April 29, 2003

Mr. Leon Reiter
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Blvd, Suite 300
Arlington, VA 22201-3367

Dear Mr. Reiter,

Following are my comments on the information presented at the Nuclear Waste Technical Review Board Joint Panel Meeting in Las Vegas, Nevada on February 24, 2003:

This meeting, along with the material submitted in preparation for it, was my first exposure to the multi-year Yucca Mountain Project. In addition, some of the information presented was not sufficiently detailed in my view for an in-depth assessment of its accuracy and value. As a result, my evaluation and comments are not as detailed and thorough as I would have liked or might have been desired. It is hoped, however, that they may still prove helpful. Only a few of the issues covered at the meeting are addressed here.

My evaluation is based on:

a. A study of the preparatory material submitted for the Panel's review, which consisted primarily of a summary of the information presented at the DOE-NRC Appendix 7 Meeting in Las Vegas, Nevada on August 6-8, 2002;
b. My participation in the meeting of February 24, 2003; and
c. The subsequent re-examination and study of the material distributed at the latter meeting.

Ground Motions for Preclosure Analysis and Design

The annual exceedance probabilities of 10^{-3} to 10^{-4} used for the definition of the seismic ground motions for preclosure analysis and design, and the resulting motions and response spectra are, with the qualifications noted in the following, deemed to be quite reasonable. They are, in fact, similar to those used in the design of nuclear power plants and their components. On the assumption that the design will be based on existing code provisions with definite factors of safety against unacceptable performance, the annual exceedance probability for such performance will definitely be lower (may be as low as 10^{-6}).

The qualifications, which are definitely minor and unlikely to be of practical importance, concern the very high frequency, limiting characteristics of the response spectra presented in the handout material by Silva & Wong titled "Proposed Ground Motions for Preclosure Seismic Design and Analysis".

Even for natural frequencies of 100 cps, the response spectra for both the horizontal and vertical components of the ground motions presented on pages 11, 12 and 23 of their report do **not level off** to the maximum ground accelerations. If, as I believe to be the case, the reported spectra are for a damping factor of 5 percent, they should equal the maximum ground acceleration at much lower frequencies. Additionally, for the response spectra presented on p.10, the natural frequencies corresponding to the absolute maximum spectral accelerations are unrealistically high in my view. These comments are made with due appreciation of the fact that the dominant frequencies of the ground motions for sites in the central and eastern parts of the country are generally higher than for those in California, with the result that the absolute maximum spectral accelerations for the non-California sites also generally occur at higher natural frequencies.

Probabilities for Postclosure Analysis

The ground motions at the repository site for postclosure analysis and design are determined for annual exceedance probabilities ranging from 10^{-6} and 10^{-8}. Two questions of fundamental importance arise in this regard:

1. **Are these probability levels consistent with** those used for preclosure analysis and design? It is recognized, of course, that the desired containment period for the facility at the repository is 10,000 years while the life expectancy of the surface facilities is only 100 years.
2. **Are the procedures used to arrive at the ground motions** for these low-probability events and for the associated response spectra reasonable?

It is the answers to these questions that determine the foundation on which the analysis and design of the project is built.

First Question. Although I cannot claim expertise on probabilistic approaches, based on discussions I have had with knowledgeable colleagues, I feel that these questions have not satisfactorily been addressed; that the values used for postclosure analysis are not consistent with those used for preclosure analysis and design; and that the postclosure values are unduly low. If "regulations require that postclosure analyses be conducted for" seismic events that have an annual exceedance probability of 10^{-8}, then I effectively question the appropriateness of the regulations and of their consistency with those specified for the analysis and design of the surface facilities.

The ratio of the proposed exceedance probabilities for postclosure and preclosure evaluations appears to be based on the assumption of statistical independence for the annual occurrence of the event, an assumption the validity of which becomes increasingly questionable in my view with increasing mean return period of the event.

(In clarification of my concern, I note that if the life expectancy of a facility being designed for an anticipated seismic event is one hundred years and that event has not occurred in the first fifty years, I find it believable that the event may occur in the following fifty years. By contrast, if the design is for a life expectancy of, say, a million years and that event has not occurred in the first half a million years, I have difficulty accepting the premise that it is likely to occur in the following half a million years.)

