conjunction with a specific seismic design procedure and a specified acceptable hazard level, can be used to define seismic design ground motions, a formal seismic hazard analysis will be performed. A general discussion of a methodology to perform seismic hazard studies at all repository sites is presented in this section.

Beginning over fifteen years ago several procedures were developed that allowed formal calculation of probabilistic earthquake design parameters (Cornell, 1968; Cornell and Vanmarke, 1969), and a number of studies have been performed incorporating these procedures in the Yucca Mountain site area (Algermussen and Perkins, 1976; Algermussin et al., 1982; Algermussin et al, 1983; Rogers et al., 1983, Blume, 1985). In each of these studies the region is divided into seismic sources for which future earthquakes are considered equally likely to occur at any location. For each seismic source, the rate of occurrence for earthquakes larger than a threshold level are estimated. This parameter is termed the source activity rate. The sizes of successive events for each source are assumed to be independent and exponentially distributed; the slope of the log number versus frequency relationship is estimated from the relative frequency of different sizes of events observed in the historical data. This slope, often termed the b-value (Richter, 1958), is determined either for each seismic source individually or for all sources in the region jointly. Finally, the maximum possible of earthquakes for each source zone is determined using judgment and the historical record.

One strength of this type of analysis is that all assumptions underlying a measure of earthquake hazard potential are explicit. Also, a wide range of assumptions may be employed in the analysis procedure. For example, different conclusions about source shape, activity, or maximum magnitude may be reached by different experts for any specific repository site region. Each set of assumptions can be given a relative confidence value, and all assumptions included into the seismic hazard evaluation weighted by these confidence values.

Earthquake sources may also be modeled as faults instead of as homogeneous areas. Because some repository site regions contain a number of faults that might be considered potential sources of future vibratory ground motion at the site, it will be necessary to include the ability to considered fault sources in the detailed site hazard analysis. This has not yet been done in previous evaluations.

A number of details of earthquake parameter characterizations for use in seismic hazard analyses are ultimately important to the results. Several of these are mentioned briefly here as suggested incorporations into the hazard analysis for any repository site.

Derivation of reasonable seismic source areas and recurrence statistics requires a careful compilation and analysis of all site region earthquakes. Several catalogs exist for the candidate repository sites as noted in Section 4.0. All earthquake catalogs are imperfect and especially the one near the Yucca Mountain site for which earthquake population density has always been low, instrumental coverage has been poor until the 1970's, and NTS explosion aftershocks have been difficult to separate from possible natural tectonic events in the same area. Some special efforts will be required at some repository areas to overcome these difficulties in the development of appropriate earthquake recurrence statistics. Several newly developed procedures to analyze earthquake catalogs for completeness and cluster event removal are now available, (Venesiano, 1985). These and more conventional analysis should both be tried at the repository sites.

The time-independent occurrence and exponential size distribution of earthquakes are two basic features of the conventional preliminary seismic hazard analyses. Both assumptions are excellent for seismic sources of adequate size. For detailed site-specific analyses, however, both time-dependent (non-gaussian) and characteristic magnitude (non-exponential size) models have been proposed in the literature.

These models, used for adequately characterized faults, can use explicit evidence from historic earthquake or geologic studies to specify seismic hazard from a fault whose time of expected next rupture depends on the time since the last rupture and where expected maximum earthquake in the future is assumed to be similar to past events. These types of models should be considered, and particularly at the Yucca Mountain site.

Seismic hazard results also typically depend critically on the rate of ground motion attentuation with distance and depth. Little direct measured evidence of attentuation from earthquakes exists at some repository sites. Some data is required to develop an adequate hazard characterization. Preliminary evidence suggests that near-surface attenuation may be higher than normal at Yucca Mountain. This and any near field attenuation from very close sources, will be issues that will need to be resolved for all repository sites.

3.2.2 Subsurface Ground Motion

(This is tbd) This section will describe how the design ground motion parameters for the underground repository facilities are determined from the basic sesimic hazard analysis discussed in Section 3.2.1.

3.2.3 Design Earthquakes

This section describes the rationale and the method used to establish single design values of levels of ground motion for the surface and subsurface facilities during the preclosure and postclosure periods. The values are taken from the seismic hazard curves for specific recurrence intervals.

3.3 Design Approach for Design Earthquake

This section describes the design approaches used for the surface and subsurface repository facilities for the preclosure and postclosure periods. The design approaches will be the bases for licensing the repository and for demonstrating compliance with performance requirements in 10CFR60 which ensure public safety and waste isolation.

3.3.1 Preclosure Period

This section discusses the specific design approaches used for the operating period of the repository as the bases to licensing.

3.3.1.1 Surface Facilities

The repository surface facilities include the waste handling facilities, and support and service facilities. The support and service facilities that do not contain radioactive materials such as the administration building and warehouse, etc, will be designed according to the Uniform Building Code. The waste handling facilities contain radioactive waste materials and may be related to public health and safety. The analysis and design approaches for these waste handling facilities which are to resist the design earthquake during the pre-closure period are described as follows.

The waste handling facilities are enclosed in buildings of low profile. The remote handling operations are performed in hot cells which are constructed of thick reinforced concrete walls and concrete mat foundations. This type of structure and construction provides high resistance to earthquake vibratory ground motion. These buildings are founded on stiff soils or bedrock, and thus limit the amplification of ground motion by soil strata.

The waste handling facilities will be analyzed with the state-of-the-art dynamic seismic analysis methods and computer codes, and designed according to current dynamic seismic design procedures and industrial codes and standards.

Mathematical modeling of structures will utilize either the lumped mass model or the finite element model. For structures supported on rock, a fixed based model will be used. When a structure is supported on soil, soil-structure interactions, using lumped parameter representation (foundation impedances) or finite element representation, will be taken into account by coupling the structural model with the supporting soil.

To evaluate the response of structures, the modal superposition method will be used for cases with frequency independent parameters. In case frequency dependent parameters are present, such as the foundation impedance functions for a layered site, the method of frequency domain solution will be used.

The modal damping values, expressed as a percentage of the critical damping, will be those recommended in Table 1 of the USNRC Regulatory Guide 1.61.

The modal responses in each direction will be combined using the square root of the sum of the squares method for not closely spaced modes, and using the ten percent method for closely spaced modes. The total structural response from the analysis of two horizontal and one vertical directions will be combined using the square root of the sum of the squares method. These methods of combining modal responses and spatial components will be in accordance with regulatory positions 1.1., 1.2.2, and 2.1 of the USNRC Regulatory Guide 1.92.

An additional eccentricity equal to 5 percent of the maximum width of the structure normal to the direction of the horizontal input motion will be used in the design to account for ground torsional motion as specified in subsection II.11 of the USNRC Standard Review Plan Section 3.7.2.

The floor design response spectra are needed for the dynamic analysis of the systems or components supported at various locations of the supporting structure. For generation of floor design response spectra from the time history motions at the various floors or other locations of concern, a synthetic acceleration time history which is compatible with the design response spectra will be used as the ground input.

For structures and components to perform their design functions, the loads generated by the DE will be combined with other applicable design loads and the design will meet the acceptance criteria in accordance with subsections II.3 and II.5 of the USNRC Standard Review Plan Sections 3.8.4 and 3.8.5.

The design of concrete hot cells and other reinforced concrete components of the waste handling building will be in according with ACI-349, "Code Requirements for Nuclear Safety-Related Structures" or ACI-318, "Building Code Requirements for Reinforced Concrete". The design of structural steel portion of the waste handling building will be in accordance with AISC S326-78, "Specifications for Design, Fabrication and Erection of Structural Steel for Buildings". Alternatively, inelastic seismic analysis and design methods will be considered for application.

The waste handling building will be designed to resist the design ground acceleration in according to the stringent requirements for the nuclear facilities and conforming to the conventional structural design practice. Additional design provisions and considerations may be implemented based on the analysis results of Section 3.4.1.1 which may improve the probability of maintaining the safety functions of the waste handling building subject to speculated fault movement as well as postulated larger ground motion than the design earthquake ground motion.

Some other general structural design considerations that could be used include:

- Provide Ductility at Critical Areas of the Structure: Provision of additional reinforcing steel at the connections between wall and ceiling slabs and wall and floor slabs and other critical locations of the reinforced concrete waste handling cell structure will increase the ductility of the building. This will improve the performance of the structure in the post-yielding stages, further reduce the chance of any sudden collapse, and reduce cracking and spalling. Thus it will increase the structural resistance to the ground motion or displacement.

- Limit the Maximum Structural Dimension to 200 ft: Seismic separation joints will be introduced into the waste handling building structures at locations of abrupt changes in physical dimensions. This will reduce eccentricity and stress concentrations in the structure. Each portion of the structure between seismic structural joints will not be more than 200 ft in any direction. This will help controlling stress and cracking due to temperatures and shrinkage during construction. This structure separation will also control and localize cracking and damage of a portion of the waste handling building due to any ground displacement.

- Separate the Surface Storage Vault: The surface storage vault has the largest inventory of nuclear waste in the waste handling building. It may be separate from the rest of the building as an independent structure. It can be relocated or can be structurally strengthened if necessary.

- Conservative Operational Procedure: Operating procedures can be instituted to minimize the waste material stored on the surface and to limit the amount of waste stored in one facility at any given time. This will reduce the potential radiological consequence if an accident should occur.

- Sand Cushion Foundation: These are other structural devices being developed for improving the structural performance during ground motions or displacements. These include the use of a sand cushion or other energy absorbing materials as part of the structural foundation. These ideas can be evaluated and considered for implementation for critical areas of the waste handling building.

- Additional Analyses: More sophisticated analyses include non-linear structural analysis to study the post-yielding behavior of the structure and probability risk analysis to assess the risk of structural failure and potential radiological consequences. These analyses will address certain "what if" questions or speculations of a larger earthquake than the design earthquake or a potential fault movement and are discussed in Section 3.4.1.1.

3.3.1.2 Subsurface Facilities

(This is t.b.d.)

3.3.2 Postclosure Period

This section discusses the specific design approaches used to ensure waste isoloation for 10,000 years as required by 10CFR60 and 10CFR191.

(This is t.b.d.)

3.4 Design Response and Consequence Analysis

This section describes the approach used to quantify the "what if" questions due to seismic-tectonic issues that will be raised for the surface and subsurface repository facilities during the licensing process. The approach is based upon the probabilistic risk assessment analyses (PRAs) used for the preclosure and postclosure safety analyses and the probabilistic seismic hazard results used to establish ground motion design parameters.

3.4.1 Preclosure Period

This section discusses the methodology to be employed during the operating period of the repository facilities.

3.4.1.1 Surface Facilities

Introduction

The seismic design practices for structures, systems and components as outlined in Section 3.3.1.1 above have margins of safety due to the numerous conservatisms used in the seismic design analyses. The largest single source of conservatism is due to ignoring the inelastic absorption capacity of a structure and the fact that an earthquake provides only a limited amount of energy input. Additional conservatisms are generally introduced into the analyses by modifying with a bias the design earthquake (DE)* response spectra taken from the seismic hazard analysis. This biased spectra is used for subsequent deterministic linear elastic analyses of the response parameters. The calculated stress responses of structures, systems and components used in the elastic design analyses are usually based on code allowable stress levels that are well below the inelastic range. The analyst also generally employs conservatively specified minimum material strength parameters that are well below actual strengths of materials in order to introduce further factors of safety into the design analyses. This type of conservative, or deterministic, approach is used in order to be assured that a structure designed for the DE will not fail.

No quantitative attempt is generally made by the deterministic structure analyst or by the design process to address the response of the structure, system or component to ground accelerations greater than the DE. The structure analysts can quantify conservatisms in their deterministic designs used to assure an acceptable performance at levels of ground motion equal to the DE. However, this is not routinely done as part of the design process.

To systematically address and to quantify the responses of structures, systems and components beyond the DE levels of ground motion, a supplemental probabilistic analytical approach must be used. The approach is based on and guided by the results from probabilitstic risk assessments used for preclosure safety analyses (PSA) of the repository structures, systems and components and probabilistic seismic fragility analyses. These combinations of analyses allow the systematic development of the "what if" answers to the response of structures, systems and components, for levels of ground motion greater than the DE.

However, it must be remembered that the DE is itself unlikely to occur as there is only a 5% chance of exceeding the DE ground motion

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* See definition in Section 6.

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during a 50 year operating lifetime of the repository based on a seismic hazard analysis. Thus, the results of probabilistic analyses for ground motions beyond the DE are even less likely to occur and this fact must be kept in perspective at all times. The objective of this probabilistic analytical seismic design or assessment approach is to extend, refine, and quantify the seismic design approach and any uncertainties outlined in 3.3.1.1. If desired, the result of these analyses can be used to introduce larger margins of safety present into the final structural designs. This section outlines those probabilistic seismic design methods.

Background

In the design of the repository facilities, safety analyses are performed. For first-of-a-kind facilities, preliminary safety analyses together with the facility designers experience and judgment are used to develop a set of design bases accidents. These include a design earthquake (DE) and the determination of associated systems, structures and components that must be designed to withstand the DE. For the Yucca Mountain repository design, a probabilistic risk assessment approach is being used as the bases for the preliminary preclosure safety analyses (PSA). The preclosure safety analyses are the key to developing a sound approach to the "what if" answers for questions that will arise during the licensing process, including "what ifs" for the response of structures, systems, and components due ground motions larger than the DE values. The PSA is used to identify all accident scenarios within the repository facility, the radiological consequences resulting from the scenarios, and the probability of accident occurrences.

The PSA methodology to be employed is comprised of three levels of evaluation: (1) systems analysis, (2) release analysis, and (3) consequence analysis. For the PSA, an initiating event is selected and evaluations are performed to determine the potential radiological consequences and associated occurrence probability within the facility as a result of that initiating event. Initiating events include both external events and internal process-generated events. External events typically include earthquakes, floods, tornadoes, loss of offsite power, or other on-site natural phenomena, and human induced events. Process-generated internal events include mechanical failures, fires, human errors, or other events which could ultimately result in accident scenarios.

In the systems analysis portion of the PSA analysis, earthquake accident scenarios are developed into detailed event trees featuring different accident sequences based on the response of structures, systems, and components to the initiating seismic event and subsequent seismic introduced interactions with the design structures, systems and components. Radionuclide release analyses are then performed to determine the quantity and type of radioactive releases resulting from each accident sequence in the earthquake event tree. Finally, consequence analyses are performed to determine the calculated radiological doses to the general public. After completion of the PSA analysis for a well-compiled set of key initiating events, a comprehensive safety analysis for the repository will be produced. At this point, the structures, systems and components required to achieve public safety have been initially defined.

The PSA analyses depend not only upon the selection of initiating events, but also they rely heavily on a sound database for the purpose of the probability evaluations. The data base must include data not only on mechanical and human reliability and other process related parameters but also on historical and the repository project specific data on regional and location specific seismic-tectonics. Estimates of the uncertainties in both the probabilities and the consequences associated with each scenario are important as each is used to evaluate the risk of a postulated accident. To reduce the uncertainty and raise the level of confidence in the PSA results, the data base must be as complete as possible. Data may be compiled from literature, government, and industry data banks wherever applicable. Since any repository facility is a first-of-a-kind or prototype facility, only experimental research and testing data will be available for some process-generated internal events. New repository project specific data will need to be obtained for the case of external initiating events such as earthquakes. These data needs will be determined by the site specific hazard analyses and soil-bedrock interaction properties discussed in Sections 3.2 and 3.3.1.1.

