May 29, 2001

MEMORANDUM TO: Ashok C. Thadani, Director
Office of Nuclear Regulatory Research

FROM: Ernst G. Zurflueh, Geophysicist /RA/
Engineering Research Applications Branch
Division of Engineering Technology, RES

SUBJECT: AMENDMENT TO DIFFERING PROFESSIONAL VIEW
ON SEISMIC HAZARD/RISK DETERMINATION

On May 16, 2001, I submitted a DPV related to seismic hazard and risk determination. Unfortunately, some of my conclusions were based on a wrong table of plant design accelerations. The error does not affect most of the points made in the DPV. However, amendments are necessary for sections 2.4.2, 2.5, 2.6.2, and 3.2, which are concerned with simplified licensing procedures. An amended DPV is attached.

Attachment: As stated

DIFFERING PROFESSIONAL VIEW
ON SEISMIC HAZARD/RISK DETERMINATION

1. SUMMARY OF ESTABLISHED AGENCY PRACTICE

This DPV refers to the following 2 areas of regulatory practice within the NRC:

1.1 General Practice for Determining Seismicity, Ground Motion and Seismic Hazard:

Agency procedures related to this subject rely on Probabilistic Seismic Hazard Analysis (PSHA). PSHA procedures have been worked out to a point of considerable refinement. However, a remaining problem is extrapolation of data far beyond the length of actual data available. While the resulting figures appear reasonable, they are nevertheless carried to a point where their validity is seriously in question.

1.2 Plant Licensing with Respect to Vibratory Ground Motion:

In the past (plants established before January 1997), site investigations related to seismicity were probably the most disruptive and contested procedure in licensing. It may fairly be said that these procedures were mostly responsible for bringing nuclear plant construction to a halt in this country.

In 1996, new licensing requirements were published for plants built after January 1997. The new requirements included probabilistic hazard studies and were thought to represent an improvement over the previous regulations. However, the actual required field procedures were not substantially changed from the previous regulations based on Appendix A to 10 CFR 100. It is therefore clear that future plant licensing will hardly be any easier than under the preceding onerous regulations. Pertinent regulations are contained in Appendix S to 10 CFR 50; 10 CFR 100, Part B; and in Regulatory Guides 1.60, 1.132, and 1.165.

This is not a safety issue, the plants are likely to be safe based on present regulations. However, the reduction in burden that is possible compared to present procedures is so great and will have such a substantial influence in deciding whether further nuclear plant construction is possible that taking no action concerning this matter would be irresponsible.

2. DESCRIPTION OF MY VIEWS AND THEIR DIFFERENCES FROM ESTABLISHED PRACTICE

2.1 Introduction

After having been involved in a series of projects dealing with Probabilistic Seismic Hazard Analysis (PSHA), it has more recently occurred to me that many of the assumptions used in PSHA and its use in nuclear plant regulation are not well founded. The insight developed after reading papers on wave height calculations that stated that extrapolation of data should not be carried beyond twice the length of data available. Although wave heights are different from seismic hazard data, the statistical principles applying to extrapolation of data are equivalent. Some of these questions were discussed with Dr. Leon Borgman of the University of Wyoming.

An NRC statistician, Lee Abramson, later explained that he considers one length of data to be the limit for extrapolation. Finding that the NRC routinely deals with probabilities of 10^{-5} to 10^{-6} per year, and in some cases even with much smaller numbers, I started to realize that hazard calculations based on very limited data are being carried too far.

This DPV outlines the problems I see with the use of seismic hazard and risk data and suggests avenues for resolving these problems. Because of my impending retirement, I have not had the time to work out more complete solutions. However, I believe that the statements made here will contribute to a more realistic view of hazard/risk calculations and will eventually lead to an approach that is more defensible. This is particularly important because many NRC regulations are now being adapted to a risk-informed framework.