If the 10^{-7} and 10^{-8} annual probabilities of exceedance are indeed appropriate for postclosure analysis, it may well be argued that those for preclosure design must be lower than 10^{-3} and 10^{-4}. Considering further that the motions at the ground surface are likely to be more intense than (estimated to be from 2 to 3 times as large as) those at the repository, the use of the lower probability levels will almost certainly lead to unreasonably demanding seismic design criteria for the surface facilities.

Second Question. The approach used to arrive at the ground motions corresponding to the low probability values also impresses me as questionable, as it leads to results that are deemed to be physically unrealizable. This matter, which is addressed in detail in the following sections, definitely requires additional attention.

Ground Motions for Postclosure Analysis

1. On p.14 of the handout material by Stepp & Wong titled "Probabilistic Seismic Hazard Analysis", the horizontal component of the maximum ground acceleration for the site is plotted as a function of the annual exceedance probability, and a similar plot is presented on p.28 for the horizontal component of the maximum ground velocity. It is noted that, even at an exceedance probability of 10^{-8}, both the acceleration and velocity values continue to increase with decreasing probabilities. The lack of definite limits at these low probability levels does not impress me as realistic.

The **mean value** of the horizontal component of the maximum ground acceleration at the latter probability level is 11g, while that of the corresponding maximum velocity is 1,350 cm/sec. These are extremely large values that I expect to be physically unrealizable. The same view was also expressed by Dr. Stepp in the discussion that followed his presentation, as well as by others in subsequent presentations and discussions.

A number of studies are currently under way to establish realistic upper bounds for these motions. It is of the utmost importance in my view that these studies be **continued.** The most promising of these are identified in the following sections.

2. Following are some of the reasons for which the estimated ground motions, even for the annual exceedance probabilities of 10^{-6} and 10^{-7}, are deemed to be unrealistic:

a. The calculated motions are more intense than any that have ever been recorded. The larger horizontal components of the maximum ground accelerations for the five most intense ground motions listed on p.32 of the handout material by Silva & Wong on Postclosure Analysis range from 0.44g to 1.78g, and those of the maximum ground velocity range from 127 cm/sec to 263 cm/sec (see p.33). By contrast, the maximum ground velocity for the proposed motions at the repository is taken as 244 cm/sec at an annual exceedance probability of 10^{-6} and as 535 cm/sec at a probability level of

10^{-7}. These values, in turn, lead to peak ground accelerations ranging from 1g to 7g for the 10^{-6} probability and from 2g to 20g for the 10^{-7} probability. (The lateral values were obtained from the high-frequency limiting accelerations of the response spectra presented on pages 9 and 7 of the Silva & Wong report on Postclosure). No information on either maximum ground velocities or maximum ground accelerations has been presented for the 10^{-8} exceedance probability, but the estimated values would **definitely have been larger**.

Incidentally, the statement on p.13 of the Silva-Wong report on Postclosure to the effect that "the largest recorded peak ground accelerations range from about 1.5g to over 2g" is misleading, as it is based on consideration of **both** the horizontal and vertical components of the motions. Consideration of the **horizontal components only** will broaden this range between the values of 0.44g and 1.78g.

b. The magnitude of the maximum earthquake for the site is expected to be limited between 7.0 and 8.0. These limits should also limit the severity of the ground motions to levels that are commensurate with such magnitudes.

c. Even for the ground motions corresponding to the 10^{-6} exceedance probability, the calculated shearing strains for the site were in many cases in excess of 0.3 percent, and in some cases as high as or more than 1.0 percent. Considering that these strains exceed those that can be sustained by the medium, the results of the analysis cannot be considered to be realistic.

   In fact, by determining the ground motion levels for which the calculated strains reach the fracture strain threshold of the material for the site, it should be possible to arrive at realistic upper bounds for the possible ground motions. The strain threshold approach outlined on pages 15 and 17 of the Silva-Wong report on Postclosure has this objective, and it should definitely be pursued.

d. The equivalent linear method used to evaluate the response of the deposit at the high shear strains associated with the low-probability events is of questionable accuracy. Its reliability at such strains must be demonstrated by comparing representative results with those obtained by a more realistic, nonlinear analysis.

e. Many of the uncertainties involved in the analyses appear to have been handled conservatively, with the result that the estimated ground motions are higher than may be appropriate. The use of upper bound estimates for the shear wave velocities for the site deposits, coupled with equivalent damping values that may be too low, clearly have this effect.

f. Finally and very importantly, as demonstrated by Dr. Brune's studies, the stability of precarious rocks provides definite upper bounds on realizable ground motions. In the interpretation of such information, it should, of course, be kept in mind that the severity of the ground motion at the emplacement area is likely to be substantially lower than at the ground surface.

g. Valuable insights into realistic upper bound estimates for the ground motions at the site may also be gained from a study of the results of past nuclear tests.

