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29 April 2003

Dr. William E. Barnard
Executive Director
Nuclear Waste Technical Review Board
2300 Clarendon Blvd.
Suite 1300
Arlington, VA 22201-3367

Re: Independent Consultant Report on February 24, 2003
Meeting of "Panel on the Natural System and Panel
on the Engineering System Joint Meeting on
Seismic Issues"

Dear Dr. Barnard:

Arrangements were made by Leon Reiter and John Pye of your staff for me to attend the February 24, 2003 meeting referenced above as an independent consultant to the Nuclear Waste Technical Review Board. Peter Kaiser, Arthur McGarr, and Anestis Veletsos also participated in this meeting in the same capacity.

About three weeks prior to this meeting, I was sent a draft Agenda by Mr. Reiter and a ring binder containing handouts and papers on each item included in the draft Agenda. I reviewed the materials shortly after receiving them and called Mr. Reiter; my comments were in general that the authors of each of the topics were giving the methods used in their studies but not really giving the bottom line design recommendations I would have expected from work which has been conducted for such a long period of time.

During the meeting the presentations were given according to the Agenda given in Attachment I. For each technical presentation given there was a new handout which superceded the papers sent to me prior to the meeting. In general, the handouts at the meeting were more detailed and more informative than the materials furnished prior to the meeting.

The group of independent consultants met with your staff and members of the Nuclear Waste Technical Review Board on Sunday evening, February 23 to discuss technical issues to be covered in the February 24 meeting. A close out meeting of the same group was convened in the early evening of February 24. Board Member Priscilla Nelson chaired both of these meetings.

In the remainder of this letter report I have given my response to technical issues within the framework of the questions posed to the consultants prior to the meeting by Mr. Reiter as shown in Attachment II.

The general questions in Attachment II are responded to in the immediate paragraphs below.

Question a) Are ground motions realistic and/or appropriate in light of intended use?

Response a) A response to this question first requires an establishment of the ground motions currently being proposed for preclosure design and for post closure analyses. These proposed design motions were not clear from the package sent to me prior to the meeting but the handouts at the meeting were improvements and at least gave more definite values on which to comment.

For preclosure, the presentation given by Ivan Wong indicated that the 5×10^{-4} annual exceedence probability (AEP) motions were being considered and that for the repository, Point B, the horizontal and vertical peak rock accelerations were .19 g and .17 g, respectively. For this case the peak horizontal acceleration for a rock outcrop at the repository elevation, Point A, was 0.27 g. For the surface facilities on alluvium both the peak horizontal and vertical accelerations were .63 g. The maximum peak horizontal particle velocity for the surface structures on alluvium, as shown on page 27 of the Silva-Wong handout, was 30 cm/sec.

From p. 27 of the Silva-Wong handout it is noted that the peak acceleration of .63 g is defined by only two very high frequency peaks and that there are many cycles of acceleration at about 0.42 g. In relation to the rock outcrop peak acceleration of .27 g and the rock repository peak acceleration of 0.19 g it was my judgment, based on studies of similar calculations on other jobs that the amplification of calculated accelerations from 0.19 g to 0.63 g was somewhat high. This could have been caused by using a material damping which was too low in the alluvium and possibly a curve which did not degrade the alluvium shear modulus values enough as a function of the dynamic strain increment. It is my observation that the maximum particle velocity of 30 cm/sec and maximum displacement of about 12 cm shown on p. 27 of the Silva-Wong handout give reasonable velocity/acceleration ratios and $v^2/a{\cdot}d$ values if it is considered that the peak acceleration is considered to be about 0.42 g and the two high frequency spikes of 0.63 g are ignored. The amplification values from .19 g to 0.42 g from rock to the top of alluvium are also reasonable if the "effective" peak acceleration at the top of alluvium is considered to be about 0.42 g.

