JACOBS	Calculation No: C-12	Page: 1 of 22
Calculation Cover Sheet	Rev. No.: 2	Revision Date: 4/15/08
(Ref. FOWI 116 Design Calculations)	Previous Revision Date: 2/13/08	Current Revision Date: 4/15/08
Issuing Department: *Federal Operations Design Engineering*	Supersedes: Revision 1 (dated 2/13/08)	
Client: U.S. Department of Energy Project Title: Moab – UMTRA Project Project Number: 35DJ2600 System:	Engineering Discipline: Geotechnical	

Calculation Title: Liquefaction Analysis of Uranium Mine Tailings Repository at Crescent Junction, UT

Purpose:

Assess the liquefaction potential of the uranium mill tailings pile to be constructed at the Crescent Junction Disposal site.

The present condition and characteristics of the uranium mill tailings at the Moab repository site are considerably different than what is anticipated to be placed at the Crescent Junction disposal site. Material properties of the existing mine tailings are available for the Moab site. During the course of this project, the mine tailings at Moab will be mixed and dried out to optimum moisture content before being transported to Crescent Junction. There, the tailings will be placed and compacted to 90% relative compaction. Since Standard Penetration Test data are not available for the "modified" tailings deposited at the Crescent Junction site, it is necessary to use empirical relationships to assume final conditions for liquefaction analysis.

The analysis will focus on the liquefaction potential of the proposed tailings pile instead of the natural subsurface materials since all natural soils will be removed full depth and the excavation extended 2 feet into the underlying Marcos Shale beneath the entire base footprint of the tailings pile. The underlying Mancos Shale is not considered to be liquefiable.

NQA-1 QUALITY LEVEL: 2

Prepared by: Kurt J. Bettger Date: 4-28-2008

Checked by: Ahmad Hans Date: 4-30-2008

Engineering Managers Approval: William D. Bartlett Date: 5/5/2008

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Revision History:

Pages Affected By Revision	Revised/Added/Deleted	Description of Revision
Rev. 2	Revision, Page 4 Section: Design Inputs	Revised tailings pile geometry from 60% to 90% drawings resulted in the following changes to design input: Tailings thickness: 46.7 ft (from 38 ft) Cover thickness: 9 ft (from 10 ft) Total soil thickness: 55.7 ft (from 48 ft) Saturated soil thickness: 46.7 ft (from 38 ft)
	Revision, Page 6 Conclusions/Recommendations	New factor of safety calculations based on revised tailings pile geometry: ..."calculated factor of safety ranged from 1.37 to 2.38 in the tailings containing 17% fines, and from 1.74 to 3.04 in the tailings with 46% fines". (Changed from "1.37 to 1.84 in the tailings containing 17% fines, and from 1.74 to 2.34 in the tailings with 46% fines.")
	Revision Pages 7 & 8 Calculation Page	Revised tailings pile geometry resulted in the following change to calculation input for liquefaction analyses (for both tailings with 17% fines and with 46% fines): Soil thickness: 55.7 ft

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Description of Calculation:

Evaluation of soil liquefaction potential using Seed-Idriss Simplified Procedure based on Standard Penetration Test and modified for 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils.

Design input includes soil property characteristics (soil type, percent passing No. 200 sieve, and unit weight), soil thickness, depth to groundwater, and seismic design properties (earthquake magnitude and estimated peak acceleration at the ground surface for Crescent Valley).

Spread sheet calculates seismic cyclic stress ratio (CSR) and cyclic resistance ratio (CRR) and factor of safety (FS). The factor of safety against liquefaction in a tailings layer can be calculated by dividing the shear stress required to cause liquefaction in the layer by the shear stress generated in that layer by the design earthquake.

Assumptions:

1. Existing tailings at Moab site will be dried out to optimum moisture content prior to transport to Crescent Junction site. Once there, tailings will be placed in layers per specification and compacted to 90% relative compaction. In general, mine tailings should not be saturated.
2. For analysis purposes only, assume tailings are saturated full depth (worst case)
3. Seismic design input as given in Technical Approach Document and RAP Attachment 1, Appendix D for estimated peak acceleration at the ground surface for Crescent Valley.
4. Liquefaction potential will be analyzed using earthquake moment magnitude = 6.5 (see attached paper by Wong & Olig (refers to design earthquake magnitudes at Moab site).
5. SPT blowcounts can be reasonably estimated for the placed and compacted materials based on assumed relative density of the compacted tailings layers.

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Design Inputs:

Tailings thickness: 46.7 feet
Cover thickness: 9 feet (per discussion with Jacobs' Oak Ridge personnel)
Total soil thickness: 55.7 feet

Saturated soil thickness: 46.7 feet (tailings saturated)

Cover Unit Weight: 104 pcf dry
112 pcf at 7% moisture content

Tailings Unit Weight: 98 pcf dry
124.1 pcf at 27% moisture content

Tailings Fines Content: 17% minimum (SM)
46% mean (SM-ML)

Seismic Data:

Peak acceleration at ground surface: 0.22 g
(Note: for stability analysis, TAD allows for surface acceleration = 0.11g at end of construction, and 0.66 x 0.22g = 0.15 g for long term conditions)

Earthquake moment magnitude: 6.5

Tailings to be compacted to 90% relative compaction. The equivalent relative density is 50% (Holtz and Kovacs). Based on correlations of SPT blow counts, N, and relative density, an N_{60} of 10 to 15 (at overburden pressure of approximately 20 psi) will be required to achieve 50% relative density. This field N is equivalent to N_{60} = 15 where N_{60} is the corrected blow counts for 60% rod energy ratio and for overburden pressure.

Software:

Title	Developer	Versions	Revision Level
Liquefaction Analysis Spreadsheet	Jacobs		

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Calculation Section:

See attached spreadsheets.

Liquefaction analysis has been performed for two cases:

1. Tailings with 17% fines (i.e. 17% passing the No. 200 sieve); and
2. Tailings with 46 % fines (i.e. 46% passing the No. 200 sieve).

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Conclusions/Recommendations:

The results of the analyses indicate that liquefaction of the tailings will not occur under the assumed soil and seismic conditions. Furthermore, it is considered likely that field SPT N-counts in 90% relative density material may result in higher blow counts than assumed in this liquefaction analysis.

The Technical Approach Document (TAD) indicates the minimum factor of safety considered acceptable for UMTRA sites is 1.5. The calculated factors of safety ranged from 1.37 to 2.38 in the tailings containing 17% fines, and from 1.74 to 3.04 in the tailings with 46% fines. Due to the extreme (and unlikely) assumption made for saturated conditions to be present full height of the tailings, it is concluded that the tailings at the site are not liquefiable.

Reference:

Technical Approach Document (December 1989) DOE/UMTRA-050425-0002

Wong, I.G. and Olig, S.S., "Earthquake hazards in the Intermountain U.S.: Issues relevant to uranium mill tailings disposal".

