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Comment on Draft Regulatory Guide DG-1145, Section C.I.2.5.2.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquake and C.I.2 in General.

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The draft guide DG-1145 bases the development of the safe shutdown ground motions completely on the results of a PSHA. The report NUREG/CR-6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" (published in 1997) is provided as a reference.

The NUREG/CR-6372 report [1] no longer reflects the state of the art in many of the associated areas of science and technology:

1. The expert elicitation method is based on principles of a political consensus rather than on principles of rational consensus. The principles of rational consensus established by Cooke [2]:
   - Reproducibility: it must be possible to reproduce all calculations.
   - Accountability: the basis for the probabilities assigned must be identified.
   - Empirical control: the probability assignments must in principle be susceptible to empirical control.
   - Neutrality: the methods for combining or evaluating expert opinion should encourage experts to state their true opinions.
   - Fairness: all experts are treated equally prior to processing the results of observations.

   The procedures in [1] deviate from these principles especially with respect to the principle of empirical control, because they lack any formal step of comparison of the results with empirical observations characterizing the seismicity of the site area. Furthermore, practical applications of this method were preferably based on an equal weight aggregation procedure and not on the true performance of experts. Significantly improved methods for expert aggregation have been developed in the past [2,3]. In other NRC projects aggregation methods differing from the procedures in [1] have been applied (e.g. geometrical mean in NUREG/CR-1829 [4]).

2. The probability of exceedance of a specified ground motion level is given in [1] on page 12 as:

$$\Phi'\left(\frac{\ln a - g(m,r)}{\sigma}\right) \tag{1}$$

   This expression assumes that the residuals of the regression equation for ground motion attenuation are completely independent from the model used in the PSHA. This is mathematically incorrect [5,6] and contradicts empirical observations (σ depends on either magnitude or distance [7] or both). The σ value derived from regression represents an estimate of the total uncertainty of ground motion at a given site including travel path and source characteristics as well as the variability of site conditions. It also includes the uncertainty associated with the incompleteness of the model used in the analysis.

$$\sigma = \sqrt{\sigma^2_{source} + \sigma^2_{path} + \sigma^2_{modeling}} \tag{2}$$

   The uncertainties associated with the source in a PSHA model are addressed in the seismic source models, the uncertainties with respect to the travel path are at least partially addressed by using a mixture of different attenuation modes and by using empirical attenuation models representing data collected from many different regions of the world. Therefore, the use of equation (1) systematically leads to some double counting of uncertainties.

3. The model described in [1] is mainly based on a very specific PSHA model developed by Cornell [8] and McGuire [9]. The methodology described and supported in DG 1145 (as well as in NRC RG 1.165) potentially leads to a violation of energy conservation principles. The consequence is that the derived controlling earthquake(s) may be too optimistic with respect to their potential damaging impact.
According to the procedures in [1], frequencies of earthquakes (from the same seismic source or from different seismic sources) resulting in the same ground motion at a specific site are added. The problem here is that this summation is performed despite the fact that these frequencies from different sources (or from the same source representing different magnitudes) correspond to different percentiles of the magnitude size distributions of the different sources and also to different energy levels. For example, an earthquake of magnitude 7 at a distance of 10 km to the site at a confidence level of $-1\ \sigma$ can produce the same spectral acceleration as an earthquake of magnitude 5 at the same distance to the site at the confidence level $+1\,\sigma$. The contributions to the hazard (to the corresponding spectral acceleration) are combined although the energy content and therefore the damaging potential of the two earthquakes are very different. This can be illustrated by the following figure 1 showing the uniform duration of earthquakes (as defined by Bolt, [10]) of different magnitudes resulting in the same value of peak ground acceleration (pga =0.5g) at the site.

