TP

GUIDANCE FOR PERFORMING PROBABILISTIC SEISMIC HAZARD ANALYSIS FOR A HIGH-LEVEL WASTE REPOSITORY

Internal Draft - March 1990

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CONTENTS

* Characterization of Seismic Source Zone

or

Seismic Source Zone Considerations.

ABSTRACT

The purpose of "Guidance for Performing Probabilistic Seismic Hazard Analysis for A High-Level Waste Repository" this document is to provide the U.S. Department of Energy (DOE) an acceptable probabilistic seismic hazard analysis (PSHA) approach for identifying and assessing the hazard of seismic ground motion ~~hazard~~ and differential fault displacement at a repository site. The results obtained from the PSHA will complement the results from the deterministic approach by providing a total picture of the seismic ground motion hazard. # Once developed, the results of the PSHA will also be combined with analyses of other processes and events into a complementary cumulative distribution function (CCDF). The CCDF will be used to demonstrate that the probability of radionuclides released to the accessible environment will not exceed the radiation protection standards promulgated by the U.S. Environmental Protection Agency and incorporated by reference into 10 CFR Part 60.

① What about differential fault displacement?

② In addition to assessing the seismic hazard, PSHA will also contribute to the CCDF. True? Moreover, how does one achieve the total picture of seismic activity.

1. INTRODUCTION

For many years, the U.S. Nuclear Regulatory Commission (NRC) has regulated nuclear reactor facilities using deterministic rather than probabilistic approaches. ~~The~~ deterministic approaches ~~has~~ have relied upon the careful analysis of a wide spectrum of design criteria for initiating events. However, experience gained in using the deterministic approach established that the technique itself did not adequately address significant weaknesses in the data bases that describe or characterize the initiating events nor did the technique address all the relevant design issues.*

Thus, because of these limitations ~~Therefore,~~ attention was directed toward using probabilistic techniques, in the form of probabilistic risk assessments (PRAs) ~~techniques~~ to obtain expanded (quantitative) measures of risk. ①

The first major application of a probabilistic ~~risk assessment~~ technique for assessing risks at nuclear reactor facilities was the "Reactor Safety Study" (U.S. Nuclear Regulatory Commission, 1975). ② This study showed, for example, that the design basis accident review approach was not sufficient to describe many important design weaknesses nor to address all the relevant design issues. Additionally, the "Reactor Safety Study" demonstrated that, through the use of a PRA, quantitative measures of risk could be obtained. ~~using PRA techniques.~~ The study also demonstrated that PRA could provide valuable information and insight with respect to evaluating safety issues of regulatory significance. Consequently, a committee was formed for the purpose of developing a PRA Procedures Guide (U.S. Nuclear Regulatory Commission, (1983)).

underline proper names of publications

So what

② This conclusion/finding was stated in the previous ¶. Also, you are now saying something about DBA that wasn't previously stated. Significance is what

① Is it being implied that deterministic approaches provide a quantitative measure of risk? I don't think so. PRA's quantify the risk by/through the use of probability theory. That is the innovation provided by the technique

* or one of them

how so?

narrower error bands?

The methodology for performing PRAs has advanced within the last decade, and it is continuing to develop rapidly. It is anticipated that PRA methodology will continue to mature, offering increased promise that PRA estimates will be made with narrower error bands. #However, in employing PRAs there is large inherent uncertainty, due in part to the lack of adequate data bases on which to formulate the PRA and due in part to reliance on the subjective judgment. Consequently, uncertainty analysis has become an integral part of the PRA process, which includes considering not only the uncertainties in the data bases but also the uncertainties arising from modeling assumptions.

delete this phrase. redundant

how are these different?

PRA methods and procedures include evaluation of both internal and external events. Internal events, such as loss of coolant accidents (LOCAs), are those events/initiators which occur within the nuclear facilities, whereas external events are generally those which are external to the normal operating ~~systems~~ and ~~to the~~ safety systems. External events generally include earthquakes, fault displacements, fires, floods, tornadoes, and man-made hazards. This guidance document will address seismic hazard analysis.

① Wasn't this a weakness in the deterministic approach? So what has been gained w/ a PRA?