2.2 Statistical Problems with Data Extrapolation

2.2.1 Types of Data: Probabilistic seismic hazard calculations are based on a) Seismicity data describing the distribution in space and time of past earthquakes, and b) Relationships of the attenuation of seismic waves versus distance based on analysis and modeling of earthquake wave propagation.

On this continent, we have seismicity data that go back about 200 years, and in a few locations, the record may be as long as 400 years. However, there are problems with using these data, because they are not uniform. First, we have modern instrumental data that go back, say 100 years. Even these data are not uniform in that the quality of instruments used and the spatial coverage obtained have changed substantially over that time. Second, we have the historical, intensity-based data going back another 100 years. Again, the coverage diminishes as we go back in time, due to large areas not having been settled yet. These disparate data sets are statistically not equivalent. Trying to use them to arrive at a mathematically consistent extrapolation to the past is not only difficult, it is something that has not really been attempted in a concerted way.

The time span available for estimating the occurrence of large seismic events can be expanded considerably to thousands, if not tens of thousands of years by means of paleoseismic investigations. Such geological methods include studying fault displacements of the past, as exposed for instance in trenches, or analyzing soil liquefaction induced by strong earthquakes, in addition to other, more exotic applications. While such methods have provided considerable insight into large earthquakes of prehistoric times, they are limited to large events and to selected locations, where it is feasible to conduct such studies. Therefore, they too do not solve the overall problem of arriving at consistent seismic hazard estimates.

2.2.2 Extrapolation: Considering the problems inherent in the data sets, it is unreasonable to attempt to extrapolate them farther into the past than about 1000 years. By statistical norms explained in the introduction, even that may be going too far. These are not just my personal opinions, other people within and without the NRC have expressed similar views. For instance, the USGS limits its National Seismic Hazard Maps to an exceedance probability of 2% in 50 years, which is equivalent to 4×10^{-4} per year. Dr. Art Frankel has told me that he thinks this is about as far as he can go and still be reasonable.

2.2.3 Statistical Distribution: The integration used to combine the seismicity and ground motion attenuation data is usually done assuming a lognormal distribution. This is a reasonable assumption, but an assumption, nevertheless. Other distributions, such as Weibull have been used before and, obviously, the choice of statistical distribution will influence the results.

An additional fact is that, even if a certain distribution fits the data well within the range of data, there is no way of telling if the same distribution still applies to the portion extrapolated beyond the data.

2.3 Present Practice in the NRC

2.3.1 PSHA and Hazard Estimates: PSHA procedures have been refined over the years, and they have reached a more advanced stage. PSHA in its present form relies on elicitation of expert opinions. Methodologies for collecting such opinions have become more sophisticated, and they have eliminated many of the problems that led to inconsistent answers in the overall analysis. Problems occurred in the past because of incomplete geological knowledge, questions that could easily lead to wrong answers, and other procedural arrangements.

The basis for deriving seismic hazard estimates, therefore, is a combination of individual estimates of experts in seismicity and in ground motion attenuation. With proper elicitation methods, the hazard is determined by integrating the answers given by the experts to questions, such as: What ground motion do you expect in this area from a magnitude 6 earthquake at a distance of 200 km? The answers are based on a thorough explanation of seismic and geologic facts, including a catalog of seismicity. Even then, it is the individual opinions and not the basic (and partially unknown) facts that enter into the calculation. Answers to the ground motion question above, for instance, also depend on ground motion models chosen by the experts. Ground motion models and models of soil amplification or basin reverberation, etc. are continuously being revised, and the revisions often involve substantial corrections that do not necessarily match the accuracy implied in a probability of exceedance of 10^{-3} per year or less.

While the elicitation of expert opinions neatly sidesteps the requirement of finding a statistical procedure that will do justice to the divergent data sets, it does not necessarily lead to more accurate hazard estimates. In fact, it is fairly clear that, in spite of the seeming consistency of the estimates derived, the accuracy of the results is less than what a consistent statistical treatment would produce if it were available.