Lambe and Whitman (1969), Soil Mechanics.

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USGS Earthquake Hazards Program
http://eqint.cr.usgs.gov/deaggint/2002/out/Moab_17395_seismogramps.jpg

Seed, H.B. and I.M. Idriss (1971), "Simplified Procedures for Evaluating Soil Liquefaction Potential", American Society of Civil Engineers, Journal of Soil Mechanics and Foundations Division, 97(9).

Shaw E&I Inc., (2006), Geotechnical test results on tailings samples, March 13 and November 7. Presented in RAP, Attachment 5, Appendix N, Supplemental Geotechnical Properties of Tailings Materials from the Moab Processing Site.

Gibbs, H.J. and Holtz, W.G., "Research on Determining the Density of Sand by Spoon Penetration Test," Proceedings, Fourth International Conference Soil Mechanics and Foundations Engineering, vol I, (1957)

Holtz, R.D. and Kovacs, W.D. (1981) An Introduction to Geotechnical Engineering.

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EVALUATION OF SOIL LIQUEFACTION POTENTIAL USING SEED-IDRISS SIMPLIFIED PROCEDURE - STANDARD PENETRATION TEST

Jacobs Civil

By: KB
Chkd:
Date: 4/15/2008

Job #: 35DJ2600
File:

Density of water (pcf)	62.4
Water table depth (ft)	10
Peak bedrock acceleration (g)	
Estimated surface acceleration (g)	0.22
Earthquake moment magnitude	6.5
Atmospheric pressure (psf)	2116.2
Borehole diameter (inches)	4.0
SPT hammer efficiency	60%
Split spoon liner	FALSE

soil thickness (ft) 55.7
maximum amplification 1.5

Magnitude Scaling Factor, MSF 1.4
Sloping Ground Correction Factor, K_α 1.0

Soil Boring: Assumed to get N60 = 15

depth (ft)	N_{FIELD}	% passing #200	Soil Type	Strength, Q_u (tsf)	Unit weight (pcf)	Total stress (psf)	effective stress (psf)	Cn	C*	N_{60}	N_{60CS}	K_σ	Cyclic Resistance Ratio (CRR)	r_d	Cyclic Stress Ratio (CSR)	factor of safety	Comment
0.0	0	95	0		1	1	8	1.70	0.90	0.0		3.0	0.05	1.0	0.02	13.76	
5.0	10	95	cl		112	560	560	1.50	0.95	14	22	1.3	0.24	1.0	0.14	3.25	Clay
10.0	12	17	sm		124	1150	1150	1.26	1.01	15	19	1.1	0.20	1.0	0.14	2.38	Okay
15.0	12	17	sm		124	1770	1458	1.16	1.06	15	19	1.1	0.20	1.0	0.17	1.84	Okay
20.0	12	17	sm		124	2390	1766	1.08	1.11	14	18	1.0	0.20	1.0	0.19	1.57	Okay
25.0	13	17	sm		124	3010	2074	1.01	1.17	15	19	1.0	0.21	0.9	0.20	1.52	Okay
30.0	13	17	sm		124	3630	2381	0.94	1.22	15	19	1.0	0.20	0.9	0.20	1.42	Okay
35.0	14	17	sm		124	4250	2689	0.89	1.20	15	19	1.0	0.20	0.9	0.20	1.37	Okay
40.0	15	17	sm		124	4870	2997	0.84	1.20	15	19	0.9	0.20	0.9	0.20	1.38	Okay
45.0	16	17	sm		124	5490	3305	0.79	1.20	15	19	0.9	0.21	0.8	0.19	1.42	Okay
50.0	16	17	sm		124	6110	3613	0.75	1.20	14	18	0.9	0.20	0.8	0.18	1.39	Okay
55.7	16	17	sm		124	6817	3964	0.71	1.20	14	18	0.9	0.19	0.7	0.17	1.38	Okay

Note:
N_{FIELD} - blow counts measured in the field
Q_u (tsf) - soil strength (RIMAC, PP) used in estimating the density for cohesive soil
Cn - factor to normalize blow counts to an effective overburden pressure of approximately 1 atm.
C* correction factor for N taking in account the rod length, split spoon liner, borehole diameter, and hammer efficiency
N_{60} Corrected blow counts (excludes correction for fines).
N_{60CS} Corrected blow counts to equivalent clean sand (correction for fines content).
K_σ - Overburden pressure correction factor [Ref. 1 and 2]
K_α - Sloping ground correction factor [Ref. 1 and 2]
MSF - Magnitude Scaling Factor (applied when design eartquake moment magnitude is not equal to 7.5)[Ref. 1 and 2]
r_d - Stress Reduction Factor [Ref. 1 and 2]

Soil Type - CH, CL & ML are cohesive and should have RIMAC or PP values
Soil Type - SM-ML, SM, SP, SW & GP are cohesionless soils
SM-ML - Very Fine Silty Sand
SM - Fine Sand
SP - Medium Sand
SW - Clean Medium to Coarse Sand
GP - Sandy Gravel

Reference:
1. "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils", by Youd et al., by Youd et by Youd et al., Journal of Geotechnical and Geoenvironmental Engineering, October 2001
2. "Liquefaction Evaluation Procedures", IDOT Bridge Section - Foundation Unit.

EVALUATION OF SOIL LIQUEFACTION POTENTIAL USING SEED-IDRISS SIMPLIFIED PROCEDURE - STANDARD PENETRATION TEST

Jacobs Civil

By: KB
Chkd:
Date: 4/15/2008

Job #: C5X58706
File: G:\TPW\GEOTECH\Moab-Oak Ridge\crescent junction calculations\[crescent junction liquefaction analysis 17% fines-Rv 04-15-2008.xls]46% fines

Density of water (pcf)	62.4
Water table depth (ft)	10
Peak bedrock acceleration (g)	
Estimated surface acceleration (g)	0.22
Earthquake moment magnitude	6.5
Atmospheric pressure (psf)	2116.2
Borehole diameter (inches)	4.0
SPT hammer efficiency	60%
Split spoon liner	FALSE