② What does this mean? Errors in modeling assumptions? Elaborate/clarify.

③ Point needs to be made that faulting and earthquake constitute seismic hazards; the connection is missing i.e. How do you go from PRA to PSHA?

① There is no explicit requirement in Part 60 or 40 for a PSHA. This connection and the acceptability of a PSHA for assessing the hazard needs to be established.

② Connection between PSHA and CCDF not clear; where is the "g" in all of this?

2. REGULATORY FRAMEWORK

~~2.1~~ ① Background

Under the Nuclear Waste Policy Act of 1982 (NWPA), as amended, ~~The~~ the ~~U.S. Nuclear Regulatory Commission~~ (NRC) is responsible for licensing a mined geological repository for high-level radioactive waste (HLW). NRC's ~~regulations for~~ requirements for licensing the ~~mined geological~~ repository are contained in 10 CFR Part 60. Performance objectives and design criteria described in 10 CFR Part 60 establish the basis for considering the seismic hazard. For example, 10 CFR 60.131(b)(1) requires that structures, systems, and components important to safety ~~in the geologic repository area~~ be designed so that natural phenomena do not interfere with their intended safety functions. Also, incorporated within 10 CFR Part 60 ~~(USNRC, 10 CFR Part 60, Section II, Proposed Rule, 1986)~~ is the U.S. Environmental Protection Agency's (EPA's) radiation protection standard, 40 CFR Part 191, promulgated by the EPA. NRC is responsible for implementing the EPA standard ~~(40 CFR 191.13)~~, which ~~states:~~ establishes the overall system performance objective for the geologic repository after permanent closure with respect to both APEs and UPEs.

one regulation

In discharging its statutory responsibility under NWPA, NRC is ...

> ~~"Disposal systems for spent nuclear fuel or high-level or transuranic radioactive waste shall be designed to provide reasonable expectation, based upon performance assessment, that the cumulative releases of radionuclides to the accessible environment, for 10,000 years after the disposal, from all significant processes and events that may affect the disposal system, shall:~~
>
> ~~a. Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to table 1 (Appendix A); and~~

It is not clear what this contributes to the discussion - the key is that the EPA performance standard applies to APEs/UPEs

(1) Discussion needs to be re-worked to establish relationship between "investigations" and "assessment" The connection isn't clear.

~~b. Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A)."~~

Therefore, the investigations performed to address the requirements of 10 CFR 60.131(b)(1) of 10CFR Part 60 for the pre-closure period of performance and 40 CFR Part 191.13 for the post-closure period of performance must be adequate to assess any potentially adverse conditions which result from the vibratory ground motion hazard. (1)

2.2 Discussion

redundant - previously stated in last section

~~EPA has set a standard (40 CFR 191) to protect the health and safety of the public from radiation releases for 10,000 years after closure of a high-level waste repository. NRC is responsible for implementing this standard. The U.S. Department of Energy (DOE), in its license application to NRC, must demonstrate its compliance with the EPA standard. Compliance with the EPA release standard is a necessary requirement for the Commission to issue an authorization to DOE to operate a mined geologic repository to dispose of high-level radioactive waste.~~

probabilistic containment section

(4) The environmental standard (40 CFR 191.13) states that whenever practicable, demonstration of compliance can be accomplished by assembling all results of performance assessments into a complementary cumulative distribution function (CCDF). A CCDF indicates the probability of exceeding particular values of the

EPA standard. A CCDF that falls below the EPA limit indicates that the disposal system has satisfied the EPA requirements, whereas any portion of the curve that falls outside the envelope may imply noncompliance with the requirements (Fig. 1).

B

To demonstrate compliance with the pertinent EPA requirements, the probability of occurrence of each individual process and event that may cause a release must be determined. 1 Then, the probability of the scenario is estimated by combining all the probabilities of processes and events in it (for an example, see Hunter and others, 1987). Two event classes that have to be considered in the scenarios are earthquake ground motion and fault displacement.

1 How are these probabilities estimated/calculated

Q:
How are ¶s A + B different? It sounds like ¶B is a more generic description of ¶A.

① what about differential fault displacement?