Overall the preclosure motions are within the ranges which are considered realistic and within the ranges of recorded motions. I emphasize that for the underground repository however that maximum particle velocities be given priority to peak accelerations when discussing effects on the tunnels and when selecting appropriate records. In the Silva-Wong handout, the peak particle velocities at the repository (Point B) and the rock reference outcrop, Point A, are not given. It would be helpful for Wong to give the peak particle velocities for these locations, especially the repository location. It is my estimate that the peak particle velocities at the repository location could be in the range of 15-20 cm/sec, to be consistent with the 0.19 g acceleration.

For the underground repository it is more meaningful to evaluate the structures in terms of the peak particle velocity because the peak particle velocity divided by the shear wave velocity in the rock is the peak free-field shear strain in the rock. There are field correlations between damage to tunnels in rock and maximum free-field strains produced by both nuclear and high explosive detonations in rock.

For post closure ground motions, it is my understanding from the handouts that at the waste emplacement level (Point B) that horizontal peak ground free-field particle velocities for AEP of 10^{-6} and 10^{-7} are 244 cm/sec and 535 cm/sec, respectively. The values of the vertical peak particle velocities for AEP of 10^{-6} and 10^{-7} are 233 cm/sec and 625 cm/sec, respectively. In general the particle velocities associated with the 10^{-7} AEP yield shear strains calculated on the order of about .003 for this rock which are consistent with failure or beyond failure for the rock. The particle velocities associated with the 10^{-6} AEP give peak shear strains on the order of .0013, or 0.13%. Even at the strain levels for the 10^{-6} AEP particle velocities, the rock has most likely degraded considerably and it is most likely that the rock strength and actual shear stress drops along the fault would not permit these high particle velocity pulses from being propagated away from the fault. It is definitely my judgement that the particle velocities which can be propagated away from a fault are limited by the strength of the rock along the fault and there are finite rupture models available from which motions can be calculated in this manner (i.e., for example, refer to O'Connell and Ake, 1994). From these rupture models it is observed that the maximum particle velocities generated at the fault are a function of the stress drop on the fault and are attenuated with distance away from the fault.

As has been pointed out by Wong and Silva in their handout, the particle velocities they have come up with for the 10^{-6}, 10^{-7} AEP would be consistent with unreasonably high stress drops in these finite fault rupture models. In order to “cap” the maximum motions used for design it is my recommendation that these type of calculations be used where the stress drops to be used have been calibrated to give results consistent with “real” close in rock records. The records should be from seismographs founded on materials with shear wave velocities of at least 3000 ft/sec to qualify as a rock record. In addition, very close in raw records should be studied to determine the maximum values that have been recorded for peak velocities and peak accelerations. The peak displacements should also be known for these records in order to make other judgments about the reliability of the particular records used. The records shown on pages 32-33 of the Silva-Wong handout should be screened to determine if they qualify as rock records; and other worldwide records should be considered.

There is some indication in the handout given at the meeting that Wong and Silva are now studying the possible capping of motions by the two approaches given above using (1) very close in rock records and (2) fault plane calculations. This is a step forward as there was no indication that this was being done in the information we received prior to the meeting.

It is recommended that in the study of rock records, such as those presented in the tables on pages 32 and 33 of the Silva-Wong presentation, that only those records be kept which are truly rock records. (I.e. the seismograph should be founded on materials with shear velocities exceeding 3000 ft/sec.) For the rock records, then the most interesting records are for those with the largest recorded peak particle velocities, as these are the records which would produce the largest strains around the tunnels. The most intense, close in, real rock records are the most reliable means of capping the ground motions extrapolated by the Probabilistic Seismic Hazard Analysis (PSHA) method to low values of AEP.

b) If not, what might be an alternate approach?

As discussed above, the ground motions arrived at by the PSHA method for the 10^{-6} and 10^{-7} AEP are not appropriate for engineering analyses. These motions are too high and will set unrealistic precedence for other Nuclear Regulatory Commission projects.

These motions should be physically capped by 1) a study of real rock records which are from stations close to capable faults, 2) the use of finite fault rupture models taking into account fault slips and strain or stress drops along the fault, and the resulting motions as a function of distance away from the fault. These two approaches have been mentioned in a) above. It appears as if Silva and Wong are beginning to consider these physical limits to the ground motions. It is my opinion that the studies presented by James Brune at this meeting are another possible approach for capping motions by physical studies and analyses.