soil thickness (ft) 55.7
maximum amplificatior 1.5

Magnitude Scaling Factor, MSF 1.4
Sloping Ground Correction Factor, K_α 1.0

Soil Boring: Assumed to get N60 = 15

depth (ft)	N_{FIELD}	% passing #200	Soil Type	Strength, Q_u (tsf)	Unit weight (pcf)	Total stress (psf)	effective stress (psf)	Cn	C*	N_{60}	N_{60CS}	K_σ	Cyclic Resistance Ratio (CRR)	r_d	Cyclic Stress Ratio (CSR)	factor of safety	Comment
0.0	0	95	cl		112	0	0	1.70	0.90	0.0		#DIV/0!	0.05	1.0	#DIV/0!	**#DIV/0!**	
5.0	10	95	cl		112	560	560	1.50	0.95	14	22	1.3	0.24	1.0	0.14	**3.25**	Clay
10.0	12	46	sm-ml		124	1150	1150	1.26	1.01	15	23	1.1	0.26	1.0	0.14	**3.04**	Okay
15.0	12	46	sm-ml		124	1770	1458	1.16	1.06	15	23	1.1	0.25	1.0	0.17	**2.34**	Okay
20.0	12	46	sm-ml		124	2390	1766	1.08	1.11	14	22	1.0	0.25	1.0	0.19	**1.99**	Okay
25.0	13	46	sm-ml		124	3010	2074	1.01	1.17	15	23	1.0	0.26	0.9	0.20	**1.94**	Okay
30.0	13	46	sm-ml		124	3630	2381	0.94	1.22	15	23	1.0	0.26	0.9	0.20	**1.80**	Okay
35.0	14	46	sm-ml		124	4250	2689	0.89	1.20	15	23	1.0	0.26	0.9	0.20	**1.74**	Okay
40.0	15	46	sm-ml		124	4870	2997	0.84	1.20	15	23	0.9	0.26	0.9	0.20	**1.76**	Okay
45.0	16	46	sm-ml		124	5490	3305	0.79	1.20	15	23	0.9	0.26	0.8	0.19	**1.81**	Okay
50.0	16	46	sm-ml		124	6110	3613	0.75	1.20	14	22	0.9	0.25	0.8	0.18	**1.76**	Okay
55.7	16	46	sm-ml		124	6817	3964	0.71	1.20	14	21	0.9	0.23	0.7	0.17	**1.74**	Okay

Note:
N_{FIELD} - blow counts measured in the field
Q_u (tsf) - soil strength (RIMAC, PP) used in estimating the density for cohesive soil
Cn - factor to normalize blow counts to an effective overburden pressure of approximately 1 atm.
C* correction factor for N taking in account the rod length, split spoon liner, borehole diameter, and hammer efficiency
N_{60} Corrected blow counts (excludes correction for fines).
N_{60CS} Corrected blow counts to equivalent clean sand (correction for fines content).
K_σ - Overburden pressure correction factor [Ref. 1 and 2]
K_α - Sloping ground correction factor [Ref. 1 and 2]
MSF - Magnitude Scaling Factor (applied when design eartquake moment magnitude is not equal to 7.5)[Ref. 1 and 2]
r_d - Stress Reduction Factor [Ref. 1 and 2]

Soil Type - CH, CL & ML are cohesive and should have RIMAC or PP values
Soil Type - SM-ML, SM, SP, SW & GP are cohesionless soils
SM-ML - Very Fine Silty Sand
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GP - Sandy Gravel

Reference:
1. "Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils", by Youd et al. by Youd et by Youd et al., Journal of Geotechnical and Geoenvironmental Engineering, October 2001
2. "Liquefaction Evaluation Procedures", IDOT Bridge Section - Foundation Unit.

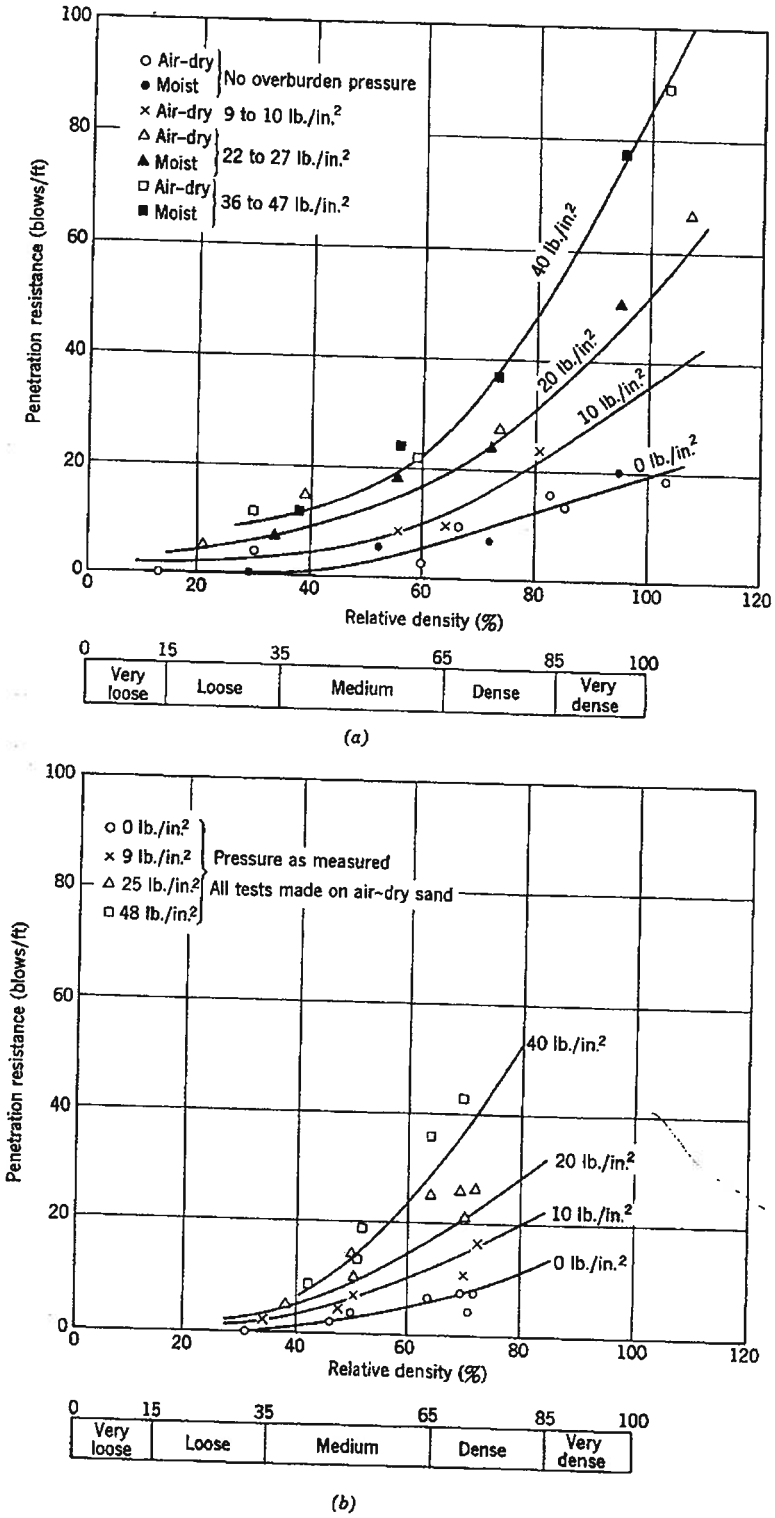


Fig. 7.5 Results of standard penetration tests. (*a*) Coarse sand. (*b*) Fine sand. (From Gibbs and Holtz, 1957.)