Methodolgy for Structural Design Response and Consequence Analyses

Selection of structures, systems and components for fragility evaluations is an iterative process which requires close interactions between the PSA systems analyst and the structural analyst. Initially the PSA systems analyst based on his knowledge of the plant systems and radioactive contents has to generate a list of candidate structures, systems and components whose failure may lead to undesired radiological consequences during a DE. The PSA systems analyst is guided in the selection and identification by the earthquake accident sequences or event/fault trees constructed during PSA systems analyses. The number of items requiring seismic structural analysis will vary with the stage of the design, or the design detail, available for the structures, systems or components. This detail is also reflected in the level of detail in the PSA accident sequence analyses. Therefore, the degree of efforts and resources required will vary and increase as the stage of design advances through advanced conceptual, license application and the construction package repository designs.

Once the items requiring analyses of seismic responses and consequences are identified from the PSA earthquake accident sequence event/fault trees, the structural analyst develops fragility curves for significant failure modes for each of these structures, systems and components. After an initial set of fragility analyses are performed, a screening analysis is then used by the PSA system analyst and the structural analyst to reduce the number of items requiring further more detailed seismic fragility analysis. This screening step allows the resources to be concentrated on the items which contribute the most to the total radiological release risks due to seismic initiating events. For example, items identified by the structural analyst as having low frequencies of failures at extremely high ground accelerations such as 6-10 times the DE are dropped from further refinements in the fragility analyses. Refinements of fragility analyses are continued for those items identified with significant frequencies (probabilities) of failures at ground accelerations in the range of 1.5 to 4 times the DE acceleration. The objective of the initial screening process is to allow more detailed fragility analyses to be carried out only for those components of accident sequences which contribute significantly to unacceptable radiological consequences.

Because no repositories facilities have yet approached final design, unique opportunities exist to identify and introduce changes to the design that can remove and reduce primary seismic failure mechanisms through redesign well before any construction has taken place. This is a unique opportunity for the repository projects and illustrates the strength of using this dual approach to quantify the responses of structures due design parameters greater than the DE and to, if desired, add additional margins of safety into already conservative and safe designs. For example, a design change could be to increase the level of ductility and detailing of connections at the most common failure points or to increase the ductility at a specific point in order to either remove or to shift a failure mode to outside of the range of interest in the fragility analyses. (e.g., 6-10 times the DE levels of ground motion). Design changes would only be proposed for items that contribute significantly to reducing the seismic risk portion of the overall radiological consequences from the repository facility calculated in a repositories PSA.

For seismic fragility analyses, the seismic fragility of a structure, system or component is defined as the conditional frequency of its failure for a given value of a seismic response parameter such as a stress, a moment, an acceleration, a displacement, etc. The fragility analysis results are typically plotted as the cumulative probability or frequency of failure (Y-axis) between 0 and 1 of as a function the peak ground motion or acceleration (X-axis) less than or equal to a given value. A key issue is that the definition of failure must be agreeable to both the structural analyst performing the fragility analyses and to the PSA systems analyst who must judge the consequences of seismic failure of an item in the specific earthquake event/fault trees. Development of failure definitions needs to be done before the initial fragility analyses are performed. For example, structures may be considered to fail when they can not perform their designated function--which could be containment of radioactive materials. Structures could be considered to fail functionally when inelastic deformations of the structure subject to a seismic load are estimated to be sufficient to potentially interfere with the operability of the ventilation system or other equipment attached to the structure. Alternatively, failure could be defined as when the structure is fractured sufficiently so that certain equipment attachments fail.

Once definitions of failure have been agreed to and fragility analyses made, the relative importance of a particular seismic failure mode, as determined by the structural analyst, is assigned by the PSA system analyst. In some cases, seismic failure modes will not be considered important to the overall consequences and no further seismic fragility analyses will be made. In other cases, recommendations will be made by the PSA systems analyst and the structural analyst for possible facility design changes in order to improve the overall margins of safety in the facility designs and to lower the overall calculated radiological risk consequences. It must be recognized that the fragility analyses are not used to determine structural design values which are all set deterministically with the methods of section 3.3.1.1. Instead the fragility results are used to identify and if desired remove significant failure modes.

The above discussions for seismic design have considered vibratory ground motion but not explicitly the movement of faults directly under a major nuclear structure. To date there are few known established design practices for buildings located on active faults. The probablistic analysis methods and the fragility analyses discussed above can be used to systematically develop some insights into the range of consequences from fault displacements under a major waste handling building structure. The results from such "what if" analyses can be used and compared with the bounding consequences determined from the probabilistic analyses for the vibratory ground motion earthquake scenarios. It is anticipated that any consequences from fault displacement scenarios will have a much lower frequency than ground motion scenarios. This may produce results that show fault displacements will not provide any significant contribution to the overall seismic risk of a specific repository site or design and therefore can be neglected in the explicit structure design analyses of Section 3.3.1.1.

3.4.1.2 Subsurface Facilities (t.b.d.)

3.4.2 Postclosure Period (t.b.d.)

4.0 Seismic-Tectonic Site Description: Status

4.1 Yucca Mountain Site

For the purposes of this discussion only two tectonic design events are considered: vibratory ground motion and faulting. Consideration of these events is further restricted to the repository operating surface facilities during the preclosure period. The preclosure period is defined as the time when the repository is open and waste can be emplaced or retrieved. It formally includes the siting, construction, and operation phases of the geologic repository but we are concerned here only with the operation phase. Surface facilities include any building, structure, or piece of equipment on the surface of the repository site used for handling or storing radioactive waste.

The reasons for concern about vibratory ground motion and fault offset are simply stated. If energetic enough, vibratory ground motion could damage surface repository facilities by dynamically deforming structural numbers or by causing failure of surface facility foundation materials. The potential for damage is great for surface facilities located within zones undergoing surface fault offset. The damage mechanism is differential static displacement of the structure foundation.

To define the effect and degree of importance of seismicity in operational facility design it is necessary to specify what earthquake affects are reasonably expected at the Yucca Mountain site. This requires characterization by size, location, and frequency of occurrence of earthquakes reasonably expected during repository existence. One important tool used in such a characterization is the study of the available history of tectonic earthquakes. Inevitably, alternative interpretations are possible for all three parameters in any given area.

Faulting occurs where accumulated stresses in brittle crustal rock can no longer be accommodated elastically, and deformation concentrates along a plane (or fault) causing failure and movement. When failure along the fault is sudden, occurring in seconds or minutes, and the stresses that have accumulated arise from tectonic processes, the result is a tectonic earthquake. This general cause and effect relationship between faulting and earthquakes was first proposed by Reid (1910) in response to seismological and geodetic observations made before and after the 1906 San Francisco earthquake.

Although there are nontectonic shallow sources of seismic waves, either naturally occurring (volcanic activity, landslides, cavern collapses, meteorite impact) or caused by human activity (induced earthquakes or explosions), and although faults may move seismically, most seismic waves (and almost all energy associated with seismic waves in the earth) arise from tectonic earthquakes.

Faults associated with tectonic earthquakes are often idealized as simple planar discontinuities. Rupture at considerable depth may actually approximate this idealized state. However, as the rupture surface propagates upward through less competent near-surface strata, slip may occur along several branching, subsidiary faults, leading to a wide region of surface deformation. In particular, detailed mapping of fault offset associated with historic seismicity frequently indicates that offset has occurred along a set of discontinuous, subparallel, en echelon rupture segments comprising a fault zone.

The empirical evidence relating width of fault zone, amount of fault offset, and length of fault rupture to earthquake magnitude and fault type suggests that the maximum distance from the centerline of the main zone of faulting to the farthest associated branch faults known for all cases of historic fault offset is somewhat less than 1 kilometer (with secondary fault involvement known to occur out to 15 kilometers), although much narrower zones are representative. Magnitudes of about 4, 6 and 8 are indicated for rupture lengths of about 0.1, 5, and 250 kilometers and for fault offsets of about 0.005, 0.25, and 11 meters, respectively (Slemmons, 1977). Diffusion and absorption of the rupture in less competent near-surface rock and soil may imply narrower zone widths and greater offsets at depth than at the surface.

Limited data specifying static relative displacements of the ground surface away from the fault rupture trace have been collected. These indicate that for the 1906 San Francisco, 1940 Imperial Valley, and 1954 Fairview Peak earthquakes, the displacements were from about 300 to 5 centimeters at distances of zero and 100 kilometers, respectively (Byerly and DeNoyer, 1958). Shear strains calculated from these displacements at the same distances are about 3.2×10^{-2} and 7×10^{-5} percent. Smaller shear strains and more rapid decrease of strain with distance would be expected for faulting associated with smaller earthquakes.

Important information about sense of fault offset in the absence of surface observation may be obtained from focal mechanism (or fault plane) solutions. A focal mechanism solution, is an upper or lower focal hemisphere sterographic projection of the first motion polarities of P-waves. That is, it is an attempt, given certain assumptions about the velocity structure of the earth, to project onto the surface of an imaginary sphere surrounding the earthquake hypocenter the ray paths of waves that left the source with an initial outward motion (compressional polarity) or with an initial inward motion (dilatational polarity). Assuming a fault (dislocation) model for the earthquake source, this polarity pattern may be used to help specify the orientation of the fault and the direction of slip on the fault surface. Information of this type is useful to supplement stratigraphic and geodetic indications of regional stress regime and tectonic framework.

As is the case for vibratory ground motion, alternative interpretations are always possible about the best estimates of expected fault activity, offset, and character at any particular site.

In the rest of this section, brief summary reviews all presented on faulting and expected vibratory ground motion at the NNWSI Yucca Mountain site.

4.1.1 Site Area Seismicity and Generalized Tectonic Features

The NNWSI site area has been proposed to lie near or within a belt of relatively active seismicity that extends east-west across the Great Basin in southern Nevada and southwestern Utah and connects with north-south seismic belts on the west side (California-Nevada Seismic Zone) and east side (Intermountain Seismic Zone) of the Great Basin (Smith and Sbar, 1974, Fig. 2, Smith, 1978; Rogers, et al, 1983, Fig. 2;

Algermissen, et al, 1983, Pl. 2; Carr, 1984, Fig. 20; USGS, 1984, Fig. 41). Unlike the north-south seismic zones, which are coincident with major Quaternary faults, the east-west seismic zone does not correlate with any obvious through-going east-west tectonic structure. Carr (1984, p. 41) notes, however, that the greatest density of epicenters within the east-west seismic zone appears to coincide with areas in which northeast-trending late Cenozoic faults and shear zones are prevalent. The largest historical earthquakes within 100 km of the site range up to about magnitude 5+, although a poorly located event of about magnitude 6 (MM intensity VII-VIII) occurred in 1968 in the Death Valley area about 110 km southwest of the site. The nearest great earthquake was the 1872 Owens Valley shock, magnitude 8-1/4, which occurred about 150 km west of the site. Focal depths in the southern Great Basin appear to be bimodally distributed with modal values at 2 and 5 km (USGS, 1984, p. 69).

Within the NTS, the Yucca Mountain site area is characterized by a relatively low level of seismicity compared to that of the east-west seismic zone for events greater than about magnitude 3, as is evident on inspection of epicentral plots (e.g., Rogers, et al, 1977, Fig. 1; Algermissen, et al, 1983, Pl. 2; USGS, 1984, Fig. 42). Well-defined clusters of apparently induced seismicity in the Pahute Mesa area (about 40 km north of the site) and at Yucca Flat (40 km northeast) are associated with underground nuclear testing (Rogers, et al, 1983, Fig. 11; Carr, 1984, Fig. 20). As pointed out by Blume (1985, p. 52), however, assessing the distribution of natural seismicity of NTS is problematical because, even with underground nuclear events and identified induced after shocks deleted, it is not at present possible to deduce what natural events would have occurred in the absence of nuclear testing. Nevertheless, epicentral plots of all recorded natural events in the vicinity of NTS (Rogers, et al, 1983, Fig. 9 and Pl. 1; Carr, 1984, Figs. 7 and 19; USGS, 1984, Fig. 46) confirm the relative seismic quiescience of recorded earthquake activity at and near the Yucca Mountain site (Rogers, et al, 1983, p. 1). Apart from the nuclear test areas mentioned above, seismicity appears most intense in the southeastern portion of the NTS, where it is associated with the northeast-trending Spotted Range-Mine Mountain structural zone of Carr (1984, Figs. 3 and 7), important elements of which include the Rock Valley and Cane Spring fault zones (Rogers, et al, 1983, pl. 1). These faults are major northeast-trending left-lateral faults which, along with similar faults farther east (e.g., the Pahranagat shear zone, 120 km east of the site) have localized a large percentage of the regional earthquakes, according to Rogers, et al. (1983, p. 12). It is interesting to note, however, that nodal plane solutions of earthquakes in these areas, though indicating strike-slip movement, are not consistent with the orientation or displacement on the associated faults (Blume, 1985, p. 45; Rogers, et al, 1983, Fig. 9). Studies of seismicity in the Pahranagat shear zone suggest that the actual mode of seismogenic faulting may be right-lateral strike-slip movement on short north-trending fault segments contained between major northeast-striking shear zones (USGS, 1984, p. 67, 76-77; Rogers, et al, 1983, Fig. 8 and p. 31).

The dominant tectonic pattern in the site area is a series of north-south, high-angle normal faults, generally west-dipping, separated by relatively unfaulted blocks of rhyolitic volcanic rock 1 to 2 km wide (Carr, 1984, Fig. 21). Subsidiary faulting of both northeast and northwest orientation tends to form tectonic contacts on the northern and southern ends of these blocks. A number of the north-trending faults display minor Quaternary offset, but Holocene movement has not been documented, nor do earthquake epicenters generally correlate with known north-trending high-angle faults, except for the Bare Mountain fault (20 km west), which, however, is not known to show evidence of Holocene displacement (Swadley, et al, 1984; Carr, 1984, Fig. 21). Seismicity is also associated with north-trending faults at underground nuclear testing areas at Yucca Flat and Pahute Mesa.

The fault nearest to the site that exhibits known Holocene displacement is the Yucca Flat fault, about 50 km northeast. Studies are in progress to determine whether the Rock Valley fault (30 km southeast) shows evidence of Holocene movement, based on possible minor offset of surficial material exposed in one of two trenches across the fault.

The thick pile of rhyolitic volcanic rock at the Yucca Mountain site has buried older Precambrian through Paleozoic clastic and carbonate rocks that dominated the area prior to the eruptive events, which began in late Eocene to early Miocene time in the site region. Major eruptions accompanied by both extensional and strike-slip faulting occurred between 11 and 17 million years ago. The strike-slip faulting consisted of minor left-lateral movement along northeast-striking faults and major right-lateral movement along northwest- striking faults (USGS, 1984, p. 37). The northeast-striking right-lateral displacement, such as along the Las Vegas Valley shear zone, rotated the north-south-trending traces of extensional faulting (which must therefore have begun prior to this lateral crustal movement) as well as older Mesozoic structural elements. However, normal extensional faulting continued after cessation of major strike-slip tectonics. Ash-flow tuffs of the Paintbrush tuff (12.5 to 13 m.y.) are cut by major north-trending normal faults, yet the overlying Timber Mountain tuff (11.1 to 11.4 m.y.) is restricted to topographic and structural basins that must have developed between 11.4 and 12.5 m.y. ago (USGS, 1984, pp 38-40). Major basins (e.g., Yucca and Frenchman flats) are considered to be essentially post-Miocene in age, and extensive caldera development took place immediately west and north of Yucca Mountain during later stages of volcanic activity (Carr, 1984, Fig. 29). The prevalence of minor Quaternary faulting within and in the vicinity of Crater Flat has been related by some investigators to downwarp of the caldera complex. By this model, normal faulting at the margins of the caldera complex (for example, Paintbrush Canyon fault) could be listric at depth into the bottom of the caldera depression.