The topic of estimating maximum particle velocities in rock from earthquakes was discussed by Ambraseys and Hendron in Chapter 7 of Stagg and Zienkiewicz (1967). This discussion was a follow on to a paper by Housner (1965) on the "Intensity of earthquake ground shaking near the Causative Fault" and took into account a paper by T. Harding and others in which data from the Parkfield Earthquake of June 27, 1966 was analyzed to show that the change in shear strain near the San Andreas Fault was about 2×10^{-4} for that event. Similar studies can be done today taking into account the more numerous rock records which are available today.

c) Are the approaches to seismic preclosure and postclosure issues appropriate?

In general the approaches to preclosure and postclosure issues are appropriate, but the estimates of tunnel damage should not be based on numerical analyses only. In addition to the analytical studies, the performance of tunnels in tuff at Nevada Test Site to ground motions from Nuclear Explosions should also be considered when making judgments on the vulnerability of the repository tunnels to earthquake motions.

d) If not, what might be some alternate approaches?

In addition to the analytical model presently being used to estimate vulnerability of the tunnels to earthquake motions, the project should become familiar with the performance of the Nevada Test site tunnels in tuff in terms of the peak particle velocities and strains from rock motions produced by nuclear explosions in tuff.

SPECIFIC QUESTIONS TO BOARD OF CONSULTANTS

1. Are the proposed ground motions within the range of the worldwide instrumental record?

The preclosure design ground motions are within the instrumental record. The ground motions proposed for postclosure analyses are beyond the instrumented record.

2. Are there physical constraints that might limit surface and subsurface ground motions at the Yucca Mountain Site?

Yes, these have been discussed in parts a) and b) above.

3. What kind of studies/analyses can be carried out that could help determine whether there is a limit?

These studies have been indicated in sections a) and b) above. They basically include using fault rupture models with realistic stress drops which are a function of the shear strength along the fault and by using "real" rock records from locations close to causative faults. Studies of the type described by James Brune at the meeting are also helpful.

4. What can be learned from earthquake motions in mines that would help address this problem?

I do not have enough experience in this area to make a meaningful contribution.

5. What can be learned from ground motions related to nuclear testing that would help address this question?

I have analyzed all of the important ground motions produced by contained nuclear explosions in rock in the publication "Scaling of Ground Motions from Contained Explosions in Rock for Estimating Direct Ground Shock from Surface Bursts on Rock," Technical Report No. 15, Omaha District, Corps of Engineers Omaha, by A. J. Hendron, Jr. In this study it was apparent that at the same scaled ranges (i.e. same values of $R/W^{1/3}$) where R = range in feet and W = yield in kilotons, that the motions (accelerations and velocities) in tuff were significantly lower than in the granites, andesites, and basalts. In general this was always thought to be because the tuffs were much weaker than the other rocks and less capable of transmitting the high stress and velocity pulses that the stronger rocks are capable of transmitting. This same effect is shown in the fault plane source models as the motions are limited by the stress drops along the fault plane which are limited by the rock strengths along the fault plane.

6. How do these ground motions compare to those assumed on other projects?

The proposed motions for the preclosure case are within the ranges selected for other projects.

For example, I served for a three year period on a consulting based for the United States Bureau of Reclamation in their re-evaluation of Hoover Dam for a modern day earthquake motion. One design earthquake was an M = 6 3/4 earthquake on the Mead Slope Fault which is as close as 3 km from the dam. The rupture was a normal faulting rupture mechanism. A floating earthquake of magnitude 6 ½ was also considered as close as 1 km from the dam. As a result of the analytical simulations the peak ground acceleration was taken as 0.63 g as compared with 0.54 g from empirical estimates. The larger value was used for a re-evaluation of Hoover Dam. The complete details of this study are given by O'Connell and Ake, 1994.

The Diablo Canyon Nuclear Reactor is another important structure. During construction, the Hosgri Fault was discovered at a distance of 4 km offshore from the structure. It was determined to be capable of producing a Magnitude 7.0 earthquake. The structure has been designed on the basis of a response spectrum consistent with a zero period acceleration of 0.75 g.