3. TECHNICAL GUIDANCE AND DISCUSSION

go back to abstract ①

The purpose of this ~~guidance~~ document is to provide DOE with guidance on ~~an~~ acceptable ~~probabilis~~tic approaches for conducting a PSHA. When completed, the PSHA will be able to describe ~~seismic hazard approach for identifying and assessing~~ the seismic ground hazard at a geologic repository.

The staff is developing this guidance with the following objectives :

delete sounds like mother hood what does it add?

wasn't this stated above?

a. To identify the attributes of an acceptable PSHA.

b. To ensure that necessary and sufficient information is obtained for use in the hazard analysis by identifying the information needs.

c. To summarize an acceptable methodology to calculate a seismic hazard function for a geologic repository.

d. To ensure that the seismic hazard results and the quantified uncertainty in the results at a proposed site are in a form suitable for use in assessing the implications for the public health and safety.

wasn't this already stated?

The seismic hazard results will be used to calculate the likelihood of mechanical and structural failure (fragility) in DOE's proposed design and to estimate consequences of such ~~a~~ failures for both the pre-closure period (100 years) and post-closure period (10,000 years).

Earthquake ground motion calculations should be based on different models and should be presented in the form of a family of curves showing the probability of exceedance of ground motion at different levels of acceleration.

is this a staff position?

These outputs/curves will be combined with the probabilities of the other processes and events in a given scenario such as climate changes, shaft seal failure, flooding, and pumping that alters the ground-water flow. The probabilities and consequences of the scenarios are evaluated and a CCDF should be estimated and compared to the EPA requirements.

out of context here!

OK

Approaches and solutions different from those set out in this guidance will be acceptable if they provide a basis for the findings requisite to the issuance of a permit or license by the Commission.

I think that we can get by w/out this

3.1 Summary of Guidance

- Develop seismic source zones and alternative source zone models.
- Estimate the rate of earthquake occurrence.
- Develop attenuation models appropriate for the site.
- Perform uncertainty analysis for the seismic source zones, the maximum earthquake magnitude, and ground motion attenuation models.
- Perform sensitivity analysis on the models' input parameters.
- Generate seismic hazard curves with their uncertainty.

3.2 Probabilistic Seismic Hazard Analysis (PSHA)

PSHA provides the frequency distribution of earthquake ground motion, i.e., it develops an estimate (annual probabilities of occurrence) of earthquakes greater than the design basis earthquake of the facility. The annual probability that the peak ground acceleration (A) will exceed a certain acceleration (a) at a given site is defined mathematically by:

$$P(A > a) = \int_m \int_r P(A > a \mid m,r) \; f_{sm}(m) \; f_{sr}(r) \, dm \, dr,$$

where $P(A > a \mid m,r)$ is the probability that the acceleration (A) at a given site is greater than (a), for an earthquake of magnitude (m) at a distance (r).

f_{sm} and f_{sr} are the probability density functions for magnitude and distance, respectively. In studying seismic hazards, we are concerned about the probability that the ground motion associated with an earthquake would occur at a site during a specific period of time, and the annual probability that the peak ground acceleration (A) from this earthquake will exceed a certain design acceleration (a) at the site. The development of a probabilistic model for earthquake hazard analysis requires data and assumptions concerning parameters, such as:

- fault rupture length;
- earthquake magnitude distribution;
- geometry of the seismic source zone; and
- attenuation of seismic waves.

but there are four (4) here

Figure 2 shows the three basic input parameters required to calculate the probabilistic seismic hazard. Therefore, the hazard methodology, when developed, should include the following attributes:

what happens if we don't like their rationale? Is this meaningful guidance?

is this the position guidance

a) the rationale for the choice of specific models, parameters, and procedures used in the analysis; and

b) quantification of the uncertainties of the results.