Earthquakes Researched for this Project

Click on Common Name for information about that earthquake.
Click here for an explanation of Magnitude or Intensity.

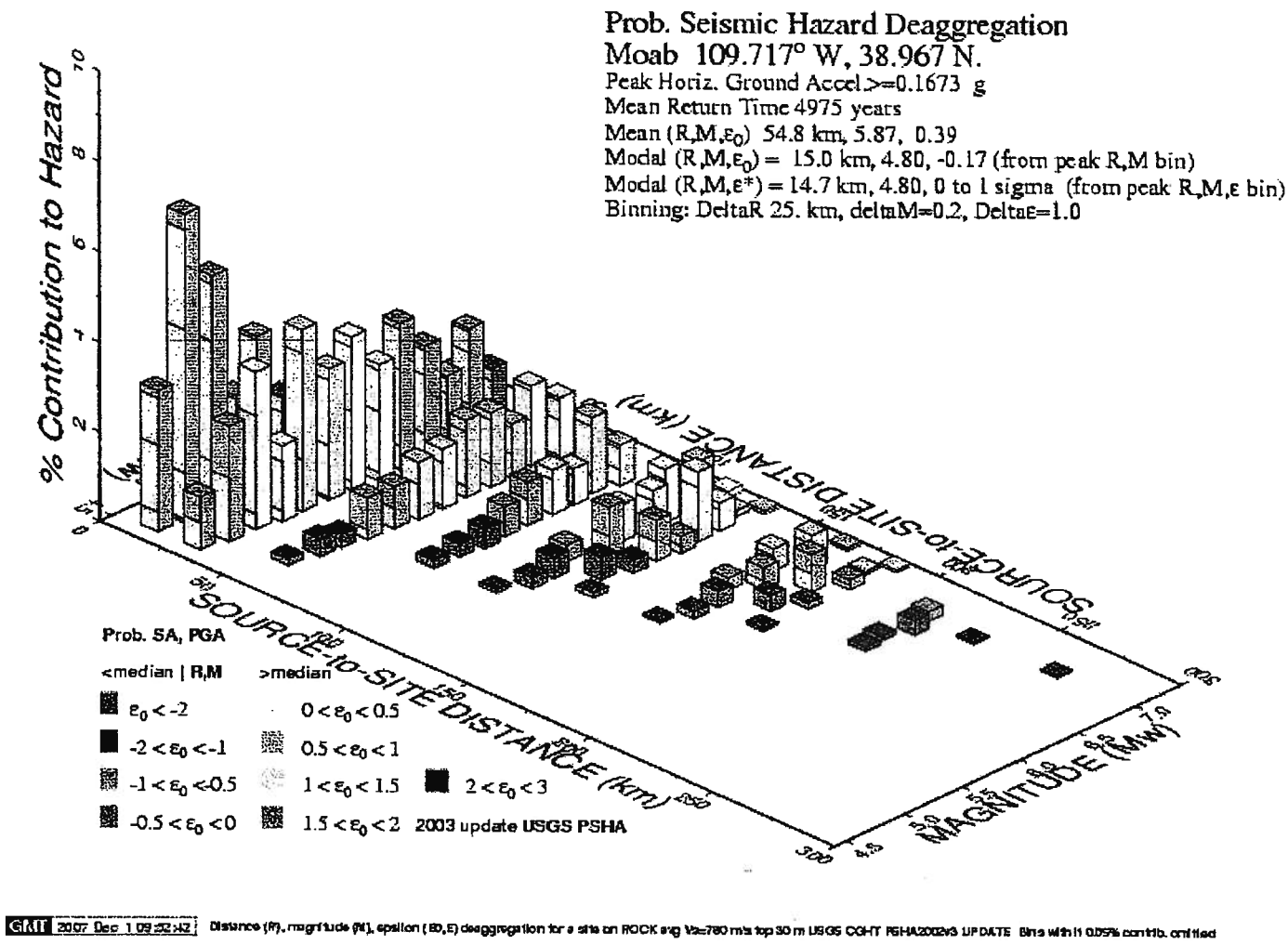
Sorted by Magnitude

Date	Common Name	Magnitude	Intensity
Mar 22, 1876	Moroni, UT	5.0	VI
Jul 18, 1894	Ogden, UT	5.0	VI
Apr 20, 1891	St. George, UT	5.0	VI
Apr 15, 1908	Milford, UT	5.0	VI
Jan 10, 1910	Elsinore, UT	5.0	VI
Jul 15, 1915	Provo, UT	5.0	VI
Jan 20, 1933	Parowan, UT	5.0	VI
Aug 30, 1942	Cedar City, UT	5.0	VI
Sep 26, 1942	Cedar City, UT	5.0	VI
Feb 22, 1943	Magna, UT	5.0	VI
Nov 17, 1945	Glenwood, UT	5.0	VI
Mar 06, 1949	Salt Lake City, UT	5.0	VI
Feb 13, 1958	Wallsburg, UT	5.0	VI
Feb 27, 1959	Panguitch, UT	5.0	VI
Apr 15, 1961	Ephraim, UT	5.0	VI
Sep 05, 1962	Magna, UT	5.2	VI
Oct 04, 1967	Marysvale, UT	5.2	VII
Aug 14, 1988	San Rafael Swell, UT	5.3	VI
Jan 29, 1989	So. Wasatch Plateau, UT	5.4	VI
Aug 01, 1900	Eureka, UT	5 1/2 +/-	VII
Nov 11, 1905	Shoshone, ID	5 1/2 +/-	V
May 22, 1910	Salt Lake City, UT	5 1/2	VII
May 13, 1914	Ogden, UT	5 1/2 +/-	VII
Feb 29, 1928	Helena, MT	5 1/2 +/-	IV
Sep 23, 1945	Flathead Lake, MT	5.5	VI
Mar 31, 1952	Big Fork, MT	5.5	VII
Feb 15, 1929	Lombard, MT	5.6	V
Dec 05, 1887	Kanab, UT	5.7	VII
Jul 21, 1959	Southwest UT	5.7	VI

Aug 30, 1962	Cache Valley, UT	5.7	VII
Jun 12, 1930	Grover, WY	5.8	VI
Sep 02, 1992	St. George, UT	5.8	VII
Feb 03, 1994	Draney Peak, ID	5.9	VII
Nov 17, 1902	Pine Valley, UT	6 +/-	VIII
Oct 05, 1909	Hansel Valley, UT	6 +/-	VIII
Sep 29, 1921	Elsinore, UT	6 +/-	VIII
Feb 13, 1945	Central Idaho	6.0	VI
Mar 27, 1975	Pocatello, ID	6.0	VIII
Jul 12, 1944	Central Idaho	6.1	VII
Jun 30, 1975	Yellowstone, WY	6.1	VII
Oct 18, 1935	Helena, MT	6 1/4	VIII
Nov 23, 1947	Virginia City, MT	6 1/4	VIII
Nov 10, 1884	Bear Lake, ID	6.3	VIII
Nov 13, 1901	Southern UT	6 1/2 +/-	IX
Mar 12, 1934	Hansel Valley, UT	6.6	IX
Jun 27, 1925	Clarkston Valley, MT	6 3/4	VIII
Oct 28, 1983	Borah Peak, ID	7.3	IX
Aug 17, 1959	Hebgen Lake, MT	7.5	X

Note: Date listed in Local Time

University of Utah Seismograph Stations «» 135 South 1460 East, Room 705 WBB
Salt Lake City, Utah 84112-0111 «» Phone 801-581-6274 «» Fax 801-585-5585
E-mail UUSS!