For both of these structures, the design motions are considerably lower than the postclosure Yucca Mountain proposed motions. The Yucca Mountain proposed motions have not been appropriately capped by the physical faulting mechanisms which produce real earthquakes. They are extrapolations from probability methods unrestrained by the physics of the real problem.

7. Have the site conditions, including rock properties, been characterized properly and approximately taken into account?

For the most part the shear wave velocities at the site have been determined from methods supplying energy from the surface. These measurements should be supplemented by determining shear wave velocities of the repository levels from measurements taken from the exploratory tunnels. It is also my impression that about 80% of the repository will be in the weaker tuffs, identified as the Lower Lithophysal unit of the Topopah Spring Tuff. From the limited information I have seen it appears that more exploration in this area is warranted.

8. Are the models of drift stability (seismic and thermal) suitable and have they been used appropriately?

The drift stability model seems reasonable for seismic analysis within the limits of my knowledge. An inspection of the actual excavations would be helpful for my perspective. As indicated in d) above, it would seem appropriate to study the behavior of actual tuff tunnels to motions produced by nuclear explosions.

9. Have the rockfall analysis, drip shield structural response, and waste package structural response to seismic ground motions been appropriately modeled?

From the descriptions received it would appear as if the system has been modeled in an appropriate manner.

10. Is the "failed area obstruction" the appropriate way to address waste package failure?

From my knowledge of the overall problem it seems reasonable to me that "damage" to the engineered barrier system (EBS) can be represented by a "failed area" that allows flow through the drip shield and transport from the waste package.

11. If the ground motion estimates remain the same, are there methods to mitigate potential problems in drift stability and repository operations and maintenance?

If post closure motions remain the same the drift stability can be improved by including a structural soft layer between the tunnel surface and the drip shield to reduce the forces a rock fall places on the drip shield.

12. If the ground motion estimates remain the same, are there means of mitigating adverse effects on waste packages?

In addition to the suggestion given in 11 above, the spacing between waste packages can be increased to minimize the waste package to waste package interactions.

Respectfully submitted,

Alfred J. Hendron, Jr.

REFERENCES

Ambraseys, N. R. and A. J. Hendron, Jr. (1968), "Dynamic Behavior of Rock Masses," Rock Mechanics in Engineering Practice, Ed. By K. G. Stagg and O. C. Zienkiewicz, John Wiley and Sons, London, pp. 203-227.

Hendron, A. J. Jr. (1973), "Scaling of Ground Motions from Contained Explosions in Rock for Estimating Direct Ground Shock from Surface Bursts on Rock," Technical Report No. 15, Omaha District, Corps of Engineers, Omaha.

Housner, G., "Intensity of Earthquake Ground Shaking Near the Causative Fault," Proc. World Conf. Earthquake Eng., 3rd, New Zealand, 1965, 1, III-94-111.

Harding, T., and others, "The Parkfield, California, Earthquake of June 27, 1966", U.S. Dept. Commerce, Environmental Sci. Serv. Adm. Publ., 1966.

O'Connell, D. R. and Ake, J. P. (April, 1994), "Strong Motion Study of the Lake Mead Portion of the Lower Colorado River, Arizona, and Nevada," for Hoover Dam-Boulder Canyon Project. Seismotectonic Report 94-1, Bureau of Reclamation, Denver, Colorado.

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201

Attachment I

Agenda

Panel on the Natural System and Panel on the Engineered System Joint Meeting on Seismic Issues

Best Western Tuscany Suites and Casino
255 East Flamingo Road
Las Vegas, NV 89109
Phone: 702-947-5918 Fax: 702-732-2564

Monday, February 24, 2003

8:00 a.m. **Call to order and introductory comments**
Priscilla Nelson, Meeting Chair
Nuclear Waste Technical Review Board (NWTRB)

8:05 a.m. **Department of Energy (DOE) approach to Yucca Mountain seismic**
issues
William Boyle
Office of Repository Development, Department of Energy (ORD)