2.3.2 Hazard and Risk: In addition to inaccuracies arising from the hazard data and their extrapolation, we must realize that for plant engineering considerations, hazard must be further developed into a risk calculation. In order to estimate the effects of earthquake ground motion on nuclear plants, their foundations, structures, systems, and components, it is necessary to include soil-structure interaction and related questions of soil amplification, and fragilities of structures and components. Many of these items cannot be determined with accuracies greater than about ±10%. This is particularly so for soil-structure interaction, which usually has to deal with varying nonlinear soil conditions around a plant foundation. It makes therefore little sense to estimate seismic hazard to levels of 10^{-5} per year or less, as is customarily done at present, even if that were theoretically possible. The overall risk determination, as is well known, will be no more accurate than the factor with the lowest accuracy, which may only be ±10%.

In many of the meetings I attended, it was obvious that PSHA was treated as a procedure of high accuracy, including elaborate estimation of uncertainties. My contention here is that the actual uncertainty may be considerably higher than the estimates. But, most importantly, after establishing the hazard at a given site, ground motion spectra derived from PSHA are changed into "engineering" spectra by enveloping spectra at different frequencies with a broad-brush, "hand-drawn" spectrum. These may actually be standard spectrum envelopes of various types, but the effect is the same as that of a hand-drawn approximation. The assumed precision of the PSHA results is negated by this approach, again making it unnecessary to pretend that the results are more accurate than they actually are.

More recently, a group of experts providing a technical basis for the revision of Regulatory Guide 1.60, has provided a more straightforward approach for developing design spectra. They used Uniform Hazard Spectra (UHS) from PSHA calculations and adapted them to Uniform Risk Spectra (URS), which are still very similar to the UHS. This is more directly based on probability than earlier methods of deriving design spectra.

2.3.3 Deaggregation: The new method above still uses deaggregation of hazard curves. This is a procedure that was instituted by a panel of experts, when new plant siting regulations were being formulated with the purpose of using a probabilistic hazard approach. Many of these experts were more accustomed to deterministic hazard methodology and felt more comfortable with this pseudo-deterministic procedure.

Deaggregation is used to back out data on magnitudes and distances that may more strongly influence ground motion at a site, and to analyze dominant frequencies associated with the significant magnitude/distance bins. This is a feasible procedure, if certain limitations are kept in mind, as explained below. However, the information on dominant earthquakes and distances is contained in the hazard curves for individual sources, and a deaggregation should not be necessary. Ground motion vs. frequency is given by the UHS and, again, I do not believe it is necessary to go to deaggregation to arrive at suitable risk spectra. It would take more serious consideration and sensitivity studies to analyze this question more completely. However, I remain convinced that a simpler procedure could be developed, and the simpler the procedure, the more transparent it will be.

<u>2.4. Specific Problems with the Current NRC Approach</u>

2.4.1 Excessively low Probabilities: As described above, I and other people have come to the conclusion that levels of probability beyond 10^{-3} to 5×10^{-4} per year are too low to make sense. In NRC hazard calculations, numbers of 10^{-5} to 10^{-6} are routinely used. In Regulatory Guide 1.165 the procedure is carried to the extreme. In tables showing the results of deaggregation, the figures are carried down to levels of 2.36×10^{-15}. That, I would say, is going much too far, even to the point of being ridiculous. In a recent discussion with Dr. Jean Savy of LLNL, he mentioned that he thinks deaggregation is accurate to about 10^{-3} to 10^{-4}. I agree with that, considering that the secondary operation of deaggregation can be no more accurate than the original hazard data.

It is worth noting that, after going to the extreme with probabilities from deaggregation in Appendix C, Regulatory Guide 1.165 then goes to an engineering adaptation of the SSE spectrum in Appendix F. In doing so, it is throwing all caution to the wind by fitting various broadband spectra to the originally “very accurate” high and low frequency spectra.