changing gears here

Within the last decade, different PSHA methodologies have been developed to calculate probabilistic seismic hazards in the United States. The principal methodologies are those of: the Lawrence Livermore National Laboratory (LLNL) (Bernreuter and others, 1989), the Electric Power Research Institute (EPRI, 1986), and Algermissen and others (1982). For example, the LLNL methodology uses input from multiple experts. Each expert provides an interpretation of the different seismic sources and the associated seismicity parameters. Added to this input, the expert-best-estimate of these parameters is also provided. The EPRI methodology uses the team approach, i.e., different teams are formed and each team provides its interpretation of the seismic sources and the associated seismic parameters. Each team uses a systematic approach in delineating the seismic sources and ensures that the approach used is traceable. For example, each team identifies the type of data to be used in delineating the sources, such as crustal structures, gravity, and magnetic and all relevant crustal stress measurements. In the Algermissen approach, one of the authors chose the parameters to be used in the model, based on his best professional judgment.

define

The probabilistic approach discussed in this guidance follows the LLNL and EPRI methodologies and is similar to that used by the Office of Nuclear Reactor Regulation for calculating seismic hazards at reactor facilities. The approach is acceptable for use in both the pre-closure and post-closure period of operation of the geologic repository. For the pre-closure period, (100 years or less), where it can be assumed that there is a cyclic recurrence of earthquakes, the Poisson model may be used. During the post-closure period, the Poisson model may not be the appropriate distribution model to use because the adequacy of the

which "this" Guide?

where has this been described?

STAFF POSITION

Poisson model has not been established for such an extended time period (10,000 years). However, Cornell and Winterstein (1986), in examining high seismicity areas, found that the Poisson model may be applicable for long time-periods. To identify the appropriate distribution to be used at the site of concern for such a long time-period, it is acceptable to consider earthquake records from areas with similar tectonic and seismological features to that of the site under investigation.

3.3 Seismic Hazard Model Considerations

The seismic hazard model and the basic methodology to estimate the seismic hazard at a site have been described in detail by Cornell (1968, 1971), McGuire (1976), and Algermissen and others, (1982). The fundamental initial step in seismic hazard analysis is delineation of the parameters of the seismic model. The different parameters that characterize a seismic hazard model for a site typically are ~~are~~:

A. Seismic source zones.

B. Earthquake activities (distribution of earthquake magnitudes and occurrences in time and space) within a source zone, and

Q: what happened to recurrence functions?

C. Attenuation functions for estimating ground motion as a function of earthquake magnitudes and distances.

D. Recurrence Functions

3.3.1 Seismic Source Zones

A seismic source zone is comprised of such tectonic structures as faults, fault systems, plutons, magma chambers, or other geologic features that are seismically active. Seismic source zones generally represent discrete areas where earthquakes have similar characteristics.

① what do you mean? I thought this section was about characterization of SSZ, not modeling.

Recent efforts to define seismic source zones for hazard assessments relied heavily on available tectonic and paleoseismic data to establish source zone boundaries. To identify seismic source zones, maps of historic and instrumentally recorded earthquakes should be provided to support the technical basis for identifying seismic source boundaries. However, due to uncertain knowledge about the process of earthquake generation in the United States, a ① number of alternative models should ~~must~~ be considered to adequately quantify scientific opinions.

STAFF POSITION re-order

Following is a list of products that must be provided as part of the seismic source zone evaluation documentation:

c° Maps showing historic and instrumentally recorded seismicity ~~and the tectonic features~~ in the study area; ② Isn't this asked for in 3.3.2?

a° A map showing those tectonic features that are believed to be seismically active; and

b° For each tectonic feature believed to be seismically active, a discussion of the technical basis to support the hypotheses.

d° what about alternative models? (see previous ¶)

In most of the hazard analyses performed to date, seismic sources are modeled in seismotectonic zones as point sources (Bernreuter and others, 1989). It is anticipated that seismic sources will be modeled in source zones either as line, area, dipping plane, volume sources, or combinations. When delineating seismic sources, feasible alternatives to the proposed seismic source configuration should be presented, since they may lead to a different probability of exceedance in the computed hazard curves. For example, if a fault is identified as a line source, it should be stated whether the fault is treated in the analysis as a single long fault or a segmented fault. This identification will help in assigning the appropriate maximum magnitude to be used in the analysis. STAFF POSITION