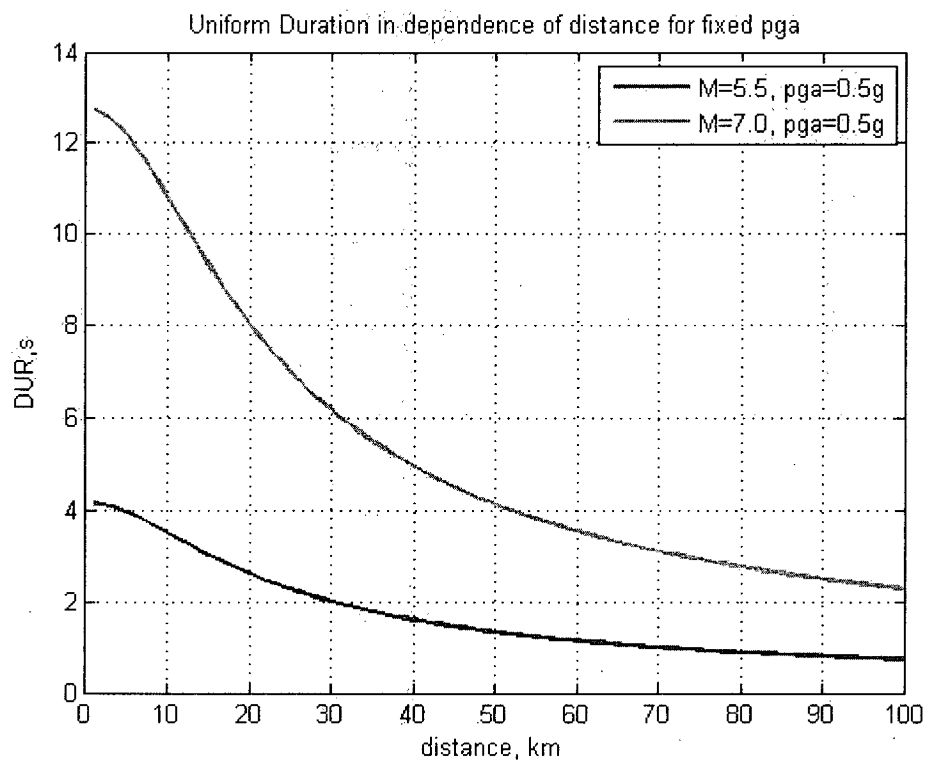

Figure 1. Dependence of uniform duration on magnitude and distance for a fixed peak ground acceleration

The correlation used for figure1 was derived from a consistent data set of the WUS database[11] and published in [12]. It is obvious that the energy content and therefore very likely also the damaging impact of the different earthquakes are significantly different. Therefore, the Uniform Hazard Spectra (UHS) derived from PSHA represent an incoherent mixture of earthquake responses with respect to their energy content. Unfortunately, the frequency of occurrence of weaker earthquakes can be significantly higher than the frequency of stronger earthquakes. This has the consequence that the weaker (from perspective of energy content) earthquakes are preferably selected as controlling events by the usual deaggregation methods (based on accelerations). Indeed, this was observed in a simple sensitivity study [13]. Therefore, the design basis of new nuclear power plants derived by the proposed procedure can be too optimistic.

Request for modification of DG-1145:

The draft regulatory guide DG-1145, section 5 has to be extended as follows:

1. In C.I.2.5.2.4 :

Provide a description of the probabilistic seismic hazard analysis (PSHA), including the underlying assumptions and methodology. Provide a detailed discussion on the link between the modelling assumptions and the available geological, geotechnical and seismological information. Discuss the potential sources of uncertainties and how they are treated in the PSHA analysis. Possible ways for treatment of uncertainties are:

- Advanced statistical techniques for parameter estimation based on the available data (e.g. NUREG/CR-6823 [14])
- Use of experts based on a formalised expert elicitation procedure based on the principles of a rational consensus [2], [3].

The methodology according to NUREG/CR-6372 "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts" may still be applied with special consideration to provide assurance that the results of PSHA are consistent with empirical observations especially with the information requested in section C.I.5.2.3. Furthermore, it is requested that the controlling earthquakes are derived by deaggregation methods based on energy measures (Arias intensity, seismic input energy, or directly CAV). The energy measure(s) selected for deaggregation has (have) to be justified. The models used for the attenuation of energy measures have to be consistent with the models used for ground motion attenuation (based on the same recorded or simulated time histories).
The request for logic trees has to be omitted, because it is generally preferable to use regionally validated models with respect to attenuation models, simulation of time histories and seismic activity.
As a part of the validation of PSHA results, a comparison with the results of a deterministic seismic hazard analysis must be performed. The results of PSHA have to be constrained by the results of the deterministic seismic hazard analysis (regression mean + 1σ). (*Remark: This must be the case for all PSHAs which are based on an instantaneous seismo-tectonic model and a stationary stochastic process model (Poissonian Model), because under these conditions uncertainties should not increase*

with the return period according to the modelling assumptions – for consistency reasons).

2. *Add a section on how to perform a deterministic seismic hazard analysis (as an empirical validation technique for PSHA results)*

Deterministic methods are used for the design of critical infrastructures (not only nuclear) all over the world besides the USA (also for dams used) and UK. The methodology should be based on the traditional MCE (maximum credible earthquake) approach with some necessary extensions. The key requirements to be considered are:

1. The maximum credible magnitudes considered in the analysis should correspond to the 95%- quantile of the magnitude-recurrence distribution for the considered seismic source. Parametric and non-parametric estimation techniques should be permitted to define the 95%-quantile.
2. The source description should correspond to the geological, geotechnical and seismological information as used for the PSHA.
3. The same attenuation models (or simulation techniques) should be used as for the PSHA.

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