3. On p.14 of the Stepp-Wong report on Postclosure, the 85th percentile value of the horizontal component of the peak ground acceleration for the 10^{-7} probability of exceedance is approximately 5.5g, and on p.28, the corresponding value of the ground velocity is approximately 600cm/sec. By contrast, for the motions determined in the Silva-Wong report, for which the peak ground velocity is taken as 535cm/sec, the corresponding value of the peak ground acceleration is reported as 14.3g (see p.8 of the report). It would be helpful if this major difference in the acceleration values were reconciled.

4. The largest horizontal components of the peak velocities for the ground motions used in the development of the time histories for the site range from 11.3 cm/sec to 112 cm/sec (p.29 of the Silva-Wong report on Postclosure). The **appropriateness of the extrapolation** of these records to the velocity value of 535 cm/sec used for the 10^{-7} probability events is highly **questionable** in my view. Even with the maximum ground velocity fixed at the latter value, the peak ground acceleration ranges approximately from 2g to 20g, and the spread in the resulting response spectra is extremely large (see p.7 of the report). There is no reason to believe that the ratios of the peak ground velocities and peak ground accelerations for the low-severity and high-severity motions will be the same.

While I realize that the possible alternatives are limited, it is worth recalling that unless factors such as magnitude, distance from the source, source mechanism, travel path characteristics and local site conditions are comparable for the recorded and anticipated events, the extrapolation is unlikely to lead to reasonable results. I would have preferred limiting the extrapolation base to a smaller number of high-severity records that most closely approximate the conditions at the site of interest.

It is also relevant to note that the maximum values of the largest horizontal components of the ground accelerations for the reference records range from 0.075g to 1.30g, values that are only 3.75 and 6.5 percent, respectively, of the values of 2g and 20g proposed for the site. These results raise further questions about the appropriateness of the extrapolation procedure used.

5. The peak value of the vertical component of the ground velocity for the 10^{-7} probability determined from the scaled time histories is given as 625 cm/sec, while that of the horizontal component is only 535 cm/sec (p.11 of the Silva-Wong report on Postclosure). That the vertical component is **larger** than the horizontal does not impress me as reasonable. It is worth noting in this regard that, for the records with the largest peak velocities presented on p.33 of the report, the peak value of the vertical component is consistently **lower** than of the larger horizontal component. In fact, for the most intense of these records, the vertical component of 187 cm/sec is only 71 percent of the larger horizontal component of 263 cm/sec.

If the seismic source is below the site of interest, it is conceivable that, for certain mechanisms of energy release, the vertical components of the ground motions may well be more severe than the horizontal. However, the horizontal components in this case are likely to be unusually small. This would be expected to be true of both the velocity and acceleration traces.

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For two of the five ground motion records with the largest peak accelerations presented on p.32 of the Silva-Wong report on Postclosure, the vertical components of the accelerations are indeed larger than of the larger horizontal components. It is important to note, however, that the horizontal components in both of these cases are quite small. They range from about one-quarter to one-half of the corresponding vertical components and from about 25 to 62 percent of the absolute maximum horizontal acceleration component for all five records. As previously indicated, an unusually large vertical component of motion is likely to be associated with a much smaller horizontal component, **and that considering the absolute maximum value of both components for a set of records is overly conservative**.

6. On several occasions during the presentations and the ensuing discussions, reference was made to the fact that the low-probability estimates of the ground motions are recognized to be unrealistic, but that "we feel comfortable in using them" because they are conservative and will lead to a safe design. Such an approach, however, in addition to leading to an unduly conservative and costly design, may set an **undesirable precedence** for future projects, and **should not**, in my judgment, **be pursued**.