3.3.2 Earthquake Activities

For the earthquake occurrence model, the location and size of earthquakes for

B each seismic source zone developed ~~must~~ should be quantified and the earthquakes in that zone should be Q1 corrected for completeness (Stepp (1972), Lee and Brillinger (1979), Veneziano and others (1984), and Kelly and Lacross (1969)). The minimum earthquake magnitude (lower bound magnitude) and the maximum earthquake magnitude (upper bound magnitude) that can be generated by seismic sources should be identified. Earthquakes of small magnitude (e.g., 5.0 or less) are usually not considered in estimating the activity rate in nuclear reactor analysis, because they rarely cause structural damage. In the case of a high-level waste repository, small magnitude events should be addressed, since they may contribute to structural damage to the underground facilities and may contribute to physical changes in the ground-water flow system.

what do these references offer? elaborate

STAFF POSITION ?

¶ The distribution of ~~the~~ seismic activity ~~rate~~ within a seismic source zone is represented by the Gutenberg-Richter relation:

? A

Q1: What does "corrected for completeness" mean?

Reorder A+B

$$\text{Log } N = a + b\,M,$$

where N is the number of earthquakes of magnitude (M) or greater, and (a) and (b) are constants to be determined. It should be noted that the configuration of the seismic-zones boundaries will dictate the earthquakes that will be used to calculate the seismicity rate and the seismic parameters for the zones. A catalog of historic and instrumental seismicity is generally prepared to estimate the seismic parameters. Bender (1982) found that for seismic source zones in which the total number of earthquakes is less than 40, significant error in the computed b values will occur. Therefore, when analysing the earthquake occurrence, the following items should be considered:

STAFF POSITION

- The completeness of the earthquake catalog;
- The uncertainty associated with the instrumental estimate of M;
- The regressions on M; and
- The constraint of using Poisson's distribution or any other distributions.

3.3.3 Ground Motion Attenuation

Q: What is the staff position

The decrease in the intensity of ground shaking with distance from the epicentral region is called attenuation. A general form of ground motion attenuation can be presented as

$$\ln(a) = c_1 + c_2\,M + c_3\,\ln(d) + c_4\,d,$$

where a is acceleration, M is magnitude, d is distance, and c's are constants. Empirical data are used to estimate the attenuation models (Nuttli, 1986, Campbell, 1981, 1982, and Joyner and Boore, 1981, and 1982). However, there is considerable uncertainty in estimating the intensity of ground motion resulting from an earthquake of a given size and distance from the epicenter, due to the lack of data. The attenuation models now in existence are generalized models and may not be applicable to sites with different tectonic styles.

significance of reference

3.4 Uncertainty in Seismic Hazard Models Uncertainty Considerations

Because of the short duration of the earthquake data set in the United States (200 to 300 years), there are uncertainties associated with each of the parameters used in the seismic hazard analysis. Also, there are other uncertainties arising due to dependencies among the seismic parameters themselves. The uncertainties can be reduced if additional data can be acquired, but in the field of seismology, this may be difficult to accomplish, due to the lack of frequent earthquake occurrences. Therefore, uncertainty associated with the different input parameters should be properly identified and assessed. ~~and expressed clearly~~. One way of accomplishing this is by presenting logic trees (National Research Council, (1988). Also, the uncertainties can be handled by putting "confidence bounds" on the calculated values. These confidence bounds are intended as some measure of the possible spread of uncertainty in the assessed values.

good!

Is this a staff position?

Different seismic source zone configurations will result in varying seismic source zone estimates.

3.4.1 Seismic Source Uncertainty

Q1 Title and text are inconsistent Text talks about alternatives

As stated earlier, the geometry of the seismic source will have a major influence on the seismic hazard estimates. Therefore, the alternative configurations should be prepared and the uncertainties associated with each should be clearly identified. Different source configurations will contribute to different a and b values. The statistical uncertainty in these values should be determined. Similarly, if only a portion of the catalog is used to estimate a and b values, the uncertainty associated with these parameters should be indicated.

what do 'a' and 'b' mean? pg 15 says constants to be determined

3.4.2 Maximum Earthquake Magnitude Uncertainty

Q why just maximum

Most of the estimates done so far for the maximum earthquake magnitude are based on previous experience or professional judgment. As noted earlier, This is because there is only a limited set of data in the United States which covers only a short time period, about 200 to 300 years~~, in the United States~~. To quantify the uncertainties in the maximum magnitude in a given seismic source, it is suggested that:

STAFF POSITION

- different distribution functions be used; and

- range of values be presented with a "best estimate," such as that presented in the LLNL study (Bernreuter and others, 1989), and Pacific Gas and Electric Company, Diablo Canyon (1988).