Probabilistic estimates of peak ground acceleration (PGA) risk at the Yucca Mountain site have been derived by Blume (1985), who adopted a frequency-magnitude b-value of 0.9 consistent with the higher seismicity of the east-west seismic zone. The conventional approach used by Blume, as well as other investigators, does not include probability estimates of ground rupture on specific faults. Ground motion attenuation functions obtained from the regression results of Campbell (1982) and Joyner and Boore (1982), and assuming a rupture depth of 5 km for events of M less than 5.5 and 0 km for M greater than 6.5. The following results are derived from the lower (more conservative) attenuation and high seismicity model of Campbell, and from Joyner and Boore: horizontal PGA at the Yucca Mountain site area for a 10,000-year return period is calculated to be 0.34 g (Campbell) and 0.39 g (Joyner and Boore), adopting a geometric standard deviation of 1.5. Using a standard deviation of 1.9, which is the deviation for the Joyner and Boore regression, these g-values become 0.53 and 0.62, respectively. Blume therefore recommends 0.65 g for a design basis earthquake corresponding to a 10,000-year recurrence expectancy for the Yucca Mountain. A similar analysis for 500 and 2,000 year recurrence expectancies yields 0.25 and 0.40 g, respectively.

These values may be compared with a regional probabilistic seismic hazard analysis performed by Algermissen, et al. (1983), which provides velocity and acceleration contours for the Basin and Range province. For the NTS area estimated peak horizontal accelerations in rock at the 90% nonexceedance probability level for 10, 50 and 250 year recurrence intervals (about 95, 475, and 2,350 year return period in are about .10, .20, and .40 g, respectively. Estimates for corresponding maximum horizontal velocities are 8, 15, and 33 cm/sec (Algermissen, et al. 1983, pls. 5-10).) These estimates also compare reasonably well with an estimated PGA of about 0.7 g at Yucca Mountain for a return period of 10,000 years (USGS, 1984, fig. 51) based on similar assumptions using the data of Rogers et al (1983); estimated accelerations for return periods of 100, 250 and 2,000 years are about 0.2, 0.3 and 0.5 g, respectively.

Deterministic seismic hazard analyses are highly sensitive to identification of faults presumed to be active, as well as to their rupture characteristics. The USGS has estimated maximum horizontal accelerations of about 0.4 g based on a 6.8-magnitude rupture along the Bare Mountain fault 14 or more km from the site. Faults closer to the site, if presumed to be active, could produce higher ground motion potential for the site. Earlier deterministic estimates by Rogers et al (1977) using the Schnabel and Seed attenuation curves indicated mean peak accelerations of up to 0.7 g at NTS, depending on particular location.

4.1.2 Site Area Faulting

Yucca Mountain is located within a zone of north-trending high-angle normal faults, most of which have displacement down to the west and gently tilt and repeat the volcanic rock section eastward (Lipman and McKay, 1965; Scott and Bonk, 1984). This structural style continues southward to the southern part of Yucca Mountain and to the north where a few of the faults continue into the Timber Mountain Caldera. Most of the faults, however, die out northwestward near the southern margin of the Claim Canyon-Timber Mountain caldera which trends generally northwestward and is aligned with Yucca Wash (Carr, 1984).

The regional distribution of faults at and near Yucca Mountain is shown by Rogers et al (1983), Carr, (1984) and most recently by Scott and Bonk (1984). The fault distribution (Figure __) indicates an approximate spacing of major faults of 2 to 3 km apart. The major faults have average vertical displacements of about 250 m (810 ft), and fault blocks are gently tilted an average of about 15°. Vertical displacements rarely exceed 450 m (1,480 ft) or result in fault blocks tilted greater than 25°. Many faults exhibit a zone of shearing generally less than 100 m (330 ft) wide, in which local extreme rotation of fault blocks has occurred and zones of minor imbricate faulting are present (Scott et al, 1983; Scott and Bonk, 1984).

Scott and Bonk (1984) have informally named many of the larger faults at and near Yucca Mountain (Figure __). These include, from west to east; (1) the Windy Wash fault about 2 km west of the repository site; (2) the Solitario Canyon fault bordering the western margin of Yucca Mountain; (3) the Abandoned Wash-Ghost Dance Fault through Yucca Mountain; (4) the Bow Ridge Fault along the western margin of Bow Ridge and Exile Hill; and (5) the Paintbrush Canyon/Fran Ridge fault system along the western margin of Alice Ridge and Fran Ridge. In addition, a postulated fault may extend northward through Midway Valley about 1 km east of Exile Hill (USGS, 1984). Some, but not all, of these faults increase in displacement southward, such as the Solitario Canyon Fault (Carr, 1984). In addition, most of these faults bifurcate and intersect with adjacent faults such that lateral correlation of faults beneath valley alluvium is difficult and poorly known. This is particularly evident with the southern continuation of the Bow Ridge and Paintbrush Canyon Faults and the postulated fault in Midway Valley.

The attitude of these faults with depth is also poorly known. Cross-sections through the Yucca Mountain area by Scott and Bonk (1984) and Snyder and Carr (1982) show a generally planar attitude with depth but do not project faults below a depth of 1-2 km. Stewart (1978) summarizes three models that would explain the subsurface extent of the normal faults. The block faults may be: (1) horst-and-graben structures with planar subsurface attitudes; (2) tilted blocks bounded by planar faults; or (3) rotated blocks bounded by listric fault surfaces merging with an underlying detachment surface.

The principal period of movement along these faults is closely related to silicic volcanic activity in the Crater Flat-Timber Mountain area. Major displacement on the north-trending faults occurred between 12.5 and 11.3 m.y. ago. The 11.3 m.y. old Rainer Mesa Member of the Timber Mountain Tuff is only slightly disturbed where it overlies these faults and appears to have accumulated on the down-thrown side of existing north-striking fault blocks composed of the Paintbrush Tuff

(USGS, 1984, p. 40). Where faults displace the Timber Mountain Tuff near Yucca Mountain, the displacements are generally smaller than those of the Paintbrush Tuff, suggesting that the rate of faulting probably diminished after 11.3 m.y. ago (Carr, 1982b).

Carr (1984) concludes that: (1) in most cases, over half the total offset along faults at Yucca Mountain occurred during Paintbrush Tuff time, a duration of less than 0.5 m.y.; (2) there was a dramatic decrease in the frequency of new faulting and in the rate of displacement around 9.5 m.y. ago; and (3) nearly all faults cutting younger units are reactivations of pre-existing faults.

Recent field mapping and trench studies at Yucca Mountain (Scott and Bonk, 1984; Swadley et al, 1984), however, do indicate minor displacement along many of the north-trending faults during the late Pliocene and Quaternary. Evidence for Quaternary fault activity is described below.

Other regional tectonic trends have been proposed to be of significance in the NNWSI area. For example, Yucca Mountain is located within the Walker Lane Belt (WLB) along or slightly north of the approximate projection of the Las Vegas Valley Shear Zone (Carr, 1984). Although the WLB and Las Vegas Valley Shear Zone represent a zone of major late Mesozoic and early Tertiary northwest-trending structures, northwest-trending faults and lineaments are the least developed structures in the Yucca Mountain area (Carr, 1984).

A few northwest-trending lineaments and postulated faults, however, have been mapped (Maldonado and Koether, 1983; Scott and Bonk, 1984; Scott et al, 1984). At Yucca Mountain, several northwest-trending washes and canyons, including Yucca, Drill Hole, and Dune washes, may have developed along shear zones. The most prominent of these, Yucca Wash, has no important exposed northwest-striking faults and there is no evidence of stratigraphic displacement of the Paintbrush Tuff (Carr, 1984). The presence of an aeromagnetic lineament (USGS, 1979) and alignment of the wash with the Claim Canyon Cauldron wall, however, suggest the presence of a pre-Paintbrush Tuff structural boundary.

No evidence of Pliocene or Quaternary displacement along the postulated northwest-trending faults at Yucca Mountain has been documented. In the present regional stress field, these faults should generally be under compression and should not be active (Zoback and Zoback, 1980; Carr, 1974). This is supported by the virtual absence of seismicity along northwest-striking faults (Rogers et al, 1983) and the lack of Quaternary fault scarps along the fault traces.

Evidence for Quaternary displacement along faults at Yucca Mountain is based primarily on the mapping of surficial deposits (Hoover et al, 1981) and trench investigations across known or suspected fault traces (Swadley and Hoover, 1983; Swadley et al, 1984). Twenty-three exploratory trenches have been excavated in the Yucca Mountain area (Swadley et al, 1984). Trench locations are shown on Figure __ and include fourteen trenches on or near Yucca Mountain, six trenches on the flanks of adjacent ridges that parallel Yucca Mountain, and three trenches in Crater Flat. Trenches were located in surficial deposits across both recognized fault scarps and to expose surficial deposits across the projections of a known bedrock faults.

The exploratory trenches were mapped in reconnaissance to assess the existence of Quaternary displacement (Swadley et al, 1984). Quaternary activity was evident in several trenches along the Paintbrush Canyon/Fran Ridge Fault, the Bow Ridge Fault, the Solitario Canyon Fault, and an unamed fault in Crater Flat. Detailed mapping of several of the trenches that exhibit apparent Quaternary displacement is currently in progress by the USGS; preliminary results have not yet been released.

Swadley et al (1984) used the Quaternary stratigraphy developed by Hoover et al (1981) together with radiometric dates to determine the most recent age of faults that were observed to offset these deposits. In most trenches that expose Quaternary fault activity, samples of sediment, soil carbonate, and opal have been dated by the uranium-trend (Swadley, et al, 1984) and (or) uranium-series (Szabo and O'Malley, 1985) methods. In other trenches, Swadley et al (1984) correlated the Quaternary deposits exposed in the trench with the Quaternary stratigraphy described by Hoover et al (1981). In several instances, volcanic ash was also present along the fault plane and correlated by mineral chemistry to known, dated deposits of ash. Three of the five trenches along the Paintbrush Canyon/Fran Ridge Fault System (Figure 3) expose disrupted Quaternary deposits. Based on correlation of these deposits with the stratigraphy of Hoover et al (1981), Swadley et al (1984) bracket the age of last movement on this fault, which trends northward for over 18 km in the eastern part of the site area, at 270,000 years to 700,000 years ago.

The Bow Ridge fault of Scott and Bonk (1984) trends northward for about 6 km from Bow Ridge in the south to Yucca Wash in the north. The fault forms the western escarpment of Exile Hill immediately west of the proposed surface facilities site. Two trenches have been excavated across the fault (Figure 3); one at Bow Ridge and the second at Exile Hill. The trench at Exile Hill exposes disrupted Quaternary sediment over a clearly faulted and brecciated Tertiary bedrock. Uranium-trend dates on the displaced sediment suggest a minimum age for movement along the fault of 38,000 ± 10,000 years to 270,000 ± 90,000 years (Swadley et al, 1984). No evidence for Quaternary displacement was detected by mapping of surficial deposits.

Along the northeast side of Yucca Mountain, trenches have been excavated across the Abandoned Wash and Ghost Dance faults of Scott and Bonk (1984) and across the two northwest-trending faults postulated to exist along Drill Hole and Pagany washes. No evidence of Quaternary activity was observed in these trenches.

The Solitario Canyon fault borders the western margin of the proposed underground facility and trends northward for over 12 Km.

Mapping of surficial deposits by Hoover et al (1981) indicates that early Quaternary sediments have been displaced at several localities. Three trenches have been excavated across the fault, two of which show displaced Quaternary deposits (Swadley et al, 1984). Basaltic ash occurs along the fault plane and has been correlated mineralogically with basaltic ash deposits erupted either 1.2 or 0.24 m.y. ago, thus providing a minimum age of faulting of either 1.2. m.y. or 240,000 years old. In addition, uranium-series dates reported by Szabo et al (1981) on calcrete along the fault suggest a minimum age of fault activity of greater than 5, 000 to 70,000 years.

Three trenches have also been excavated across an unnamed fault system in Crater Flat, west of the Solitario Canyon fault. Each trench exposes displaced Quaternary sediments (Swadley et al, 1984) and the trace of the fault system is marked in places by a scarp 1 to 4 m high developed in Quaternary sedments. The 1.2 m.y. or 0.24 m.y. old ash is present in the fault zone in at least one trench and a uranium-trend date of 27,000 years ± 3,000 years has been obtained on a soil carbonate horizon that Swadley et al (1984) believe has not been displaced.

Site exploration studies in addition to those described above are continuing in support of Advanced Conceptual Design of the surface waste handling facilities. These studies include surface mapping of several areas east of Yucca Mountain and excavation of one or more trenches in several of these areas to better determine the presence or absence of surface or near-surface faulting. This additional exploratory effort is vital because it will help fix the location of the waste handling building. Much of the repository design (both surface and underground) is governed by the location of this building and, consequently, planning for detailed investigations during site characterization is dependent or finding a suitable waste handling building location.

4.2 Deaf Smith County Site

(This is t.b.d.)

4.3 Hanford Site

(This is t.b.d.)

5.0 Site Characteristics Seismic-Tectonic Data Needs

5.1 Yucca Mountain Site

Recent geologic and geophysical investigations in the Yucca Mountain area indicate that north-trending normal faults may be potentially active under the current tectonic stress regime (Section 4.2). The presence of active faulting is a potentially adverse condition and additional data are required to fully evaluate the distribution, displacement history, and age of these faults. These data should be acquired through a Quaternary fault investigation conducted during site characterization activities.

The general objectives of a Quaternary fault investigation are several. The investigation should collect and interpret data to:

(1) Identify and locate potentially active faults

(2) Characterize displacement history, recurrence interval and age

(3) Assess fault dimensions including length, orientation, behavior at depth, and relationship to adjacent faults.

The emphasis of the investigation should be to reduce current uncertainties associated with known potentially active faults and to identify and characterize unknown or postulated faults in the context of recently published hypotheses (USGS, 1984; Scott and Bonk, 1984) governing the distribution and activity of faults near Yucca Mountain.

Ideally, the results from these studies will document more precisely the time of last movement of faults near Yucca Mountain, establish the rate of displacement during the life of the fault (not just last 2 million years), and clarify whether additional Quaternary faulting heretofore unrecognized exists in the area. These results will provide a better understanding of the origin, past behavior, and predicted future behavior of faults in the area, and provide needed input to realistic seismic risk assessments.

Specific data needs for the surface waste handling operations during the preclosure period must address two issues: (1) The potential for surface faulting beneath the waste handling building; and (2) ground acceleration resulting from rupture of nearby faults. Specific data to supply information to meet these objectives are as follows:

(1) Determination of the presence or absence of surface or near-surface Quaternary faulting at the proposed foundations for surface facilities that may be important for safety (Waste Handling Buildings). In the event that such faults are found to be present at these locations, investigations should be conducted to demonstrate that the faults would not compromise the performance objectives of the surface facilities; lacking such demonstration, investigations should be conducted for the purpose of comparatively evaluating alternate siting away from active faults, so that the building design, licensing complexity and cost can be minimized.

(2) Determination of the relative and, if possible, absolute ages of various alluvial deposits in the site area and in the foundations of the surface facilities. There is a general need for a better understanding of the Quaternary stratigraphy in the site area, and the need to know the age of alluvium on which surface facilities will be founded is a specific instance of this general need.

(3) History of movement on Quaternary faults in the vicinity of the site. This information will establish deformation rates for a given fault, which will be used in evaluating ground motion potential, and in probabilistic risk assessment and derivation of the DE. Primary targets for surface facilities should be the Bow Ridge fault and the Paintbrush Canyon fault, plus a search for possible additional faulting in the Midway Valley area.