Seismic Response of Drip Shield and Waste Packages

The material on this topic was not sufficiently detailed in my view to permit a reasonable assessment of the rationality and significance of the results presented. The presentations focused mainly on the analytical process rather than on the examination and interpretation of the resulting solutions. Additionally, there was almost no information presented regarding the effects and relative importance of the various parameters affecting the response and of the sensitivity of the computed effects to the numerous assumptions and approximations involved in the analysis. Notwithstanding these limitations, it is hoped that the following brief comments may still prove helpful.

1. Areas of the drip shield and waste packages are considered to fail as flow or radioactive transport barriers when the seismically induced 'residual stresses' exceed 50 percent of the 'yield stress' for the material of the drip shield and 80 to 90 percent of the 'yield stress' for the outer shell of the waste package. The term 'residual stress' and 'yield stress' in these statements are presumed to refer to the residual and yield **strains** of the material, respectively. The basis and rationale of these criteria are by no means clear and need to be justified.

2. Also of interest is the interrelationship of the residual strains and the absolute maximum induced strains. If the residual strain due to a seismically induced motion in a

structural system or component is indeed of the order of 80 to 90 percent of its yield strain, the absolute maximum value of the induced strain will almost certainly be significantly larger than the yield. What precisely are the maximum ductilities that can safely be sustained by the drip shield and waste packages, and are these limits satisfied or not? Clearly, failure by corrosion is not the only one to be concerned about.

On p.8 of the presentation titled "General Postclosure Seismic Approach' by M. Gross, it is stated that "accelerated corrosion will damage the waste package or drip shield before ultimate tensile failure is reached". However, the information in support of this conclusion has not been provided.

3. The results of the reported analyses indicate that damage to the waste packages is typically concentrated in small areas near the ends, and that it is caused either by end-to-end impact of the packages or by the interaction of the waste packages with the contained material. It would be highly desirable in my view to explore the possibility of reducing such damage either by

a. increasing the spacing between packages;
b. interconnecting the packages elastically; or
c. attaching them to a rigid base so that they are excited by a synchronous motion.

The potential benefits of these alternatives may first be assessed by relatively simple, approximate procedures without having to resort to complex and costly analyses.

4. The effects of seismic ground motions and associated rock falls are decoupled in the analysis. Inasmuch as the effects of the coupled events are likely to be more severe than of the uncoupled, it would be desirable that they also be examined.

5. The analyses referred to above appear to have been carried out almost exclusively by fairly sophisticated, complex methods with which the effects and relative importance of the numerous parameters affecting the response cannot generally be assessed easily. Valuable insights into the effects of these parameters and the sensitivity of the results to the various assumptions and approximations involved in the analyses may also be gained by simpler, approximate procedures, and it is recommended that appropriate use be made of such approaches in future studies.

In summary, I believe that there is a lot more work to be done.

Sincerely,

A. S. Veletsos

With respect to the specific questions posed to the Board of Consultants, I should note that I have tried to answer them as best I could in the body of my report. However, they are also summarized in the following:

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

No, they are not. Even the motions corresponding to the 10^{-7} annual probability of exceedance are beyond any that I am aware of, or that have been claimed by any of the speakers to be physically realizable. Please refer to the section titled 'Probabilities for Postclosure Analysis' and to items 1, 3, 4, 5 and 6 of the section titled 'Ground Motions for Postclosure Analysis'.

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

There are definitely physical constraints that limit the severity of ground motion at any site. Please see items 2(a), 2(b) and 2(c) of the section titled 'Ground Motions for Postclosure Analysis'.

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

Please see items 2(c), 2(f) and 2(g) of the section titled 'Ground Motions for Postclosure Analysis'.

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

I cannot answer this question, but expect such studies to be helpful to the overall objective..

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

They may prove helpful in defining the boundary between safe and unsafe severities of ground motion.

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

The ground motions for the 10^{-7} and 10^{-8} exceedance probability levels proposed for postclosure analyses are definitely higher than those used for other major projects that I am aware of.

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

There are some fundamental questions that remain to be answered. Please see items 2(d) and 2(e) of the section 'Ground Motions for Postclosure Analysis'.

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

I cannot answer this question.

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

and

Is the "failed area abstraction" the appropriate way to address waste package failure?

Please see items 1, 2 and 4 of the section titled 'Seismic Response of Drip Shield and Waste Packages'.

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

Cannot answer this question.

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

Please see item 3 of the section titled 'Seismic Response of Drip Shield and Waste Packages'.

A. S. V