For another example, RG 1.165 calculates design spectra for the averages of 1 and 2.5 Hz, and 5 and 10 Hz. The newer technical basis for RG 1.60 uses spectra at 1 and 10 Hz. While reasons can be advanced for either approach, the example shows that the rules are not hard and fast, and that prescribing a rigid approach based on a theoretical high accuracy is not the way to go.

2.4.2 Simplified Licensing Procedures Are Possible: Most of the nuclear plants in the central and eastern U.S. have SSE ground motions at ~~about 0.1 g, and all licensed plants in the country have SSEs at or below 0.2 g, except for San Onofre 2 and 3, which are licensed at .34 g.~~ 0.25 g or less, and even in the western U.S. many locations are available with ground motion levels at 0.3 g or less. With standardized plants available that are designed to withstand 0.3 g, and with advanced reactors that promise to be safer than that, it is not necessary to go to the extreme in determining SSE ground motion, as was done in the past. For ~~most~~ many parts of the U.S. a plant at 0.3 g should pose no great problem in licensing.

This is a fairly obvious conclusion that could lead to a much reduced licensing burden without reducing safety. Some cautions will still be necessary in conducting site investigations, and I will try to outline ~~essentials~~ some simplifications ~~of a simplified~~ for future licensing procedure~~s~~ in the following.

2.5. Suggestions for Improvements in Hazard and Risk Determination

~~**2.5.1 Tie Site Hazard to 10^{-3} per Year:** SSE levels at existing plants are almost invariably at a median probability of exceedance of 10^{-3} per year or slightly lower. This would therefore seem to be a convenient level on which to base the hazard calculations.~~

~~**2.5.2 Use Median for Reference Levels, etc.:** It would be better to use median spectra rather than mean spectra. I have pointed out many times that the type of data we have does not lend itself to mean calculations. I realize that, from the point of view of mathematical pseudo-sophistication, the mean looks so much better, but the fact is that it does not readily apply to noisy data. At the 10^{-3} level, this is less important than if we go to lower probabilities, as the mean is better behaved at higher probability levels.~~

2.5~~.3~~ .1 Use Probability-Based UHS and URS: As in the revised Reg Guide 1.60, it would be advantageous to base the SSE spectra on probabilistic Uniform Hazard Spectra adapted for risk to Uniform Risk Spectra. Use of 1 Hz and 10 Hz as anchors for the SSE is probably better than the previous Reg Guide 1.165 approach. What is needed is a spectrum covering high and low frequencies. This could also be thought of as a continuous combination of, say 1, 2, 5, and 10 Hz.

2.5~~.4~~ .2 Simplify the Design Spectra Calculations: Revised Reg Guide 1.60 specifies spectra that are no more than 10% below or 30% above the URS. ~~I believe we should go directly with the URS and forget the niceties.~~ It may be possible to go directly with the URS, but without further investigation I cannot decide on the merits of such an approach. We may loose some intellectual satisfaction this way, but from a practical point of view it probably makes little difference, particularly at sites where the SSE is ~~0.2~~ 0.25 g or lower.

In addition, I feel that many of the procedures in Reg Guide 1.60 could be further simplified. For one thing, all the information on magnitudes and distances is contained in the hazard curves for individual seismic sources. It should therefore be possible to describe a simpler procedure that would forego the deaggregation. However, these thoughts are the least developed among this outline. In trying to resolve some of these questions, sensitivity studies of various kinds will be needed.

2.6. Suggestions for Improvements in Plant Licensing

2.6.1 Performance Goal - Reducing Unnecessary Regulatory Burden: This performance goal, I believe, is the one that has been taken the least seriously among the four NRC performance goals. This is in line with normal regulatory inertia; reducing burden on the licensee is just not a priority among regulators. However, if regulations can be simplified without impacting safety, it is time to do something about it. As pointed out in section 4.2, this is clearly the case today.