(4) Preliminary data on dynamic properties of foundation materials. Such data can be used in design to provide evaluations of ground motion amplification potential of site soils. In licensing application, the data will contribute to derivation of site-specific design spectra.

Quaternary fault studies to obtain the required data fall into six main catergories: (1) Surface mapping of Quaternary deposits and existing fault exposures; (2) Geophysical investigations - shallow and deep subsurface methods; (3) Trenching - both across known faults and also to determine the presence or absence of faulting; (4) Remote sensing investigations - interpretation of aerial photography, satellite imagery, and low-sun-angle photography; (5) Drilling - exploratory and confirmatory; and (6) Dating of Quaternary deposits - both relative and absolute age-dating methods.

A proposed work plan for conducting these studies in the Yucca Mountain area has been developed. The work plan includes rationale for conducting the studies, a prioritization of recommended specific studies, and an implementation schedule showing the sequence of investigations over an 18-month period for a minimum program.

5.2 Deaf Smith County Site

(This is t.b.d.)

5.3 Hanford Site

(This is t.b.d.)

6.0 Definitions

This section provides draft definitions for some key terms to be included in the draft Seismic Position Paper. Only those terms of interest to this note are given below:

ACCESSIBLE ENVIRONMENT: The atmosphere, land surfaces, surface waters, oceans, and portions of the lithosphere that are beyond the controlled area (40 CFR 191, Subpart B, 191.12 Draft 5, 3/21/85).

ACTIVE FAULT: A fault that has slipped in historic or during Holocene (approximately the last 10,000 years) time, and that is, therefore, expected to have renewed displacement during some comparable time in the future. In the context of this position paper, slip along an active fault is an anticipated event. In addition to direct historic or geologic evidence of activity, the spatial association of earthquakes with a fault indicates that it is active, although such evidence is not as certain.

ANTICIPATED EVENT: A natural process or event that is reasonably likely to occur during the period that a potentially affected performance objective must be achieved. To the extent reasonable in the light of the geologic record, it shall be assumed that those processes or events occurring during the Quaternary Period (approximately the past two million years) will continue to operate except as perturbed by construction and use of the waste storage facility. (after 10 CFR 60)

CANDIDATE AREA: An area within a geologic setting that is recommended by the Secretary of Energy under Section 112 of the Nuclear Waste Policy Act of 1982 for site characterization, approved by the President under Section 112 of the Act for Characterization, or that is undergoing site characterization under Section 113 of the Act (10 CFR 960).

CLASS I STRUCTURE: Any structure, system, or component whose failure would result in a consequence exceeding the limits and criteria specified in 10 CFR 60 and 40 CFR 191 for protection of the public during preclosure and postclosure periods.

CONSERVATISM: An approach leading to the selection of assumptions and parameters that tend to overestimate the severity of potentially adverse processes or events.

CONTROLLED AREA: A surface location under passive institutional controls that prohibit human activities incompatible with waste isolation. This area shall extend no more than five kilometers horizontally from the surface facilities or the outer boundary of the original location of the radioactive wastes in an underground disposal system. Passive institutional controls will also apply to the volume of crust underlying the controlled area. (after 40 CFR 191)

COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTION: The probability that releases of radioactivity to the accessible environment will be equal to or greater than a given value. It is developed by subtracting each probability value contributing to the cumulative distribution function from 1.0. The cumulative distribution function is the probability that releases to the accessible environment will be less than a given value. It is developed by integrating the probability density function representing releases, including uncertainties in this function over all possible releases.

DESIGN EARTHQUAKE: An earthquake ground motion for use in evaluating and designing Class I facilities present during the preclosure period. In analogy with acceptable hazards for other nuclear facilities, and recognizing the limited consequences of facility failure compared to those other nuclear facilities, a ground motion with an expected return period of about 2,000 years is recommended. This motion will be determined from a conservative probabilistic model based on the tectonics of the site region. (after Blume)

<u>DESIGN EVENT</u>: A tectonic process or event which, should it occur, might affect radiological containment capabilities of repository operation or disposal systems. It is an initiating process or event in a scenario analysis of repository performance. Design events may be anticipated (reasonably expected) or unanticipated (very unlikely). A design event, when its expected frequency of occurrence is specified, can be used to help determine an overall probability distribution of cumulative release and, in conjunction with stated performance objectives associated with maintenance of system capability, can provide a logical and systematic approach to protection by facility design and site selection.

DESIGN GROUND MOTION: Dynamic vibratory ground motion for use as a design event in a performance assessment. The source of this ground motion may by either natural or human-induced earthquakes.

DETERMINISTIC ANALYSIS: A method to estimate the maximum credible value of a design parameter reasonably expected at a site. In the case of earthquake ground motion, this is based on a characterization of the site region as containing certain geologic structures capable of causing earthquakes of some maximum magnitude, or as made up of certain seismogenic sources. Sizes and distances of earthquakes associated with structures and sources are considered, but the distributions of earthquakes in time and by magnitude are ignored.

EXCEEDENCE PROBABILITY: The probability that an event will occur during a specific exposure time. For seismic events, "exceedance probability" means the probability that a specified level of ground motion or specified social or economic consequences of earthquakes, will be exceeded at a site or in a region during a specified exposure time. (Shah et al., "Earthquake Spectra," Vol. 1, No. 1, 1984)

EXPECTED REPOSITORY PERFORMANCE: The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest." (10 CFR 960)

FAULT: A fracture or zone of fractures along which there has been displacement parallel to the fracture zone of the sides relative to one another. The amount of displacement may be from a few centimeters to many kilometers. Different types of faults are recognized (dip-slip, strike-slip, detachment, listric, to name a few). For the purposes of seismic design analysis, a fault is of principal interest if it is active.

GEOLOGIC SETTING: The geologic, hydrologic, and geochemical properties of the repository site region. The portion of the geologic setting that provides isolation of the radioactive waste makes up part of the geologic repository. (after 10 CFR 60)

IMPORTANT TO SAFETY: Reference to structures, systems, and components means those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of permanent closure. (10 CFR 60)

LIKELY CONSEQUENCES OF FAILURE: The estimate of a reasonable result following from a postulated scenario involving a design event and a series of system or component failures. (SNL/BNI)

MEAN RETURN PERIOD: The average time between design events. For example, it can be the average time between occurrences of a specific acceleration at a site or of an episode of fault offset along an active fault. (after Shah et al.)

MITIGATION: Means (1) avoiding the impact altogether by not taking a certain action or parts of an action; (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation; (3) rectifying the impact by repairing, rehabilitating, or restoring the affected environment; (4) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; or (5) compensating for the impact by replacing or providing substitute resources or environments. (10 CFR 960)

MODEL: An approximate description of a physical system, subsystem, component, or condition used as a predictive tool to estimate future behavior. A model may be qualitative (conceptual) or quantitative (mathematical).

PERFORMANCE ASSESSMENT: An analysis that: (1) identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties, caused by all significant processes and events. These estimates shall be incorporated into an overall probability distribution of cumulative release to the extent practicable. (40 CFR 191)

PERFORMANCE OBJECTIVE: The predetermined standard or specification used to evaluate the acceptability of each system, structure, or component during a performance assessment. Different performance objectives may be suitable for the preclosure and postclosure periods.

PROBABILISTIC ANALYSIS: A method to estimate the exceedance probability of a specified design event on the basis of a characterization of site region geologic structures and seismogenic sources, maximum magnitudes and recurrence statistics for each, and attenuation with distance of design event parameters. Uncertainties in these characterizations may be explicitly incorporated into the analysis.

REASONABLE ASSURANCE: The required confidence that the performance objectives will be met. (Fed. Reg. Vol. 48, 120, June 1983, 28204)

RESPONSE SPECTRUM: A set of curves calculated from an earthquake accelerogram that gives values of peak response of a damped linear oscillator as a function of its period of vibration and damping. When curves of this type are used for modal analysis design of a free-standing structure, the set of curves becomes a "design response spectrum" or simply "design spectrum."

SCENARIO: A proposed sequence of events or conditions of which the resulting consequence is analyzed to determine related consequences. (SNL/BNI)

SEISMICITY: The occurrence of earthquakes in space and time. (Bolt, 1978).

SEISMOGENIC SOURCE: A geologic area characterized by a similarity of geologic structure, tectonic setting, and earthquake characteristics. The province is a model of a seismic source for use in seismic design event analyses. (SNL/BNI)

SITE: A potentially acceptable, or candidate, area under the effective control of persons responsible for management and storage of nuclear fuel or radioactive waste. At such time as the controlled area is established, the site becomes the controlled area. During the waste isolation period, the site comes under passive institutional control. (after 10 CFR 960 and 40 CFR 191)

<u>TECTONIC PROCESS</u>: A process or event contributing to the broad architecture of the outer part of the earth; that is to the regional assembling of structural or deformational features and the study of their interrelationships, origins, and evolution through time. Igneous activity, uplift, subsidence, folding, and faulting are examples of tectonic processes.

<u>UNANTICIPATED EVENTS:</u> Those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes or events or processes and events initiated by human activities other than those activities induced by repository operation and construction (after 10 CFR 60).

<u>VERY UNLIKELY EVENTS</u>: An event that is estimated to have betwen one chance in 100 and one chance in 10,000 of occurring within 10,000 years. (40 CFR 191)

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FIGURE 3

LOCATION OF EXPLORATORY TRENCHES AND QUATERNARY FAULTS IN THE SITE VICINITY

Attachment 5

URS
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SINGAPORE

HEADQUARTERS
SAN MATEO

November 8, 1985

Mr. James T. Neal
Nuclear Waste Engineering Projects, 6311
Sandia National Laboratories
Albuquerque, New Mexico 87185

Dear Jim:

Enclosed is a draft copy of our submittal on seismic design parameters for the Seismic/Tectonic Position Paper. The section on faults was prepared by Roger Greensfelder.

The draft seems too long for inclusion "as is" into the Position paper. Some paragraphs may be redundant with respect to other parts of the Position Paper and could be deleted; other paragraphs may be too detailed. However, this should give us a basis for discussions on what needs to be written under "seismic design parameters."

This work was written before Sandia requested the current work involving faults at the site location. Somerville's approach to risk assessment of faults is different from Greensfelder's in terms of details and complexity. Once we prepare a report on Somerville's work, we probably will want to revise the section on faults to some degree.

Sincerely,

Norman Owen

G. Norman Owen
Project Manger

GNO/rmh

cc: C. V. Subramanian

NNWSI
SEISMIC POSITION PAPER

SECTION 5.2
SEISMIC DESIGN PARAMETERS

DRAFT

NOVEMBER 4, 1985

URS/John A. Blume

5.2 SEISMIC DESIGN PARAMETERS

INTRODUCTION

Preclosure and postclosure facilities need to be evaluated for impacts due to vibratory ground motion. Therefore, ground vibrations generated by possible earthquakes must be characterized for both preclosure and postclosure time frames. Vibratory ground motion due to UNEs must also be characterized.

The presence of faults below the proposed site of the surface facilities may require that the effects of possible surface displacements below foundations also be evaluated. In addition, the effects of potential dislocation of faults through subsurface facilities before and after closure may also need to be considered. Thus, fault rupture must also be characterized.

The purpose of this section is to propose procedures for characterizing vibratory ground motion and fault rupture. The presentation considers both preclosure and postclosure time frames and natural and man-made sources as appropriate. Vibratory ground motion is discussed first, followed by fault displacement. The data needed to be obtained from site characterization in order to support these procedures are presented in the final portion of this section.

VIBRATORY GROUND MOTION

Approaches to Characterizing Vibratory Ground Motion

During the preclosure (operational) period of the repository, seismic events might cause accidental releases of radiation. Thus, facilities that are "important to safety" must be designed to meet radiological performance objectives for earthquake and UNE ground motions. The experience of non-nuclear facilities in recent earthquakes has demonstrated that the application of current seismic design requirements, such as the Uniform Building Code (UBC; International Conference of Building Officials, 1982), does not necessarily insure functionality of important facilities after a major earthquake. The use of a larger value, say 1.5, for the importance factor I in the UBC lateral-force equations would appear to reduce the risk; however, major earthquakes have resulted in demands several times larger than the design capacity, not just 50% larger (URS/Blume, 1984). Thus, important nuclear facilities require special considerations for seismic design that go beyond normal code requirements. To achieve maximum safety for the general public, repository facilities necessary to mitigate off-site releases of radiation should be designed for a seismic design level that has a very high probability of not being exceeded during the operating period. Such a design level would represent a highly improbable earthquake ground motion for the region in which the proposed waste repository is located.

The traditional approach to the characterization of the design earthquake for a nuclear power plant is based upon a judgmental and empirical evaluation and is usually referred to as a "deterministic analysis" (see definitions) of the seismic hazard. This approach is the accepted method for satisfying the criteria set forth in Appendix A of 10 CFR Part 100 for establishing the Safe Shutdown Earthquake (SSE).

While a deterministic approach might be used to define the design earthquake for the nuclear waste repository, there is no regulatory basis for using the criteria of Appendix A of 10 CFR Part 100. Furthermore, the nature of the inventory of radioactive material and the manner in which it is handled in the repository facilities is vastly different from a nuclear power plant. Thus, there is no logical basis for imposing criteria which ignore risk and are, therefore, likely to impose design efforts far beyond what is necessary to meet acceptable risks.

A probabilistic evaluation of seismic hazard was applied to nuclear power plants through NRC's Systematic Evaluation Program (SEP) in the years 1978 through 1981. That program was a comprehensive effort in the field of probabilistic evaluation of seismic hazard with respect to certain existing nuclear power plant sites. The acceptance of this approach, at least in the context of review, is indicated by the comment that return periods in the order of 1,000 or 10,000 years is "the level implicitly accepted by NRC in recent (1980) licensing decisions" (Reiter and Jackson, 1983).

A probabilistic assessment of risk was used to evaluate several existing licensed plutonium fabrication plants (Bernreuter et al, 1979). Probabilistic characterization of seismic hazard was only one facit of that study; it also included an evaluation of the seismic capacity of critical structures and equipment to determine ground motion levels at which they would fail.

The point of this brief discussion is that probabilistic characterization of seismic hazard has been gaining in acceptance and application in connection with various nuclear facilities. In addition, a probabilistic approach would be a more appropriate method than a deterministic one for determing the design earthquake at the repository given the unknowns concerning the seismic sources. A probabilistic approach would permit a sensitivity study of the parameters that define both the seismic sources and structural fragility and facilitate a more meaningful evaluation of risk to the public given the occurrence of the design event.

Proposed Definitions for Waste Repository

It is proposed that the Design Earthquake (DE) be characterized as a highly improbable earthquake ground motion. The SSE for a nuclear power plant would also be regarded as highly improbable.

While this does not imply equality between the two, the similarity is noted and the SEP work is used to indicate a desired ground motion level.

The SEP studies concluded that the return periods for the SEE were in the order of 1,000 or 10,000 years (Reiter and Jackson, 1983). Since nuclear waste repository facilities will be fairly passive and will operate without radioactive water or steam and without the potential of core meltdown associated with power reactors, the lower end of this range would seem acceptable. Assuming a Poisson distribution, the 1,000-year return period associated with an SSE corresponds to a probability of exceedance of 4% during the 40-year lifetime of a nuclear power reactor. Since the lifetime of the operating repository is assumed to be approximately 100 years, a 1,000-year-return-period event has a probability of exceedance of 10% in that lifetime. This seems a little high to permit recommendation of ~~10,000~~ a 1,000-year period for the ground motion to be used in licensing a waste repository; therefore, it seems prudent to increase the return period. This rationale supports the acceptability of a 2,000-year return period for the DE with a probability of exceedance of 5% in 100 years. This corresponds to an annual exceedance rate of 5 x 10^{-4}.