8:15 a.m. *Questions, discussion*

8:25 a.m. **Probabilistic Seismic Hazard Analysis (PSHA) for Yucca Mountain**
J. Carl Stepp
Bechtel SAIC Company (BSC)/ Integrated Design Technologies

8:45 a.m. *Questions, discussion*

9:05 a.m. **Summary of geotechnical investigations and site conditions at Yucca Mountain**
Ivan Wong, BSC/URS Corporation (URS)

9:20 a.m. *Questions, discussion*

9:35 a.m. **DOE approach to preclosure analysis and design**
Richard Pernisi, BSC

9:50 a.m. *Questions, discussion*

10:05 a.m. **BREAK**

10:20 a.m. **Proposed ground motions for preclosure seismic design and analysis**
Ivan Wong, BSC/URS and Walt Silva, BSC/Pacific Engineering and Analysis (PEA)

10:35 a.m. *Questions, discussion*

10:50 a.m. **Preclosure seismic design and analysis**
Richard Pernisi, BSC

11:05 a.m. *Questions, discussion*

11:20 a.m. **General postclosure seismic approach**
Mike Gross, BSC/Beckman and Associates (BA)

11:35 a.m. *Questions, discussion*

11:50 p.m. **LUNCH**

12:50 a.m. **Proposed ground motions for postclosure analysis and additional studies**
Ivan Wong, BSC/URS and Walt Silva, BSC/PEA

1:15 p.m. *Questions, discussion*

1:40 p.m. **Geological observations bearing on limiting ground motions**
James Brune
University of Nevada at Reno (UNR)

1:55: p.m. *Questions, discussion*

2:10 p.m. **Drift Stability: seismic and thermal**
Mark Board, BSC

2:35 p.m. *Questions, discussion*

2:55 p.m. **Response of the waste package, drip shield and other structural components to seismic events and their incorporation into Total Systems Performance Assessment (TSPA)**
M. J. Anderson, BSC and Mike Gross, BSC/BA

3:15 p.m. *Questions, discussion*

3:35 p.m. **BREAK**

3:50 p.m. **Round table**
Mark Board (BSC), William Boyle (ORD), James Brune (UNR), C. Allin Cornell (BSC/Stanford University), Mike Gross (BSC/BA), Robert P. Kennedy (BSC/RPK Structural Mechanics Consulting), Jerry King (BSC), Walt Silva (BSC/PEA).

Moderator: Daniel Bullen, NWTRB

Topics for Discussion
(1) Current ground motion estimates for Yucca Mountain
(2) Alternate approaches to developing low-probability ground motions
(3) Use of ground motions in preclosure and postclosure design and analyses
(4) Alternate approaches to preclosure and postclosure design and analyses

5:20 p.m. **Public comments**

5:40 p.m. **Adjourn session**
Priscilla Nelson, NWTRB

Attachment II

Questions for Seismic Consultants

General questions:

a) Are ground motions realistic and/or appropriate in light of intended use?
b) If not, what might be an alternate approach?
c) Are the approaches to seismic preclosure and postclosure issues appropriate?
d) If not, what might be some alternate approaches?

Specific questions to Board consultants:

1. Are the proposed ground motions within the range of the worldwide instrumental record?
2. Are there physical constraints that might limit surface and subsurface ground motions at the Yucca Mountain site?
3. What kind of studies/analyses can be carried out that could help determine whether there is a limit?
4. What can be learned from earthquake motions in mines that would help address this problem?
5. What can be learned from ground motions related to nuclear testing that would help address this question?
6. How do these ground motions compare to those assumed at other projects?
7. Have the site conditions, including rock properties, been characterized properly and appropriately taken into account?
8. Are the models of drift stability (seismic and thermal) suitable and have they been used appropriately?
9. Have the rockfall analysis, drip shield structural response, and waste package structural response to seismic ground motions been appropriately modeled?
10. Is the "failed area abstraction" the appropriate way to address waste package failure?
11. If the ground motion estimates remain the same, are there methods to mitigate potential problems in drift stability and repository operations and maintenance?
12. If the ground motion estimates remain the same, are there means of mitigating adverse effects on waste packages?