GMT 2007 Dec 1 09:22:42 Distance (R), magnitude (M), epsilon (ε0,ε) deaggregation for a site on ROCK avg Vs=760 m/s top 30 m USGS CGHT PSHA2002v3 UPDATE Bins with lt 0.05% contrib. omitted

Earthquake hazards in the Intermountain U.S.: Issues relevant to uranium mill tailings disposal

Ivan G. Wong and Susan S. Olig
Seismic Hazards Branch, Woodward-Clyde Federal Services, Oakland, CA USA

Bruce W. Hassinger
Smith Environmental Technologies Corporation., Englewood, CO USA

Richard E. Blubaugh
Environmental and Government Affairs, Atlas Corporation, Denver, CO USA

ABSTRACT:

In the past two decades, a tremendous amount of new information and data has emerged on seismic sources in the Intermountain United States and their associated processes of earthquake generation. Consequently, the seismic safety of U.S. uranium mill tailings sites, which are located almost exclusively in this region, are being reviewed by the U.S. Nuclear Regulatory Commission (NRC). Based on a deterministic and probabilistic re-evaluation of potential seismic hazards at a Title II site in southeastern Utah, three significant issues have been raised which will impact other sites in the Intermountain U.S. required to revisit their seismic design criteria by the NRC. These issues are: (1) whether the NRC's required use of a deterministic approach for assessing seismic hazards is appropriate for Title II uranium mill tailings sites in a region such as the Intermountain U.S.; (2) is the alternative approach of probabilistic seismic hazard analysis acceptable to the NRC for uranium mill tailings sites; and (3) what is the appropriate return period that should be used. Based on our evaluation, we conclude that deterministic ground motion approaches such as the NRC's 10 CFR 40 Appendix A can result in overly conservative seismic design criteria for Title II sites in the Intermountain U.S. and that instead, probabilistic seismic hazard analysis should provide the bases for such criteria. Additionally, as in all decisions of this nature, the selection of a return period for a specific site should be based on what is deemed an acceptable level of risk;. Such levels may vary from site to site depending on the consequences of radionuclide release into the environment. However, the values of 200 and 1000 years cited in the Environmental Protection Agency's (EPA) 40 CFR 192.02 and NRC's Appendix A Criterion 6(1) should form the basis for the selected return period.

1 INTRODUCTION

Many portions of the Intermountain region of the western United States (Figure 1) exhibit geologic evidence for large prehistoric earthquakes although they may lack even low levels of historical and/or contemporary seismicity. Such areas are subject to future seismic hazards. Large events such as the 1959 magnitude (M) 7.3 Hebgen Lake, Montana and 1983 M 6.8 Borah Peak, Idaho earthquakes attest to the earth's potential to damage both natural and man-made environments. The recurrence intervals of such large events on a specific fault in the Intermountain U.S., however, may span from a few thousands to more than 100,000 years. Hence, one of the most significant problems

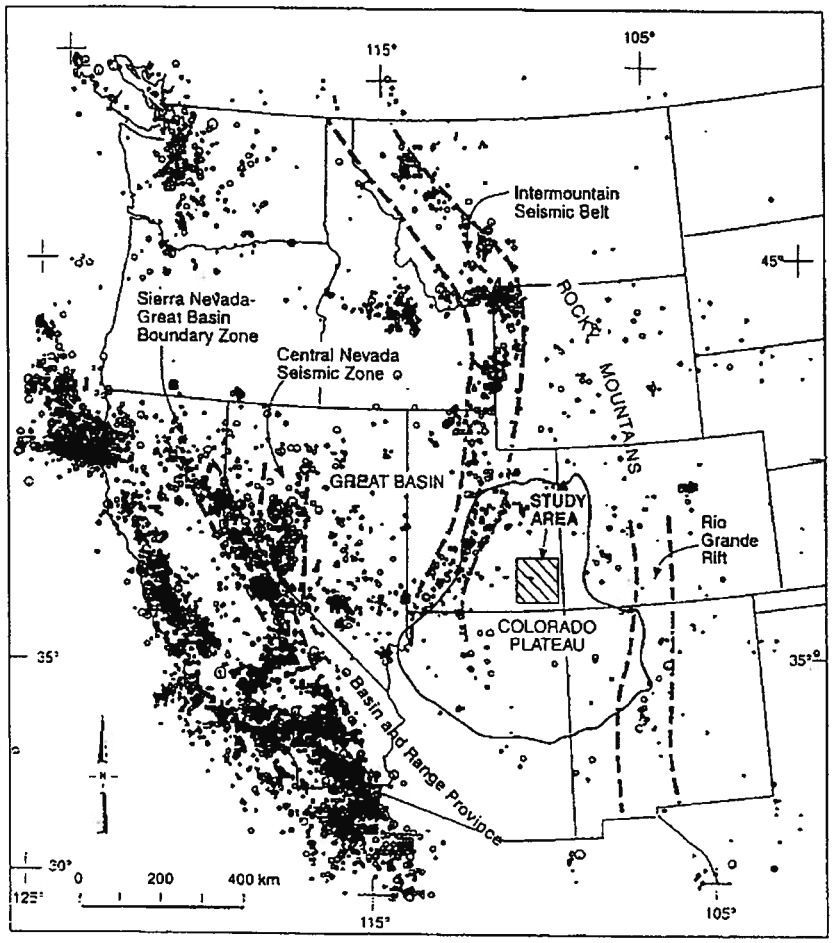


Figure 1. Seismicity of the western U.S. (1808 to 1996) and physiographic provinces and major seismic source zones located in the Intermountain U.S. Also shown is the study area around the Moab site in southeastern Utah. Earthquake data courtesy of the National Earthquake Information Center.

facing the community involved in earthquake hazard mitigation is how to address the hazard from large but infrequent earthquakes. In contrast, there also exist portions of the Intermountain U.S., such as the interior of the Colorado Plateau, where the earthquake potential is low based on both recent geologic and seismologic data.