The Design Underground Nuclear Explosion (DUNE) may also be defined from a probabilistic model. The advantage of such an approach is that is permits the hazard level for the DUNE to be set to the same level as for the DE. The problem with this approach is that Underground Nuclear Explosion (UNE) occurrence is determined by human decision-making processes rather than natural processes. However, testing might assume the appearance of a random process if the historical testing program were repeated indefinitely into the future. Therefore, the UNE occurrence model can be based on testing from a certain period of time hypothetically extended into the future with certain assumptions about the distribution of yields among test areas. By using a probabilistic approach, the value of the peak ground acceleration (or another peak ground motion parameter or spectral amplitude) can be obtained for both earthquakes and UNEs corresponding to the same hazard level.

The hazard level is best specified by the annual probability of exceedance, that is, the probability that a specific level of ground motion (usually peak ground acceleration) will be exceeded at a site or in a region in one year. The term "return period" is also used to specify the hazard level. The return period is regarded as the average time between occurrences of ground motion of a specific level or higher. Regarding earthquakes from a deterministic standpoint, the return period is also thought of as the average time between occurrences of a specific earthquake (specific magnitude and specific fault). However, this latter view is not applicable to UNEs because intermediate and high-yield detonations have occurred many times during fairly short periods of time. While it would be less confusing to discuss UNE motion levels only in terms of the annual probability of exceedance, return period will be used for convenience.

The respository facilities remaining after closure need to be evaluated for possible effects due to earthquake vibrations that may occur over an extremely long period of time, say 10,000 years. When considering release rates from the decommissioned repository, the only possible facility components that vibratory motion might affect would be the rock mass and seals. It does not seem likely that the passage of seismic waves through the repository will disturb either of these unless the seismic source is practically within the repository. Nevertheless, possible effects on the rock mass and seals should be considered. Since the rock mass cannot be "designed" (although seals can be), this ground motion will not be referred to as a design earthquake for the decommissioned period, but rather as the Postclosure Earthquake (PCE).

The PCE is applicable for repository evaluations over a 10,000-year period; thus, this event should have a very long return period, comparable to that time period. At this time, data permit estimation of return periods to about 10,000 years. Therefore, the PCE should be established by a 10,000-year return period. This corresponds to an annual exceedance rate of 10^{-4} and a probability of exceedance in 10,000 years of 63%.

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Proposed Methodology

General Comments. Probabilistic specification of design ground motions is one element of a full probabilistic risk analysis that will be needed to evaluate risk in quantitative terms. This analysis will be performed when specific performance criteria and accident scenarios are developed. In addition to its role in overall risk assessment, probabilistic analysis of ground motion at the repository serves the need for a single parameter--exceedance rate--whereby hazards of different origins (earthquakes and UNE events) can be compared on a common basis and whereby criteria for performance over different time spans (operational and postclosure) can be quantified.

Initially, probabilistic analysis of UNE ground motion appears awkward, and "deterministic" analysis seems natural. Deterministic information on the location and maximum yield of possible future UNE events is well established, while the rate of future UNE occurrence, needed for probabilitic analysis, cannot be ascertained. However, standard deterministic analysis as practiced for earthquake ground motion assessment cannot be applied in the case of UNE ground motion because multiple, rather than single, event occurrences must be considered. This requires that both the number of occurrences of the deterministic event and the standard deviation of the ground motion attenuation function are needed in order to quantify the level of confidence that the design ground motion will not be excceded during the operational phase of the repository. The method proposed for probabilistic analysis of UNE ground motion is to be model UNE occurrence as distributed over prescribed testing areas and yield ranges, in a manner analogous to that for earthquake hazard analysis. Occurrence rates for the UNE model are based on past testing at NTS.

Probabilistic response spectra, defined in terms of exceedance rate (or its inverse, recurrence expectancy or "return period") are known as uniform-hazard spectra because they have a uniform likelihood of exceedance at all frequencies. They are obtained by performing hazard calculations for a spectrum of frequencies, using an attenuation relation that gives response spectral amplitude as a function of event size, distance, and spectral frequency. Suitable attenuation functions are available for earthquakes but not for UNE ground motion, and so uniform-hazard spectra cannot be obtained for UNE events at this time. Instead, spectral shapes for design UNE motions can be obtained from statistical analysis of Yucca Mountain recordings of UNE events on Pahute Mesa and Yucca Flats.

<u>Ground Motion Attenuation</u>. Seismic ground motion criteria are conditioned by the kind of ground motion information that is available. In the case of UNE ground motion, site-specific data are available from Yucca Mountain recordings of Pahute Mesa and Yucca Flats events.

In the case of earthquake motion, there is as yet no site-specific information comparable to that for UNE events. Earthquake ground motion criteria can be obtained from regression results given by Joyner and Boore (1982) for peak ground acceleration, veolcity, and response spectral amplitude for the larger of two horizontal components. These results were obtained for shallow earthquakes recorded in the western U.S., principally in California, and are of uncertain applicability to the Yucca Mountain site region in terms of seismic source characteristics and seismic attenuation. Attenuation model-dependence of the probabilistic results was examined (URS/Blume, 1989) by performing parallel calculations for peak horizontal ground acceleration using attenuation models given by Campbell (1982) for California and for Utah. Very similar hazard results were obtained, albeit fortuitously, for the Joyner and Boore (1982) and Campbell (1982) Utah attenuation models when evaluated with the same coefficient of variation. The Joyner and Boore (1982) results should be adopted for determining earthquake ground motion criteria because they provide a consistent basis for calculating response spectral amplitudes as well as peak ground motion amplitudes. For the vertical component, not considered by Joyner and Boore (1982), response spectral amplitudes were taken to be two-thirds those for the horizontal component for DE, modeled as near-regional events, and equal to the horizontal-component amplitudes for the PCE, modeled as a near-field event.

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Event Occurrence Models. Both earthquake and UNE occurrence can be modeled as Poisson point processes of constant rate and uniform distribution in prescribed seismogenic zones and testing areas, respectively. The Poisson model specifies the long-term rate of event occurrence and the distribution of interevent time intervals, but not the individual event times, i.e., the events are unpredictable. The UNE occurrence model should not be based on current testing, which causes relatively insignificant ground motion hazard at Yucca Mountain, but rather on a hypothetical expansion of testing in terms of geography and yield. Testing ~~was~~ should be assumed to take place in the Buckboard Mesa area, which has not been used to date for UNE detonations. The closest distance from the Buckboard Mesa area to the reference surface facility site is 21.3 km. UNE occurrence should be distributed among the testing areas by yield according to established yield limits and in a manner that concentrates intermediate-yield events of the hypothetical testing model in the Buckboard Mesa area. Ⓟ For earthquake hazard calculations, the optimal strategy for modeling the seismicity of the site region is a function of the quantity of information on seismicity and tectonism of the region. Investigations initiated in support of the NNWSI project are rapidly enhancing the data base, particularly in regard to microseismicty and paleoseismicty (USGS, 1984). Yet to be assembled is a specific seismotectonic model that interrelates historic low-magnitude seismicity and earthquake focal mechanisms with paleoseismicity evidenced from fault scarp morphology and slip-rate data.

<u>Subsurface Ground Motion.</u> Spectral modulus ratios of UNE recordings at repository depth and on the surface at the Yucca Mountian site have been computed to examine near-surface propagation effects (URS/Blume, 1985). The results bear out the conclusion of Vortman and Long (1982a) that ratios of subsurface and surface motion are strongly site-dependent. Subsurface spectral amplitudes for both horizontal and vertical components were found to be significantly lower than those at the surface for all frequencies from 1 H_z up to the band limit of about 25 H_z. In the case of the horizontal components, subsurface spectral amplitudes were also significantly lower at frequencies less than 1 H_z, where a spectral ratio approaching 1 is expected. Spectral ratios for body-wave windows were similar to those for whole records, and a satisfactory explanation of the results was not found. To a fair approximation, the observed subsurface /surface spectral modulus ratios for Pahute Mesa UNE events can be represented by the value 1/2 over the entire frequency band of interest for vertical and horizontal components.

Similar results were obtained by King (1982) for earthquakes recorded at the surface and at a depth of 1,090 ft in the Paleozoic Eleana formation at Calico Hills, 12 km east of Yucca Mountain. Subsurface/surface response spectral ratios were found to be nearly independent of frequency over the recording band of 0.2 to 20 H_z, with a value of 2/3. This frequency behavior is similar to that observed for UNE motion at Yucca Mountain. The difference in spectral ratios for the two cases may be attributable to differences in geologic structure, constitution, and topography at the sites.

Pending the formulation of a physical model to explain these observations, subsurface/surface spectral ratios are taken to be 1/2 for both earthquake and UNE motion for interim design. This assumption has not been verified for earthquake ground motion at the site and has been supported for UNE ground motion by analysis of only a limited data set; therefore, further investigations are recommended. Wideband, high-dynamic-range recording at surface ans subsurface locations is recommended for investigating earthquake motions at the repository site. Further analysis of Pahute Mesa and Yucca Flat events recorded at the Yucca Mountain array is recommended to investigate the spectral characterisitcs of subsurface and surface signals.

FAULT DISPLACEMENTS

Overview

In the vicinity of Yucca Mountain, Quaternary offsets or fractures have been discovered along 32 faults, based upon trench excavations and stratigraphic correlations (Swadley et al, 1984). Most of these features are at least one million years old. The youngest fault disturbances are indicated by fractures in young alluvial deposits (40,000 to 270,000 years old) which overlie faults displacing Tertiary volcanic units. One of these faults, the "Bow Ridge" (named by Scott and Bank, 1984), passes along the west side of Exile Hill, near the proposed repository entrance. Youngest fault displacements, however, appear to exceed 270,000 years in age, with the exception of the Bare Mountain fault, located about 16 km west of the repository area. Recognized offsets are entirely dip-slip in sense, and their magnitudes do not exceed 3 meters; most are much smaller.

However, as Swadley et al point out, reliable estimates of offset magnitudes are rarely possible, due to the lack of bedding in the unconsolidated units studied. The longest continuous fault scarp has a length of 4 km, along the Solitario Canyon fault.

Information contained in the report by Swadley et al (1984) appears to be the best available at this time for Quaternary fault movements in the vicinity of the proposed repository. However, those data are not adequate to evaluate displacement hazard on any of the faults described. A great deal of additional field work would be required to develop data which might (or might not) be sufficient for this purpose.

Methods of investigation and description of fault-displacement hazard and risk are described herein, in a presentation which is meant to be indicative rather than comprehensive; it is expected that the Site Characterization Plan will entail modification and expansion of the ideas presented here.

Manifestations

Surface rupture. Fault rupture at the ground surface has been observed in close association with historic earthquakes worldwide, and with great frequency in the western United States. The Great Basin affords numerous examples of this association, as well as that with prehistoric earthquakes. Although surface rupture may also result from aseismic fault slip, no evidence suggests that this phenomenon is important in the Great Basin.

In the Great Basin, including the repository site area, historic and Quaternary fault displacements are predominantly dip-slip in style, although strike-slip motion is often seen on nominally normal faults. Single-event (single-earthquake) dip-slip displacements as large at 6 m are recognized in this region, and may have recurrence intervals as short as about 6,000 years on the most active faults, located in the west-central Great Basin, north of Tonopah, Nevada (Wallace, 1978).

Seismotectonic activity is much lower in the Yucca Mountain region than in the west-central Great Basin. Indeed, it is so low that no investigation to date has provided data which document single-event fault displacements, their sense, or their frequency of occurrence. The fact that recurrence intervals of major rupture on regional faults are so long (likely exceeding 100,000 years) renders determination of their hazard and its recurrence quite difficult, as explained in a later section.

Subsurface rupture. Subsurface fault rupture may differ significantly from surface rupture, depending upon the magnitude, sense, and nucleation depth of the dislocation, whether the slip is coseismic or aseismic (by creep), the mechanical properties of the rock and presence of pore fluids. Creep is not expected to be a significant mode of rupture in the Yucca Mountain region.

Coseismic fault rupture originates at the earthquake focus and propagates away at speeds generally near the shear-wave velocity of the rock medium. Characteristics of the fault displacement field are closely associated with earthquake source parameters, eg. moment tensor, stress drop, focal depth, and friction on the fault surface. For larger ($M>6$), shallow-focus earthquakes ($h<10$ km), displacement at depths no more than a few km beneath the fault trace is expected to be comparable to that of the surface rupture. Smaller shocks ($M < 6$), however, often produce no surface rupture and, therefore, surface and subsurface rupture may differ markedly for them. Empirical relationships between earthquake magnitude and fault rupture dimensions, based essentially on larger ($M>6$) shocks, should provide reasonable estimates of shallow subsurface displacement for smaller shocks, because the data used to develop these relations is considered representative of maximum rupture offsets (e.g., Bonilla et al, 1984).

Near-fault strain. Homogeneous shear-strain change in the near-field (within a few kilometers) of a major fault rupture (displacement exceeding 1 m) may be on the order of 1 part in 10^5 (Turcotte and Schubert, 1982, p. 95). If strains of this magnitude are important to cannister integrity, then near-fault strain changes, due to seismic or aseismic slip on faults within a few km of the repository should be considered.

Proposed Methodology

Two different methodologies, termed "deterministic" and "probabilistic" are described. We recommend that the probabilistic approach be used in respository design, as it better accounts for available fault movement data than does the deterministic approach. The latter method is the simpler one, and is therefore described first.

Definitions. According to a draft statement on definitions (Norman, 1985), a "deterministic analysis" utilizes physical parameters selected by a recognized expert in the specific field of analysis, based on estimates and judgement. In this type of analysis, parameters which are known to be subject to significant uncertainty are treated explicitly as uniquely determined. However, the process of judgement implicity accounts for the element of uncertainty in stated parameter values. On the other hand, the "probabilistic" approach accounts explicitly for the elements of uncertainty, and, therefore, its results are more nearly reproducible than are those of a "deterministic" procedure.

In assessing earthquake hazards, the times of occurrence of the hazard cannot now be predicted with any degree of confidence, i.e. "deterministically," although the average frequency of occurrence of the hazard may be estimated. Information on frequency of occurrence can be utilized only in a probabilistic calculation.

For the purposes of this section (on fault displacement), it will be convenient to give restricted, special meanings to two commonly used words, hazard and risk. By hazard, we mean the maximum expected magnitude of a threatening natural event, with no reference to its frequency of occurrence. The hazard may be evaluated either deterministically or probabilistically. By risk, we refer to the probability of occurrence of a particular hazard magnitude during a given period of time. Clearly, risk can be evaluated only in a probabilistic manner.

Deterministic Method. As just explained, the deterministic approach can be used to estimate fault movement hazard, but not fault movement risk. For a particular fault, the procedure is likely to involve three steps: 1) determine the mapped length and sense of motion of the fault; 2) from this information, estimate the maximum expected earthquake magnitude; 3) use a published empirical function (e.g., Bonilla et al, 1984) to calculate fault rupture displacement from this magnitude. Note that step (2) requires judgement, as no widely accepted scheme exists to relate mapped fault length to maximum earthquake magnitude (nor directly to displacement). The estimated displacement hazard may have any frequency of occurrence, as time is simply not an element of the procedure.

Probabilistic Method. While the methods of risk calculation set forth below appear to be original in this application, the underlying principles are well known and have been used widely in connectin with vibratory earthquake ground motion. The risk of fault displacement would be stated as the probability of exceedance of a given value of displacement during a given time interval. Fault displacement risk has not been a subject of study in earthquake engineering because structures are so rarely required to be designed to withstand fault displacement. In a few cases, fault displacement hazard has been assessed in a deterministic manner.