2.6.2 Suggested Approach to Simplified Regulations: a) From the 1993 LLNL Update calculate hazard at the site using the CEPA program. Check the hazard level at a median probability of 10^{-3} per year. Conversely, use the 5% in 50 years USGS National Hazard Map to determine the hazard level. The two values are not necessarily identical. However, by foregoing an accurate determination that does not impact most standard plants in the CEUS, the difference should not be significant. b) If the values are at ~~0.2~~ 0.25 g or less, the design spectrum for standard plants is adequate. c) At all sites, a normal site investigation according to Reg Guide 1.132 must be conducted. At sites falling into the < ~~0.2~~ 0.25 g category, most of the Reg Guide 1.165 investigations should be unnecessary, except for an investigation of unknown faults in the vicinity of the site and of possible differential settlement at the site.

For sites above ~~0.2~~ 0.25 g, more detailed investigations and more detailed determination of the SSE ground motion will be required. The Reg Guide 1.60 procedure with simplification to a straight URS can be used for this. Conversely, an even greater simplification of the procedure could be developed.

Note: The exact acceleration level is debatable, depending on what would be considered safe. The value could be raised to 0.3 g, and that might be suitable, but it remains to be seen if some other factor may affect the ultimate plant safety.

With these changes, most future plants can be built with few problems, yet they will be at least as safe as existing plants. I believe such a simplification would be most helpful to this nation, if it is decided that nuclear is again an option. The simplification has nothing to do with promoting or not promoting nuclear power, it simply makes it possible to conduct business in a less problematic and less costly manner. I challenge those in charge of future regulation and licensing to show why such simplified approaches are either not possible or why they are inconvenient to the NRC.

3. BRIEF SUMMARY OF THE MAIN POINTS MADE

3.1 Probability Figures for Seismic Hazard

Extrapolation of probabilistic seismic hazard data is being carried beyond reasonable lengths. Hazard exceedance probabilities should be limited to a median level of about 10^{-3} per year. Reasonable plant rankings and SSE ground motions can be established in this range. In terms of safety, the change to lesser extrapolations may not be very significant, but it is still important to put risk informed regulations on a more realistic basis.

3.2 Simplified Licensing

With standardized plants designed to 0.3 g, and with ~~most~~ many existing plants in the country having been licensed at ~~0.2~~ 0.25 g or less ~~(~0.1 g for most plants in the Central and Eastern U.S.)~~ - including most plants in the central and eastern U.S. - a much simplified procedure for determining SSE ground motion in such favorable locations can be established. For ~~most~~ many plant locations, particularly in the Central and Eastern U.S., a simple LLNL (or EPRI) hazard calculation, or a look at the USGS National Hazard map for a 5% exceedance in 50 years should be sufficient to establish whether the plant can be built with a standard SSE spectrum.

In addition, a simplified search for faults in the vicinity of the plant site should be developed. This search should be directed only at significant faults that would affect the overall probabilistic hazard calculation.

4. ASSESSMENT OF CONSEQUENCES

4.1 Safety Aspects

The present regulations, in my opinion, are being carried too far with extrapolation and into small probabilities. However, I believe the present regulations are probably safe, even though subject to criticism as outlined above.

4.2 Licensing Consequences

As stated, the licensing requirements for future nuclear plants are not substantially different from the previous requirements that have driven up the costs of U.S. nuclear plants to the detriment of our present energy situation. Although the position can be taken that everything is perfectly alright, that future plants will be safe, if they have a chance of being licensed, I believe a more appropriate solution must be found. The NRC would be derelict in its duty by holding on to antiquated procedures (even though dressed in a more modern garb), when it is clearly possible to substantially simplify the requirements.

As a final remark, I would like to state that the usual solution to such a challenge, namely calling in the expert panels will have very predictable consequences. The experts are certainly intelligent enough to see that their livelihood may be endangered by these ideas. Although they will never express such a thought, they will do everything in their power to preserve the status quo.

Ernst G. Zurflueh, Geophysicist