3.4.3 Ground Motion Attenuation Uncertainty

Q1: Does multiple equal family?   Q2 what does this really mean?

The selection of an attenuation equation and estimation of its uncertainties are among the key parameters for the seismic hazard analysis. In previous studies, the way the uncertainty in this parameter is treated is to consider multiple representative attenuation models (see Bernreuter and others, 1989, and Pacific Power and Gas Company, Diablo Canyon, 1988). Therefore, a family of candidate attenuation curves for the Nevada site should be presented, showing the uncertainty in the ground motion prediction. For each model, the following should be presented:

STAFF POSITION

- the mathematical form of the model, parameter estimates, logarithmic standard deviation, and data base used to estimate the model parameters; and
- probability weights assigned to each model.

3.5 Sensitivity Analysis

Sensitivity analysis is a means of quantifying estimates of the amount of variation in model output due to variation in model input parameters. Therefore, the purpose of this section is to examine the effects of varying the different parameters used in a PSHA ~~probabilistic seismic hazard analysis~~. The parameters that should be considered for a sensitivity analysis include studying the variations in:

STAFF POSITION

- the seismic source configuration;
- the "a" and "b" values of the recurrence relation;
- the lower bound magnitude;
- the upper bound magnitude truncation;
- the ground motion attenuation model;
- the different types of distribution functions;
- the upper bound peak acceleration cut off; and
- including or neglecting site effects on the hazard calculations.

3.6 Fault Displacement

In addition to addressing the ground motion resulting from fault displacement, the probability of exceeding certain fault displacements should be assessed. Fault displacement may impact directly the waste package, cause changes in the geological characteristics of the system, including the ground-water flow system, ~~change~~ fracture permeability, ~~change the~~ water table elevation, and the diversion of flow to other discharge locations. In addition, sufficient differential fault displacement may cause rupture of the waste package. The effects of fault displacement may be estimated following, for example, the approach used by Der Kiureghian and Ang (1977) or by Kiremidjian (1984). The annual probability that the slip U will exceed the displacement value u (i.e., U > u) at any location x along the fault is presented by Kiremidjian (1984) as:

STAFF POSITION ?

$$P\ (U > u) = \nu \frac{c}{s}\ (u_2^s - u^s) \qquad \text{for } \ell \ll L,$$

STAFF POSITION ?

where $c = (\alpha k/L) \exp (0.5\ \sigma^2)$

$s = \rho - \gamma + 1.0$

$\alpha = \exp (a - (bc/d))$

$\rho = b/d$

$\gamma = (\beta/d + 1)$

where β is the slope of the Gutenberg-Richter relationship, L is the fault length, ℓ is the fault fracture length, σ is the standard deviation, and ν is the annual rate of earthquake events on the fault.

It should be noted that large differential fault displacement at the site will cause inelastic deformation of the waste container, and rupture will occur when the displacements exceed the ultimate strain capacity of the container (Kiremidjian, 1984). For such an analysis, a knowledge of the fault locations, direction of the fault movements, the rock friction forces on the container, and the configuration of the container will be needed.

To evaluate the probabilities of exceeding the maximum axial strain level, an (1) iterative procedure (Wang, 1985) or another appropriate approach should be developed for the iterative search of the maximum axial stress for each value of the fault displacement.

In general, an acceptable probabilistic faulting hazard analysis will have attributes similar to those described for PSHA. For example, the results obtained should show the rationale for the choice of specific models,

(1) what characteristics or features should this procedure have?

parameters and procedures used in the analysis; and the uncertainty in the results should be quantified.