Two different approaches to the problem are treated. The first may be termed fault-specific, as it relies upon data describing a particular fault, while the second may be called regional, as it relies chiefly upon regional fault and seismicity data. Because the fault-specific method requires data which are not likely to be available, emphasis is placed on the regional method.

A fault-specific method requires abundant data concerning a specific fault in order to calcualte its associated displacement risk. These data are for the amount and age of at least several ruptures affecting any part of the fault. With sufficient data, one might develop the cumulative distribution of largest displacements for a given time, from which the probability of exceedance of a given displacement in any time interval may be calculated, using a risk function based on extreme-value theory (see, e.g., Epstein and Lomnitz, 1966). Given only sparse data, one would have to assume the shape of this distribution, perhaps based upon a theoretical mode). The data now available for faults in the vicinity of Yucca Mountain are far too few in number (see, e.g., Swadley et al, 1984) to provide a useful guide to the construction of this distribution function. As it is supposed that available data will not greatly increase in number over the next year, the fault-specific method is considered infeasible for use in the SCP.

A regional approach to probabilistic characterization of fault displacement is also possible. In order to calculate the displacement risk on faults for which very little or no displacement history data are available, it is necessary to deduce the risk from information on regional seismicity and fault displacements. The basic idea is to infer seismic activity on a particular fault based upon regional historic seismicity, wherein we attribute a fraction of that seismicity to ~~to~~ a fault based upon its individual characteristics. Hence, we require a fault model in which a collection of known, and perhaps also inferred, faults is responsible for all regional seismicity above some threshold Richter magnitude (below which the associated displacement hazard is insignificant). The activity of a fault would be a function of its geometry (length, orientation, and sense) in relation to the regional pattern of strain release (based on Quaternary faulting and historic seismicity). Once a fault's seismicity is established, it is possible to infer the frequency distribution of displacement amplitudes on that fault using an empirical formula correlating earthquake magnitude and fault displacement. By incorporating an empirical relation between rupture length and total fault length, the displacement risk at a single point on the fault can be calculated.

To illustrate the modelling procedure, we present the following simple ideas. Suppose that all seismicity in the Yucca Mountain region were attributed to north-trending normal faults whose cumulative mapped length is LCUM. A single normal fault with length L would have an inferred seismicity level of L/LCUM multiplied by the regional seismicity level. The seismicity level can be stated simply as the annual number of shocks of $M>4$, assuming a regionally uniform 'b'-slope in the frequency-magnitude distribution. A more refined model would include faults of other orientations and displacement sense, and mathematical functions for assignment of seismicity based upon these parameters.

As suggested above, three empirical formulas may be combined to estimate the fault displacement risk at a single point. These are from regressions of (1) earthquake frequency on magnitude, (2) earthquake magnitude on fault displacement, and (3) fault rupture length on fault displacement. The first of these is simply the widely used earthquake "magnitude-frequency" relation,

$$\log N = a - bM,$$

where N is the number of earthquakes per unit time (usually 1 year) with magnitude greater than or equal to M. The second and third relationships have been developed in a number of articles, most recently by Bonilla et al (1984), who performed elaborate analyses of the regression parameters. The pertinent empirical equations developed by them are

$$M = c + d \log s \quad \text{and} \quad \log L = e + f \log s,$$

where M is earthquake magnitude, L is fault rupture length, and 's' is fault displacement or slip. The regression parameters (c, d, e, f) are subject to considerable uncertainty, due to the wide scatter of the data sets used in the regressions. By appropriate combination of the three equations, one can develop a relationship for frequency vs. fault displacement amplitude,

$$\log N_S = A - B\,S,$$

where N_S is the annual number of fault rupture events with displacement greater than or equal to $S = \log s$. From the development given by Epstein and Lomnitz (1966), it is then straightforward to develop simple equations for the mean recurrence time of a given 's', the T-year modal displacement, and the probability of exceedance (risk) of displacement 's' in any period of time. This development is presented in Appendix D.

It is important to note that the method just described uses the expected values of regression parameters, which are actually subject to considerable error, with coefficients of determination generally on the order of 0.5 or smaller (Bonilla et al, 1984). Using statistical techniques not described here, it is possible to incorporate the dispersion of the regression coefficients in the risk calculation.

DATA NEEDED TO SUPPORT METHODOLOGIES

Vibratory Ground Motion

Recorded Earthquake Ground Motions. all need wide-band high-dynamic-range monitoring at site, surface and underground.

Regional Attenuation Functions. ~~[Incorporate relevant section of~~ URS/JAB ~~report 8333~~ 8467 ~~and add the following material.]~~

Currently, A. M. Rogers of the U.S. Geological Survey (telecon with R. W. Greensfelder on 9/16/85) is conducting research on the attenuation of peak ground motions from earthquakes in the vicinity of the Nevada Test Site and adjoining areas of the Great Basin. Analysis performed to date indicates that crustal Q (quality factor) is high (of order 700), and is distinctly higher than that of central and southern California. Richter (local) magnitudes computed from Berkeley and Pasadena seismographic data are too high, by amounts which are seen to vary with epicentral distance. Therefore, calculation of the risk or amplitudes of ground motion at the repository site might be made significantly more accurate through the use of the region-specific empirical attenuation function now under development.

Our specific recommendation is that the function being developed by Rogers be used to establish the regional distance dependence, while the magnitude dependence should be carried over directly from the empirical formulas already developed from California data (e.g., Campbell, 1981). This is because the southern Great Basin earthquakes recorded include very few shocks of M>4.

Map of Active Faults. In order to make the best possible probabilistic assessment of vibratory ground motion, a map of active faults within about 100 km of the site, all meeting the same criteria for activity should be prepared. The most practical approach to this problem would involve quantitative photogeologic mapping of fault scarp morphology, including parameters of scarp slope and height, as well as sinuousity. The criterion for activity might involve a weighted sum of indices computed from the above and perhaps allied morphologic measures.

Fault Displacement

Fault Location. The most fundamental data concerning fault displacement hazard are those which locate the fault surface in three dimensions, combining surface and subsurface geologic observations. For faults of small displacement (perhaps less than about 1 m), this may be infeasible. Thus, it will be necessary to establish a critical value of total fault displacement and to ignore faults of lesser offset. Even so, ambiguity may arise when attempting to connect surface and subsurface location data.

Rupture History. Gathering of adequate data to define rupture history of an individual fault is never an easy matter, and it is frequently impossible. Two fundamentally different types of data may be used for this purpose: 1) fault scarp morphologic data, and 2) measured offsets of subsurface features (e.g., bedding planes or contacts) which are dateable. Techniques of scarp morphology have been applied successfully to faults in northern Nevada (e.g., Wallace, 1977), which are much more active than those of and near Yucca Mountain. Scarp morphologic data may well be inadequate to determine rates of fault activity in the study region.

Offsets of buried horizons by faults which appear to have had Quaternary movement in the study region have been investigated in numerous excavations in unconsolidated Quaternary materials (Swadley et al, 1984), with very limited results. This is because mappable horizons are difficult to identify in the alluvial materials studied. It is likely that continuation of such investigations will not provide definitive information on fault rupture histories. Therefore, it may be necessary to study offsets in pre-Quaternary (Pliocene) volcanic rocks. Offsets of vein-filling materials (calcite or quartz) which are dateable by isotopic methods may be the most practical approach. However, it must be noted that pre-Quaternary movements bear a tenuous relationship to future fault movements.

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APPENDIX D: CALCULATION OF DISPLACEMENT RISK

This appendix presents a brief derivation of fault displacement risk at a single arbitrary point on a fault. The development is patterned directly after that of Epstein and Lomnitz (1966), and uses regression relationships of Bonilla et al (1984).

We begin with the well known magnitude-frequency law for earthquake occurrence,

$$\log N = a - bM, \tag{1}$$

where N is the annual number of shocks with magnitude exceeding M and the regression coefficients 'a', 'b' characterize a particular fault. Bonilla et al (1984) present a regression formula of the form

$$M = c + d \log s, \tag{2}$$

where M is earthquake magnitude and 's' is fault displacement, and the regression coefficients 'c' and 'd' take on values which depend upon the specific data subset analyzed (numerical values are given). By combining relations (1) and (2) we find

$$\log N = A - B\ S, \tag{3}$$

where A = a-bc, B = bd, and S = log s. Relation (3) gives the annual number of shocks with fault displacement exceeding 's' for the entire fault. But we wish to know the frequency of occurrence of slip at a single point on the fault, and this we shall call N' = N (l/L), where 'l' is rupture length for an earthquake and L is total mapped length of the active fault. Now,

$$\log N' = A - B\ S + \log l - \log L. \tag{4}$$

But from Bonilla et al (1984),

$$\log l = e + f\ S, \tag{5}$$

where 'e' and 'f' are regression coefficients for a given subset of fault data. Combining (4) and (5), we have

$$\log N' = A' - B'\ S, \tag{6}$$

where A' = A - log L + e, and B' = B - f.

Now we can adopt directly the formulas for mean return period and modal T-year displacement, as well as probability of exceedance, given by Epstein and Lomnitz (1966):

$$T_{mean} = 1/N' = 10^{-A'} s^{B'}, \qquad (7)$$

$$S_{mod} = A'/B' + (1/B) \log \qquad (8)$$

where S_{mod} is the modal T-year displacement. Finally, the probability of exceedance (P) of displacement (s) in T years i

$$P = 1 - \exp [-N' T], \text{ with } N' \text{ from (6).} \qquad (9)$$

It should be noted that equations (7), (8), and (9) assume a Poisson distribution of interoccurrence times of events, i.e., the actual time of the most recent event has no bearing on that of the next one. While this model is non-causal (non-physical) in its nature, it remains the basis of most engineeirng risk calculations, and certainly those of seismic risk.

The formulas developed above do not take into account uncertainties of the regression parameters, although it would be a good idea to do so. It is recommended that this be done during preparation of the SCP.

Attachment 6

-Jim
This is for your info.
It's only a rough draft - but may be useable as backup for the S&T paper.

Sandia National Laboratories
Albuquerque, New Mexico 87185

date: November 7, 1985

to: F. W. Bingham, 6312

from: Ralph R. Peters, 6312
J. H. Gauthier, 6312

subject: The Effect of Seismic and Tectonic Activity on Radionuclide Containment at Yucca Mountain, Nevada

I Introduction

The containment of radionuclides at a repository located at the proposed Yucca Mountain site may be affected by seismic and tectonic activity. The NNWSI project is now contributing to a position paper concerned with the affect of seismic and tectonic activity on both the pre-closure and post-closure operation of a repository. In support of this effort, this memo will address the effect of seismic and tectonic activity on the transport of radionuclides to the accessible environment. Analyses of radionuclide transport in deep unsaturated zones (DOE, 1984) indicate that radionuclide transport will be primarily by water. Thus, this memo will discuss the transport of radionuclides by water through the unsaturated zone to the water table. It is possible that the water table position may be affected by seismic and tectonic activity but the Draft Environmental Assessment for the Yucca Mountain Site specifically states "...large-scale structures control the ground-water system, and tectonic deformations of a magnitude or scale to affect the regional flow system are not expected" (DOE, 1984, Table 6-31). The focus of this memo will be on the ways seismic and tectonic activity may affect the movement of water in the unsaturated zone.

There appear to be two general regions where seismic and tectonic activity could affect the proposed site and its ability to contain radionuclides.

1) The first region is the rock mass adjacent to the fault zone. In this region the primary affect would be on the fracture density and aperture. The changes in these parameters would depend on the rock type (e.g. densely welded tuff would fracture more than the bedded, zeolitized tuffs) and the proximity to the fault zone. The consequence could be that the general flow pattern throughout the block is altered in a manner that increases the velocity of downward water movement and thus the rate at which radionuclides are transported to the water table.

2) The second region is the localized area where fault motion would occur. The primary affects of fault motion on the fault region would be additional displacement of the rock mass on one side of the fault relative to that on the other side of the fault, and changes in the fracture density and aperture. Waste package breakage, changes in

fracture hydrologic properties, and surface affects such as landslides could occur in this region. The consequences of waste package breakage would be that the radionuclides would be available for transport sooner than expected. The consequence of changes in fracture properties could be that the velocity of water movement in some localized area is significantly increased to increase the rate at which radionuclides are transported to the water table. The consequence of changes in the local surface topography could be that the local infiltration rate is increased due to ponding of arroyos and so the amount of water moving downward and the velocity of water movement downward is increased.

It has been stated on a number of occasions by USGS personnel (e.g., Robert E. Wallace on 7/23/85 at the Seismic/Tectonic meeting in Las Vegas, NV) that significant fault movement (1 m or so) most likely will occur on pre-existing faults that are readily identifiable both above and below ground. Thus, it would seem reasonable that the problem of waste package breakage as a result of fault movement could be reduced or possibly eliminated by not placing any waste packages in those areas which appear to be in or immediately adjacent to a large fault zone. The remaining affects of seismic and tectonic activity on radionuclide transport then could result from (1) changes in the flow field resulting from changes in the fracture properties, and (2) changes in the local infiltration resulting from changes in surface topography. In order to estimate that affect of seismic and tectonic activity on the flow field a model of flow in a fractured, porous medium must be adopted.

The following sections contain a discussion of the model used to estimate that affect of seismic and tectonic activity on the flow field and a discussion of the estimates made by the model.

II Hydrologic Model

The modeling of water flow in unsaturated, fractured porous media has recently received attention (e.g., Montazer and Wilson, 1984; Klavetter and Peters, 1985). The model developed by Klavetter and Peters will be used to investigate the affect of seismic and tectonic activity on both the general and local flow field. This model is a continuum model which lumps the fractures and the porous medium into a "composite medium" for the purpose of calculating the pressure field in the medium. Two major assumptions that allow this lumping are:

1) The fracture aperture is less than several millimeters. This assumption allows capillary bundle theory to be applied. Reports by a variety of authors (Sinnock et al., 1984; Peters et al., 1984) suggest that the fracture aperture at Yucca Mountain is 0.1 millimeters or less.

2) The flow field is changing relatively slowly allowing the pressure head in the fractures and the matrix to be equal in a direction perpendicular to the flow lines in the composite medium. A discussion of this assumption may be found in the paper by Klavetter and Peters (1985).

The paper by Klavetter and Peters (1985) contains a complete discussion of the derivation of the equations listed below. The governing equation for steady-state flow in the composite medium follows.

$$-[\bar{\bar{K}}_{m,b} + \bar{\bar{K}}_{f,b}] * \nabla(\psi + z) = \bar{q}_m + \bar{q}_f = \bar{q}_{total} \qquad \text{Eq. 1}$$

This equation allows the pressure-head field (ψ) in the composite medium to be calculated with the boundary conditions and material properties specified.

The average linear velocity of water in the matrix (V_m) and the fractures (V_f) may be calculated using the following equations along with the pressure-head field solution and material properties.

$$\bar{V}_m = \bar{q}_m/[n_m(S_m - S_{m,r})] = -\bar{\bar{K}}_{m,b} * \nabla(\psi + z)/[n_m(S_m - S_{m,r}) \qquad \text{Eq. 2}$$

$$\bar{V}_f = \bar{q}_f/[n_f(S_f - S_{f,r})] = -\bar{\bar{K}}_{f,b} * \nabla(\psi + z)/[n_f(S_f - S_{f,r}) \qquad \text{Eq. 3}$$

The variables used in the above equations are defined below.