In 1978, Congress enacted the Uranium Mill Tailings Radiation Control Act (UMTRCA) to provide for the disposal, long-term stabilization, and control of uranium mill tailings. The NRC, which regulates UMTRCA uranium mill tailing sites, has initiated a program of re-evaluating the seismic design criteria of Title II (licensed) sites based on the results of a recent study performed by Lawrence Livermore National Laboratory (LLNL) (Bernreuter et al. 1995). In the LLNL study, "simplified" site-

specific probabilistic seismic hazard analyses were performed for 19 Title II sites located in Utah, Wyoming, South Dakota, and New Mexico based on readily available information. Bernreuter et al. (1995) concluded that at most sites, their estimates of probabilistic peak ground acceleration at return periods of 2,000 years and more were higher than the values used in design.

In a recent re-evaluation of a Title II site in Moab, Utah, three key seismic hazard issues have emerged in our interactions with the NRC. These issues will significantly impact most, if not all, other sites in the Intermountain U.S. This paper describes these issues and our approach to resolving them.

2 EARTHQUAKE HAZARDS IN THE INTERMOUNTAIN U.S.

The Intermountain U.S., as defined in this paper, consists of the states of Idaho, Nevada, Arizona, Utah, Montana, New Mexico, Colorado, and Wyoming. Physiographically, the region consists principally of the Basin and Range province, Colorado Plateau, Rocky Mountains, and Great Plains. Four major seismic zones are located within or border the Intermountain U.S. including: (1) the Sierra Nevada-Great Basin boundary zone; (2) the Intermountain seismic belt including the Centennial Tectonic Belt; (3) the Central Nevada seismic zone; and (4) the Rio Grande rift (Wong et al. 1982) (Figure 1). Elsewhere, away from these zones, the level of historical seismicity is more subdued but there still exists the potential for the occurrence of large but infrequent earthquakes as indicated by the presence of late-Quaternary faults. For example, the 1887 Sonoran earthquake of estimated M 7.4 occurred as a result of rupture along the Pitaycachi fault just south of the Arizona-Mexico border (Bull and Pearthree 1988) in an area characterized by a low level of historical and contemporary seismicity.

Of greatest relevance to the Intermountain Title II sites are the Intermountain seismic belt and Rio Grande rift. The Intermountain seismic belt is one of the most extensive zones of seismicity within the continental United States (Figure 1). It trends 1300 km northward from- northwestern Arizona through central Utah, straddles the Idaho Wyoming border, and turns northwestward through Montana in the vicinity of Yellowstone National Park (Smith and Sbar 1974; Smith and Arabasz 1991) Much of the Intermountain seismic belt is characterized by generally north- to northwest-trending normal faults. Prominent fault zones include the Sevier and Hurricane faults in northern Arizona and southern Utah, the Wasatch fault zone in central Utah, and the Madison and Hebgen faults near Yellowstone. Since the beginning of the historical record in the mid 1800's, about 25 earthquakes of M 6 or greater have occurred along the Intermountain seismic belt (Smith and Arabasz 1991). The largest event in historical time was the 1959 Hebgen Lake earthquake.

The Rio Grande rift extends for approximately 600 hen from south-central New Mexico northward to south-central Colorado (Figure 1). Most of New Mexico's population is concentrated along the Rio Grande rift in cities such as Albuquerque and Santa Fe. The earliest report of earthquake activity was a sequence of 22 events felt in 1849 to 1850 near the town of Socorro (Sanford et al. 1991). The largest earthquakes observed to date are three events that occurred on 12 and 16 July and 15 November 1906 near Socorro. The estimated size of the latter event, the largest of the trio, is about M 6.

3 SEISMIC HAZARD EVALUATION OF THE MOAB SITE

In response to a request by the NRC, an up-to-date seismic hazards evaluation of the Title II Moab site was performed (Wong et al. 1996). This site, owned by Atlas Corporation, consists of a 130-acre pile consisting of 10 1/2 million tons of processed tailings derived from the past operation of the Atlas uranium mill. The tailings were emplaced over alluvial soils and the disposal area was developed from 1956 to 1984. The site is in the process of final closure and the Remedial Action Plan (Reclamation Plan) requires NRC approval.

According to the Standard Review Plan (SRP June 1993), "there are no NRC regulatory guidelines directly applicable to the geologic and seismologic aspects of the UMTRA Program". However, the basic acceptance criteria pertinent to the geologic and seismic stability aspects are provided in the EPA's 40 CFR Part 192, Subpart A and according to section 192.02, "control of residual radioactive materials and their listed constituents shall be designed to be effective for up to 1000 years, to the extent reasonably achievable, and in any case, for at least 200 years". NRC staff has interpreted this standard to mean that certain geologic and seismic conditions must be met in order to have reasonable assurance that the long-term performance objectives will be achieved (NRC 1994).

The SRP states that NRC staff review of seismotectonic stability must conclude whether the information and investigations in the Remedial Action Plan provide an adequate basis for selection of the Maximum Credible Earthquake (MCE) and determination of the resulting vibratory ground motion at the site. The NRC defines the NICE as the "earthquake which would cause maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material" (10 CFR 40 Appendix A). The NRC's Appendix A approach, which basically requires the determination of the 84th percentile MCE ground motions, is a deterministic approach. It requires the use of the worst case earthquake with no consideration for its frequency of occurrence. Although Appendix A stipulates that a tailings pile be designed for the MCE, the Introduction to Appendix A allows for alternatives to be proposed by the licensee. These alternatives "may take into account local or regional conditions, including geology, topography, hydrology, and meteorology. The commission may find that the proposed alternatives meet stabilization and containment of the site concerned, and a level of protection for public health, safety, and the environment from radiological and non-radiological hazards associated with the sites, which is equivalent to, to the extent practicable. or more stringent than the level which would be achieved by the requirements of this Appendix and the standards promulgated by the EPA in 40 CFR Part 192." Furthermore, Appendix A Criterion 6(1) specifies that the regulatory standard is "reasonable assurance" of stability of the tailings disposal for the 200 to 1,000 year period.

Moab is located within the interior of the Colorado Plateau which has been generally considered to be seismically inactive and devoid of large earthquakes. Seismological studies performed in the past decade, however, indicate that seismicity is fairly widespread throughout the Plateau interior, albeit at a low to moderate level, and that earthquakes up to M 6 have occurred in historical times (Wong and Humphrey 1989). Although detailed fault studies have not been performed to date within the Colorado Plateau. the available geologic data suggests that only a few significant late-Quaternary

faults may exist in the Plateau interior (Hecker 1993). Thus there appears to be at least a low level of earthquake hazard within the Plateau.