ψ - the pressure head

$\bar{\bar{K}}$ - the conductivity. The conductivity is usually expressed as the saturated conductivity (K_{sat}) times the relative conductivity (K_{rel}) which is a function of the pressure head and the material. It ranges from unity at a pressure head of zero or greater to zero at large negative pressure heads.

n - the porosity

$\bar{q}$ - water flow per unit area or specific discharge

S - saturation, a function of ψ

z - vertical position

The subscripts "m" and "f" refer to the matrix and fractures respectively. The subscripts "m,b" and "f,b" refer to bulk properties of the matrix and the fractures. The subscripts "m,r" and "f,r" refer to the residual saturation of the matrix and fractures.

III Conceptual Hydrologic System at Yucca Mountain

The conceptual hydrologic system at Yucca Mountain is discussed in a variety of documents (DOE, 1984; Klavetter and Peters, 1985; Montazer and Wilson, 1984) and will not be repeated here. The major point of these discussions is that the matrix is partially saturated and thus the percolation rate downward through Yucca Mountain is less than the saturated conductivity of the matrix. A value quoted as an upper bound for the repository horizon and below is 0.5 mm/year (DOE, 1984). Bill Wilson of the USGS has recently proposed that the maximum flux below below the repository horizon is 0.2 mm/yr (Wilson, 1985).

IV Effect of Seismic and Tectonic Activity on the Flow Field within the Repository Block

In order for seismic and tectonic activity to affect the velocity of water movement in Yucca Mountain it must affect the hydrologic properties in the flow equation (either Eq. 1 or 2) or the boundary conditions. It is thought that neither the average infiltration rate of water at the surface of Yucca Mountain nor the position of the water table will be affected by seismic or tectonic activity. (The affect of seismic and tectonic activity on the local infiltration rate and the local flow field will be discussed in a later section.) Therefore, seismic and tectonic activity can only affect the flow field by affecting the values of hydrologic properties in the flow equation. The only parameters that may be affected are those associated with the fractures (e.g., S_f and $K_{f,b}$) which would change as a result of changes in the fracture density and aperture. Eq. 1 can be used to examine the long-term response of the flow field to changes caused by seismic and tectonic activity. The only independent parameter in this equation that will change is the bulk fracture conductivity ($\bar{\bar{K}}_{f,b}$) which may change the pressure-head field (ψ) and thus the amount of water in the fracture system and the matrix ($\bar{q}_f$ and $\bar{q}_m$) and the velocity of water in the matrix and fracture system ($\bar{V}_m$ and $\bar{V}_f$).

There is currently a fairly large body of information available on the saturated conductivity of fractures, however, there is little data concerning the unsaturated behavior of fractures. There are a number of articles speculating on the behavior of flow in unsaturated fractures (Wang and Narasimhan, 1985; Klavetter and Peters, 1985; and Montazer and Wilson, 1984). These articles model the fracture conductivity as a function of the fracture aperture distribution and the fracture saturation. The fracture saturation is itself a function of the pressure head and the fracture aperture distribution. The major point in these articles is that a continuous path in the fracture must be saturated in order for the fracture to have a non-zero conductivity along the plane of the fracture. If the surrounding matrix is only partially saturated then in order to obtain this saturated path the fracture aperture along the path must be the same size as the maximum size of the nearby saturated pores. The average pore size in the tuffs that have low matrix conductivities is very small (of the order of 0.00003 millimeters or less according to Peters et al. (1984)) compared to that of the fracture aperture (of the order of 0.1 to 0.01 millimeters according to Peters et al. (1984)). Therefore, it is reasonable to assume that the fractures are currently "dry" and seismic activity which opens the fractures will further decrease the ability of the fractures to carry water at the conditions observed at Yucca

Mountain. Data concerning average fracture aperture as a function of confining stress (Peters et al., 1984) indicate that it is not reasonable to suppose that the fracture aperture can be closed sufficiently by seismic and tectonic forces so that saturated pathways can occur in the fractures under conditions that are now present at Yucca Mountain (i.e. fracture apertures that are now of the order of 0.1 millimeters cannot be closed to 0.00003 millimeters if the stress increases by a factor of ten from the current values). Finally, if the the aperture could be decreased so that the fracture system could carry water then the flow in the fracture system would be very small; in fact the characteristics of flow in the fracture system would be very similar to that in the matrix. Thus, it appears that seismic and tectonic activity cannot affect the fractures in a manner that will allow them to carry water in regions where the matrix is only partially saturated. Therefore, it is reasonable to assume that seismic and tectonic activity cannot affect the movement radionuclides downward to the water table.

VI Effect of Seismic and Tectonic Activity on Infiltration

There appears a possibility that seismic and tectonic activity could affect the surface causing landslides. These landslides could, in turn, dam an arroyo allowing ponding to occur as a result of severe storms. This scenario is one that has caused some discussion and thus a bounding calculation has been performed. The Draft Environmental Assessment states that there is no evidence of ponding occurring at Yucca Mountain (DOE, 1984).

The situation modeled was that of injecting a 10 m slug of water into a fault zone. The value of 10 m was thought to be a reasonable depth for a pond. If ponds of this depth (and consequently size) have existed at Yucca Mountain in the recent past then there should be evidence of them. The Draft Environmental Assessment (DOE, 1984) states that there is no evidence for damming of arroyos. Therefore, a 10 m deep pond represents a reasonable upper limit.

The calculation was performed by TOSPAC (Dudley et al., In prep.), which is a one-dimensional systems performance assessment code. The values of flux, velocity, and penetration distance of the slug of water in the fault zone calculated by TOSPAC are upper bounds because the one-dimensional code does not allow for seepage of water out of the fault zone into the surrounding rock (e.g., out of the fault zone into the highly conductive Paintbrush Tuff nonwelded unit which is above the repository horizon). The one-dimensional column used in the calculations is shown in Figure 1. It is based on the stratigraphy found at well USW G-4 (Ortiz et al., 1985). The units in order of decreasing depth are: (1) the Tiva Canyon welded unit (TCw), (2) the Paintbrush Tuff nonwelded unit (PTn), (3) the upper lithophysal rich zone of the Topopah Spring welded unit (TSw1), (4) the lower lithophysal poor zone of the Topopah Spring welded unit (TSw2-3) - the proposed repository unit, and (5) the zeolitized Calico Hills nonwelded unit (CHnz). Unit PTn has a high matrix conductivity (about 10,000 mm/yr) while the rest of the units have matrix conductivities of about 1 mm/yr. The hydrologic data for the calculations are very similar to those used in the paper by Peters, Gauthier and Dudley (In prep.). The only change made to the hydrologic data was to increase the saturated conductivity of each unit's fracture system by a factor of ten-thousand to represent the increase in fracture conductivity due to changes in fracture density, etc. found in a fault zone. The saturated conductivity of the uppermost unit is such that a slug of water 10 m tall will infiltrate the surface in a little over 2 days. The hydrologic data used for these calculations are listed in Table 1. The initial pressure-head distribution was specified by a constant flux through the mountain of 0.1 mm/yr and the position of the water table at the bottom of the column. The percolation rate of 0.1 mm/yr lies within the range thought applicable for Yucca Mountain (DOE, 1984).

The results of the calculation are shown in Figures 2-5. Figure 2 shows the water flux versus distance above the water table for times ranging from 1 day after injection to 200,000 years after injection. Figure 3 shows the matrix saturation profiles for the same times as in Figure 2. Figures 4 and 5 show the velocity of water in the matrix and fracture system versus distance. The injection of the 10 m slug occurred over a period of 2.2 days. At that point in time the slug of water had traveled through unit TCw and about two-thirds of the way through unit PTn. According to Figure 3 the upper two-thirds of PTn is saturated and according to Figures 4 and 5 there are high velocities throughout the region containing the slug of water.

After the injection of water at the surface is cut off (2.2 days) the water starts to redistribute itself in response to gravity and pressure-head gradients. The water flows fairly quickly to the bottom of PTn (see the 1 month and 1 year profiles in Figure 3). Because there is not enough water to saturate the bottom of unit PTn the water movement in the next unit (TSw1) is limited to the matrix (see Figures 4 and 5). The 100 yr through 200,000 profiles in Figure 3 indicate unit PTn is slowly drained by the lower units. Figure 2 shows the flux profile approaches the initial condition after approximately 200,000 years. The flux pulse resulting from the injection of the 10 m slug of water does not reach the water table until almost 10,000 years have passed.

Figure 4 indicates the water velocity in the matrix in the units below PTn is within a factor of 5 of the initial water velocity. For most of the simulation the water velocity is within a factor of 2. Thus, a particle of water injected into the surface at the start of a simulation has a travel time from the ground surface to the water table that is approximately the same as that of a water particle traveling the same distance with a steady flux of 0.1 mm/yr. The total travel time for the latter case is about 600,000 years with most of the time spent in the two lowermost units (Peters, Gauthier, and Dudley, In prep.) which are least affected by the water slug. We may conclude that radionuclide transport and travel times are not significantly influenced by the injection of a 10 m slug of water into a fault zone. It would require a slug of water approximately 15 m tall to initiate water movement in the fractures of unit TSw. Water movement in the fractures would quickly stop as soon as the bottom of PTn became unsaturated. Additional water would be required to maintain saturation in all units above the water pulse. This model indicates that in order for water movement to occur in the fractures throughout the fault zone, the fault zone would have to be saturated from the surface to the water table. The height of a slug of water require to saturate the entire fault zone can be estimated using the porosity of each unit and its initial saturation. The calculation estimates that the slug of water would have to be about 20 m tall.

This analysis assumes that there is no leakage out of the fault zone into the surrounding rock while, in fact, there may be significant leakage all along the fault zone. The results should only be used to indicate that ponding of water above a fault zone may not have significant affect on water travel times and radionuclide transport times locally. The affect of ponding on the flow field throughout the block would appear to be insignificant.

VII Summary

It appears that seismic and tectonic activity cannot affect the fractures in a manner that will allow them to carry water in regions where the matrix is only partially saturated. Therefore, it is reasonable to assume that seismic and tectonic activity alone cannot affect the movement radionuclides downward to the water table.

A scenario that has been discussed is that of damming an arroyo and then filling the reservoir with a large flood. A bounding calculation indicates that reasonable assumptions concerning the amount of water injected into the fault zone result in no significant consequence.

These topics will continue to be addressed as a part of the ongoing performance assessment effort. The positions taken in this memo are based on information and models currently available. They are subject to change as new data and the results of future calculations become available.

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ROUGH DRAFT

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Table 1 Unsaturated zone, hydrologic unit properties

Matrix Properties [a]

Unit	Sample Code	Grain Density (g/cm^3)	Porosity (n_m)	Hydraulic Conductivity (m/s) [b] (K_{mb})	S_r	Alpha (1/m)	Beta
TCw	G4-1	2.49	0.08	9.7E-12	0.002	0.821E-02	1.558
PTn	GU3-7	2.35	0.40	3.9E-07	0.100	1.50 E-02	6.872
TSw1	G4-6	2.58	0.11	1.9E-11	0.080	0.567E-02	1.798
TSw2-3	G4-6	2.58	0.11	1.9E-11	0.080	0.567E-02	1.798
CHnz	G4-11	2.23	0.28	2.0E-11	0.110	0.308E-02	1.602

Fracture Properties [c]

Unit	Sample Code	Horizontal Stress [d] (bars)	Fracture Aperture (microns)	Fracture Conductivity (m/s)	Fracture Density [e] ($No./m^3$)	Fracture Porosity [f] (n_f)	Fracture Compressibility (1/m)	Bulk Frac. Conductivity (m/s) [g] (K_{fb})
TCw	G4-2F	1.1	67.4	3.8E-3	200	14. E-3	132. E-8	5.3 E-5
PTn	G4-3F	3.3	270.	61. E-3	10	2.7E-3	19. E-8	16. E-5
TSw1	G4-2F	9.5	51.3	2.2E-3	80	4.1E-3	5.6E-8	0.90E-5
TSw2-3	G4-2F	21.9	45.5	1.7E-3	400	18. E-3	12. E-8	3.1 E-5
CHnz	G4-4F	34.3	15.5	20. E-3	30	4.6E-3	2.8E-8	9.2 E-5

Fracture saturation coefficients are S_r = 0.0395, Alpha = 1.2851/m, Beta = 4.23

Unit	TCw	PTn	TSw1	TSw2-3	CHnz
Coefficient of consolidation (1.E-7/m) [h] (α'_{BULK})	6.2	82.	12.	5.8	26.

The compressibility of water (β'_w) is 9.8E-7/m

This table is based on information in the report by Peters, Gauthier and Dudley (in prep.). The full references for the following footnotes may be found in that document.

Notes:
- a) All matrix data in this section are from Peters et al. (1984).
- b) The matrix saturated conductivity and the bulk matrix saturated conductivity (K_{mb}) are essentially the same because the factor that converts the matrix value to the bulk matrix value ($1-n_f$) is nearly equal to 1.0
- c) Unless noted otherwise, this fracture information is from Peters et al.(1984).
- d) Horizontal stress assumed to be one-third the overburden weight, evaluated at average unit depth in USW G-4.
- e) Based on the report by Scott et al.(1983).
- f) Calculated as fracture volume (aperture times 1 square meter) times number of fractures per cubic meter.
- g) This value of "K_{fb}" was obtained by multiplying the fracture conductivity by the fracture porosity.
- h) Based on the report by Nimick et al.(1984).