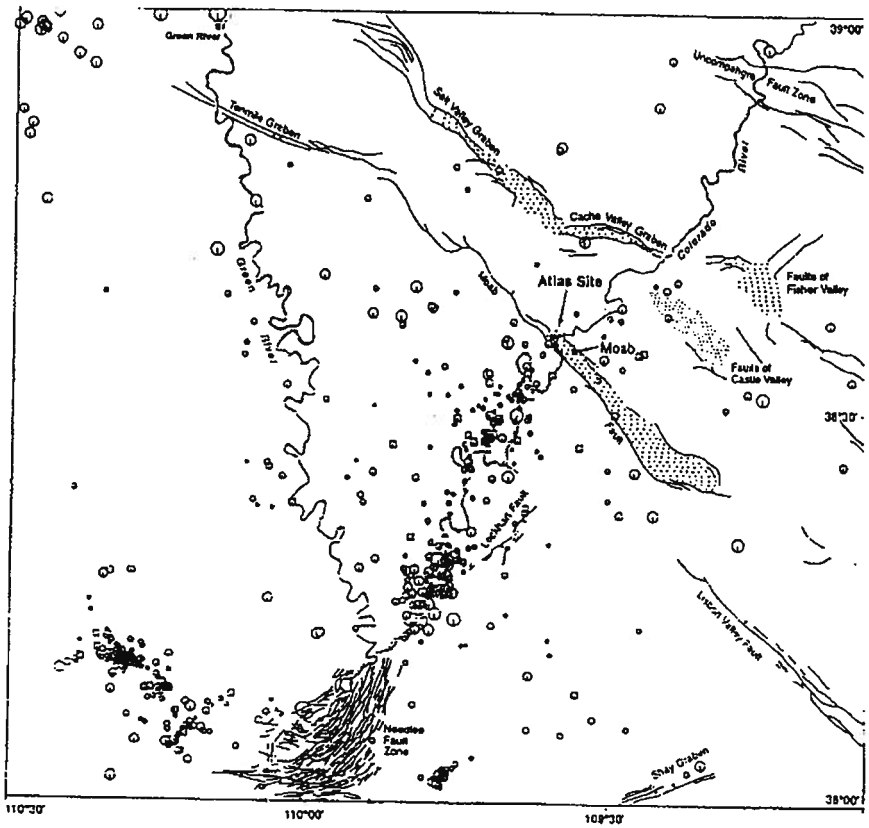
In our seismic hazard evaluation of the Moab site, potentially seismogenic faults and seismic source zones (areal sources) significant to the site were identified, characterized, and considered in the analysis. These seismic sources included 11 faults, a zone of microseismicity along the Colorado River southwest of Moab, and a seismic source zone for the Colorado Plateau which represents unknown earthquake sources having no geologic surficial expression (Figure 2). The closest fault to the site is the Moab fault which trends beneath the northeastern corner of the site. Available geologic and geophysical evidence, however, indicates that the fault is not capable of producing significant earthquakes (Olig et al. 1996). In fact, 10 of the 11 faults considered in our evaluation are associated with salt structures and are probably not seismogenic (Wong et al. 1996).

Based on an Appendix A approach, ground motions, as characterized by peak horizontal acceleration, were estimated for three potential earthquake scenarios: (1) a M 5.0 earthquake at a source-to-distance of 30 km, our proposed largest event along the Colorado River seismicity trend; (2) a M 6 1/2 earthquake along this same zone at a distance of 5 km from the site as proposed by the NRC; and (3) a "floating" earthquake of M 6 1/4 at a distance of 15 km. In the absence of any nearby capable faults, the NRC's policy requires that the MCE be represented by a floating (random) earthquake. For the second scenario, the NRC assumed that half of the seismicity zone along the Colorado River could rupture in a single large earthquake. Based on geological and seismological arguments presented in Woodward-Clyde Federal Services (1996), we consider this scenario to be extremely unlikely.

Given a maximum magnitude and source-to-site distance, empirically-based attenuation relationships can be used to estimate median (50th percentile) and median plus one standard deviation (84th percentile) ground motions for a site. The NRC stipulated 84th percentile peak horizontal accelerations at the Moab site were 0.06 g, 0.63 g, and 0.29 g, respectively for the above earthquake scenarios. Based on this analysis, the MCE for the site would be the NRC's M 6 1/2, earthquake occurring along the Colorado River seismicity trend at a source-to-site distance of 5 km.

As an alternative approach, we evaluated the earthquake hazard at the Moab site probabilistically similar to, but in a more rigorous manner than was done by LLNL. In a probabilistic seismic hazard analysis, levels of ground motions associated with a probability or likelihood of being exceeded in a specified time period (or inversely, return period) can be calculated. This approach also allows for the explicit inclusion of the range of possible interpretations and uncertainties in components of the model including seismic source characterization and ground motion estimation. The probabilistic seismic hazard model used in our study is similar to the hazard model originally developed by Comell (1968) and refined by McGuire (1974).

All seismic sources within a distance of about 150 km from the site were characterized and input into the analysis (Wong et al. 1936). This included the 11 faults such as the Moab fault, the Colorado River seismicity trend, and the Colorado Plateau source zone. Ten of the 1 1 faults were assigned low probabilities of being seismogenic because they show no evidence for Quaternary activity except deformation related to shallow salt dissolution and flowage (Wong et al. 1996). The attenuation of ground motions was addressed through the use of state-of-the-art empirical relationships for peak horizontal acceleration and stiff soil conditions.



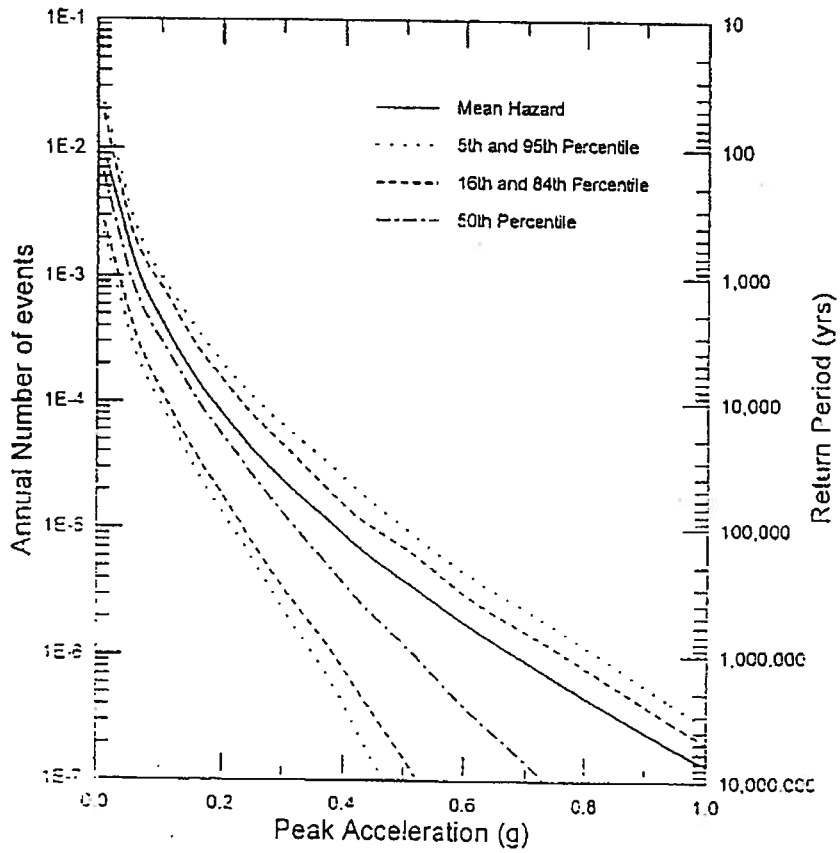
(Source: Wong et al. 1996)

Figure 2. Seismicity (1953 to 1994) and selected Cenozoic faults (after Hecker 1953) in the Moab study area. Stippled areas represent areas of distributed deformation due to salt dissolution. Ball on normal faults is on downthrown side.