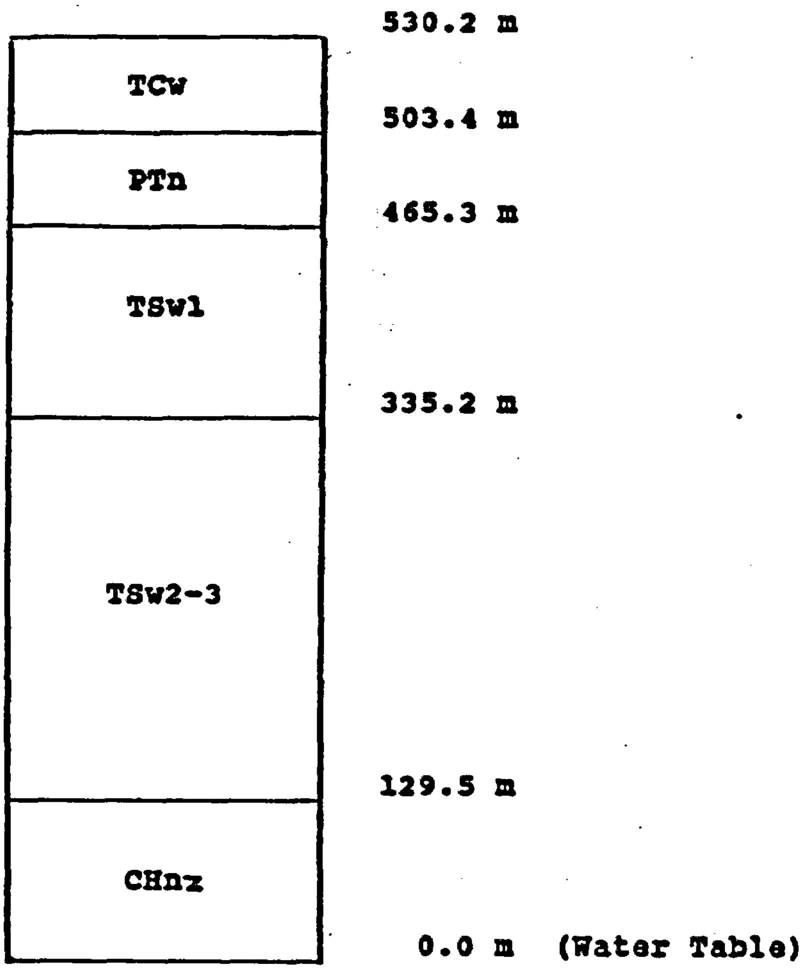

Figure 1 One-dimensional column used in calculations

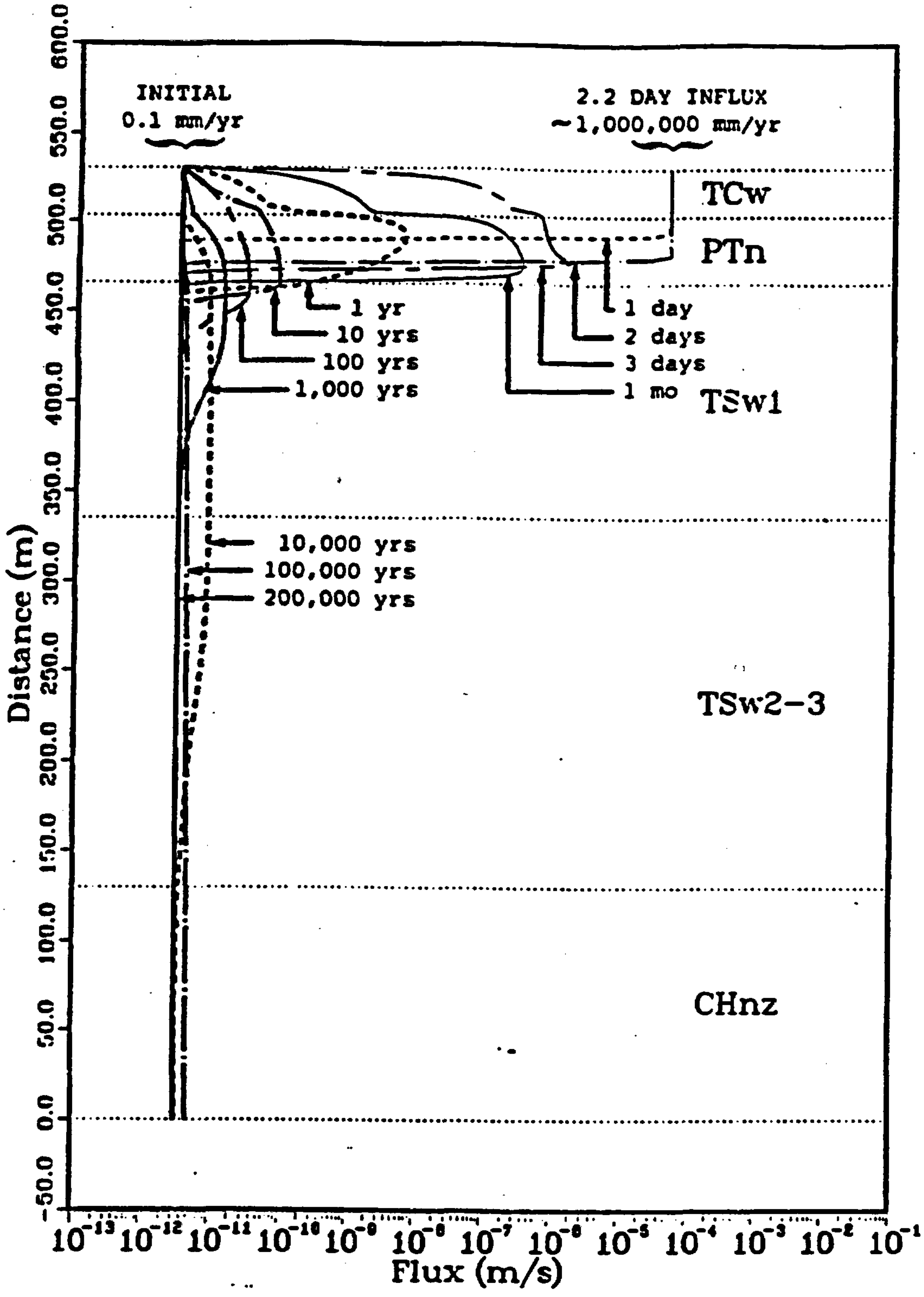

Figure 2. Water Flux Profiles

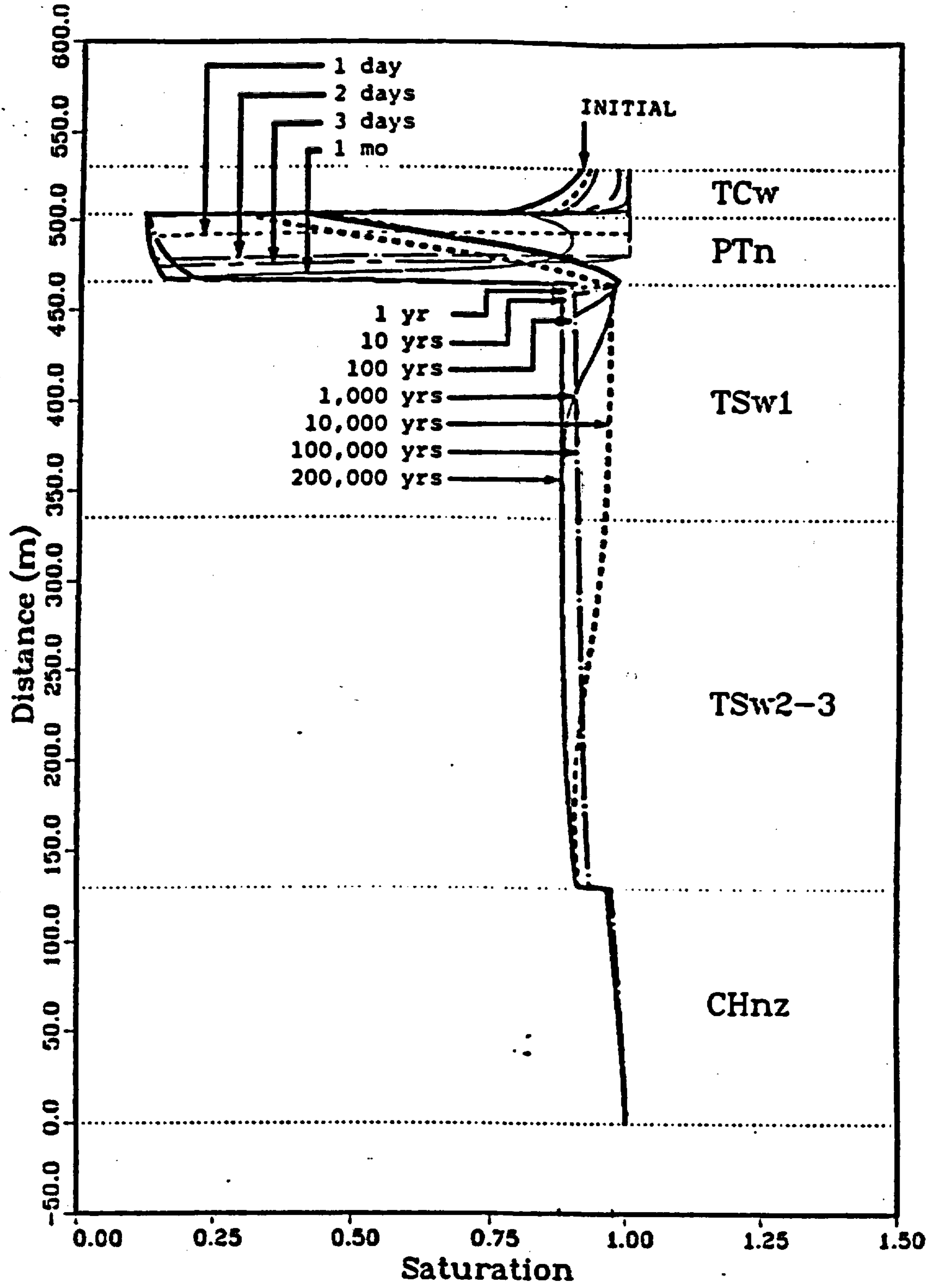

Figure 3. Saturation Profiles

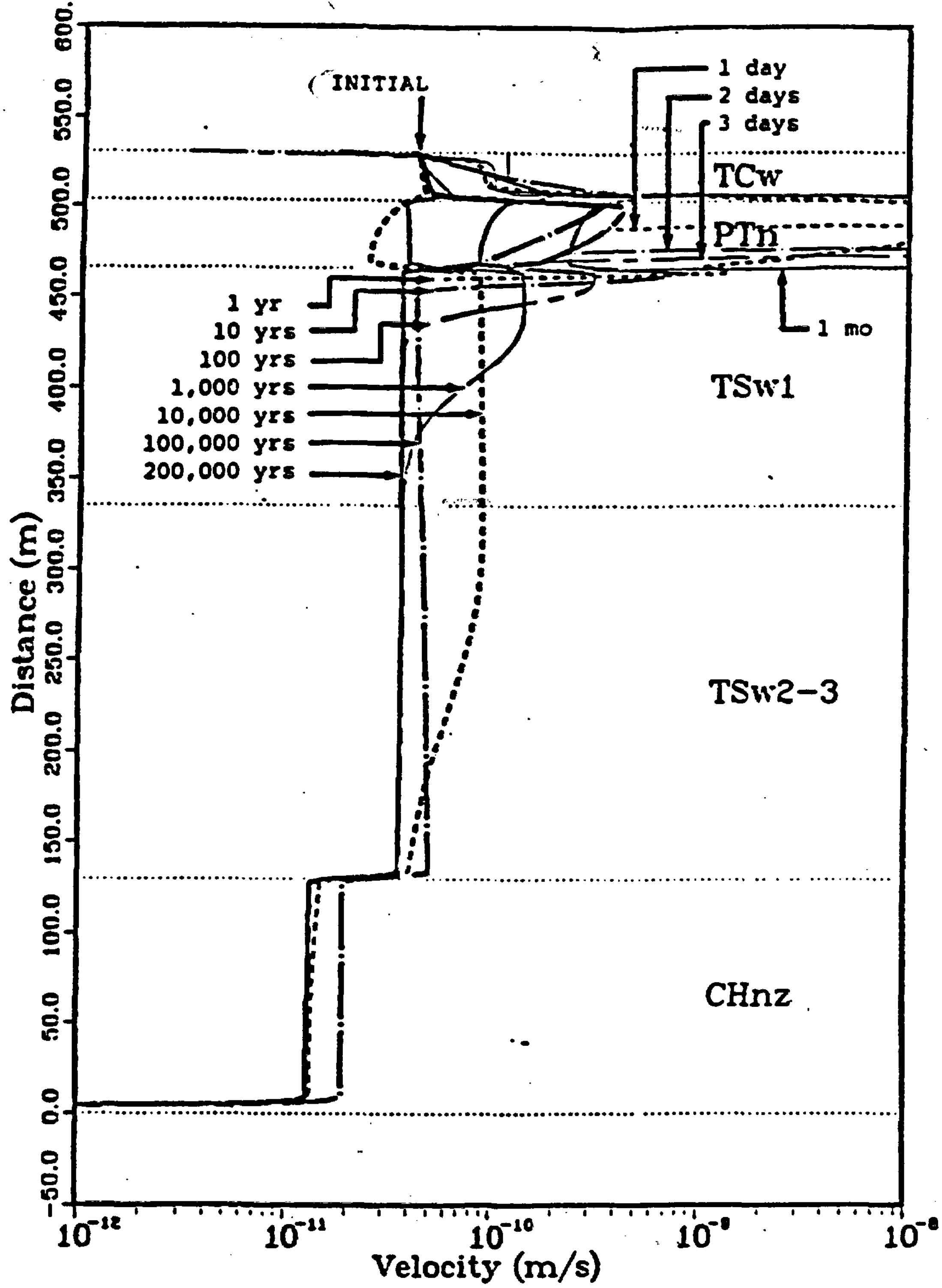

Figure 4. Profiles of Water Velocity in the Matrix

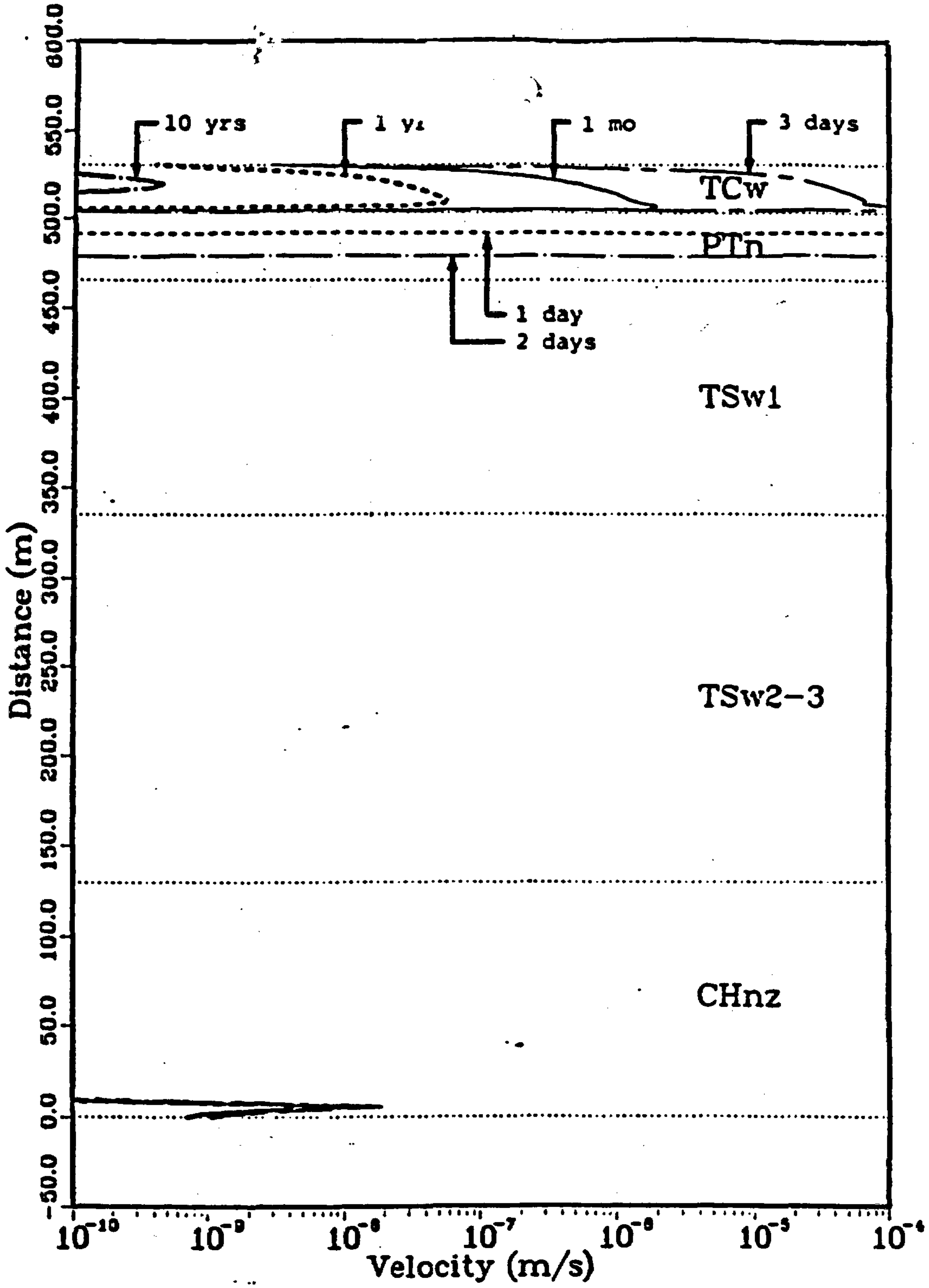

Figure 5. Profiles of Water Velocity in the Fracture System

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