The probabilistic seismic hazard analysis resulted in peak horizontal accelerations at the Moab site of 0.05 to 0.18 g for return periods ranging from 500 to 10,000 years (Figure 3). The MCE 84th percentile peak horizontal acceleration of 0.63 g has a return period of about 750,000 years (Figure 3) or 750 times greater than the 1000-year design life stipulated in 40 CFR 192.02 and Appendix A Criterion 6(1). The major contributor to peak: acceleration hazard at 10,000 years is the background earthquake in the Colorado Plateau source zone. The Colorado River seismicity trend and the Moab fault contribute little to the hazard at the Moab site at this return period (Wong et al. 1996).

4 SEISMIC HAZARD ISSUES IN THE INTERMOUNTAIN U.S.

In the seismic hazard evaluation of the Moab site, three significant issues were raised due to NRC regulations governing Title II sites. The first issue stems from the NRC's current



(Source: Wong et al. 1996)

Figure 3. Probabilistic seismic hazard curves for the Moab site. The fractile curves give the range of uncertainty about the mean or median (50th percentile) values. The peak horizontal acceleration of 0.18 g at a 10.000 year return period, our recommended seismic design value, can be read from the mean hazard curve.

position of requiring the seismic design of Title II sites be based on a deterministic Appendix A approach incorporating the concept of the MCE. In such an approach, the 84th percentile ground motions generated by the MCE provide the basis for the Design Basis Earthquake. Intertwined in this issue is also the issue of the reasonableness of the 15 km source-to-site for the floating earthquake in areas of low seismicity.

We believe the MCE peak horizontal acceleration for the Moab site (0.63 g) and even the value estimated for the floating earthquake (0.29 g) are overly conservative for seismic design purposes given the low seismic potential that exists within the interior of the Colorado Plateau. This latter observation is supported by the available seismological and geological data. In particular, the location of the Moab site in the Canyonlands region where many precariously balanced rocks occur throughout the area, some very delicately, suggests that this portion of the Colorado Plateau interior has not been subjected to strong earthquake ground shaking for at least several thousands of years (Wong et al. 1996).

As described earlier, the NRC's policy specifies the 15 km source-to-site distance for the floating earthquake. This distance is rather arbitrary because it is independent of the seismic potential of the region being considered. Thus whether a site is located along the more seismically active Wasatch Front in central Utah or the much less active Moab area, the 15-km distance is fixed. In general, deterministic approaches such as dictated in the NRC's Appendix A can result in overly-conservative seismic design criteria in areas of low earthquake potential. Even for sites in more seismically active areas of the Intermountain U.S., deterministically-based ground motions can also be too high for seismic design because the majority of late-Quaternary faults are characterized by long recurrence intervals far exceeding the lifetimes of engineered structures.

The second issue is whether probabilistic seismic hazard analysis is acceptable to the NRC as an alternative to their Appendix A deterministic approach for developing seismic design criteria at Title II sites. The NRC has endorsed the use of probabilistic risk assessment in nuclear regulatory matters as specified in their final policy statement in the Federal Register (16 August 1995). At this time, however, the NRC has not officially established a policy for Title II sites. Probabilistic analysis has become increasingly used in seismic hazard analysis for a wide range of facilities and structures. It provides the basis for the Uniform Building Code and is now become acceptable for evaluating the potential seismic hazards to nuclear reactors.

Given the uncertainties in seismic source characterization and ground motion estimation in the Intermountain U.S., probabilistic seismic hazard analysis is well suited to addressing these uncertainties. For example, given the observation that the largest known earthquake along the Colorado River is less than M 3, there is considerable uncertainty in the assumption that the maximum earthquake for this zone is M 5 relevant to the Moab site. As previously discussed, the NRC's position that a maximum earthquake of M 6 1/2, could occur within this zone is even more uncertain. Additionally, because the acceptable risk of Title II sites has been defined in terms of time (200 to 1000 years), it is best evaluated through probabilistic analysis which incorporates the recurrence of earthquake sources.
If probabilistic analysis is acceptable for Title II sites, a significant issue is at what return period (or alternatively a probability of nonexceedance) is deemed appropriate by the NRC. It was our recommendation that the seismic design criteria for the Moab site be based on a return period of 10,000 years (corresponds to a 10% chance of exceedance in 1000 years). We selected and recommended this very conservative return period based on the fact that the Moab site is located adjacent to the Colorado River and that radionuclide release into the major water source, if possible, might be considered higher risk than other Title II sites. In the probabilistic seismic hazard analysis performed by Bernreuter et al.(1995) for Title II sites, they calculated peak horizontal accelerations assuming a return period of 10,000 years. They adopted this value because, in their opinion, it satisfied the criteria cited in Appendix A. Furthermore, they stated that such a probability of exceedance may be too conservative for design because of the "relatively low risk posed by the tailings piles." For comparison, the current design life for the proposed underground nuclear waste repository at Yucca Mountain, Nevada is 10,000 years.

Because we considered a 10,000 return period to be very conservative compared to the required 1,000 years cited in 40 CFR 192.02 and Appendix A and because both EPA and NRC considered but explicitly rejected a 10,000 year control period for uranium mill tailings, our recommended seismic design value of 0.18 g for the Moab site provides

"reasonable assurance" of a level of protection "equivalent to, to the extent practicable" stipulated in Appendix A. We believe that selection of longer return periods, which correspond to lower probabilities of exceedance, would certainly result in overly conservative seismic design criteria not consistent with the available geologic, seismologic, and geophysical data pertinent to earthquake hazards in the vicinity of the Moab site and the interior of the Colorado Plateau.

5 CONCLUSIONS

Probabilistic seismic hazard analysis has been increasingly accepted as an approach often superior to deterministic methods alone for evaluating seismic hazards for a wide variety of facilities and structures. The probabilistic methodology is particularly well suited in applications for uranium mill tailings sites because of their generally lower risk and locations in the Intermountain U.S. In this region, large damaging earthquakes are possible but relatively infrequent There are also considerable uncertainties in characterizing seismic sources and estimating ground motions which can be explicitly incorporated into probabilistic seismic hazard analysis. Finally, because the level of acceptable risk for Title II sites has been expressed in a time frame of 200 to 1000 years (40 CFR 190.02), probabilistic seismic hazard analysis is better suited to providing the basis for seismic design criteria than deterministic approaches, which are time independent.

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