3.7 Seismic Hazard Analysis Results

The results of the probabilistic seismic hazard analysis are presented in the form of hazard curves, which give the annual probability of exceedance as a function of ground acceleration (a) (Fig. 3), response spectra (uniform hazard spectra) (Fig. 4), slip values (U) (Fig. 5), or maximum strain (ε) (Fig. 6). These figures are presented here mainly for illustration purposes. In the calculation of such curves, spatial and temporal randomness of earthquakes, as well as propagation of ground motion for earthquakes of different magnitudes and focal depths should be accounted for. Modeling uncertainties which are attributed to the lack of clear knowledge of the geologic and seismologic condition in the vicinity of the site, such as the different seismic zones, the different source models, and the different ground motion models, also should be considered.

Thus, the results of the seismic hazard analysis will be expressed in the form of a set of hazard curves based on the different models proposed, each having an associated weighting factor which represents the judgment of experts as to the appropriateness of a certain set of modeling assumptions. Also if the mean or the median is used for the seismic hazard estimates, the rationale for such choice should be provided (Reiter, 1989).

in the manner described by

The results obtained from the probabilistic seismic hazard analysis regarding ground motion will complement the results from the deterministic approach (Blackford, 1990) by providing a total picture of the seismic hazard at the site. To provide a total picture of the seismic hazard, it is recommended that a type I (deterministic) seismic hazard evaluation, supplemented by a type IV (multiple model PSHA) or type V (hybrid procedure) (National Research Council, 1988), be performed. A Type I seismic hazard analysis is similar to that used for reactor facilities to calculate ground motion. In this approach, the tectonic province and the maximum earthquake estimated from historical data or from fault segments are used with an appropriate attenuation function to estimate the seismic design, whereas Type IV and Type V consider the uncertainty in the different seismicity and attenuation models, in calculating the seismic hazard.

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5. FIGURES

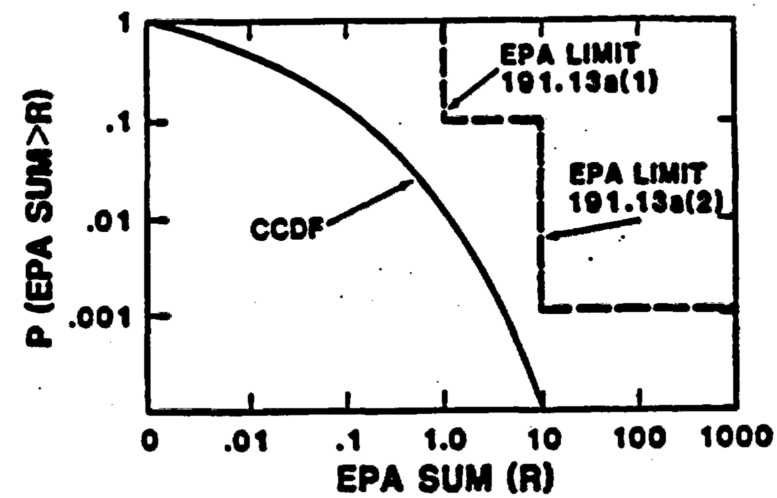
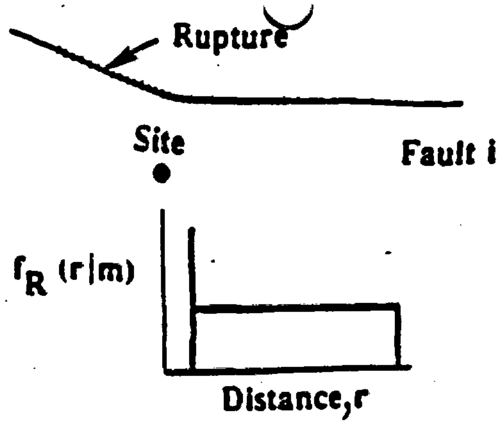


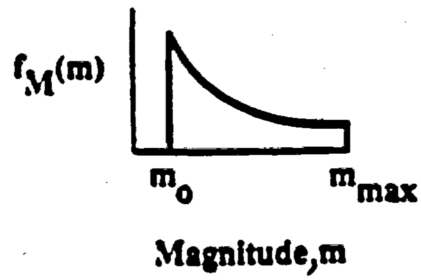
Figure 1 (From Hunter and others, 1987)

A. Seismic Source i
(Earthquake locations in space lead to a distribution of epicentral distances $f_R(r|m)$)



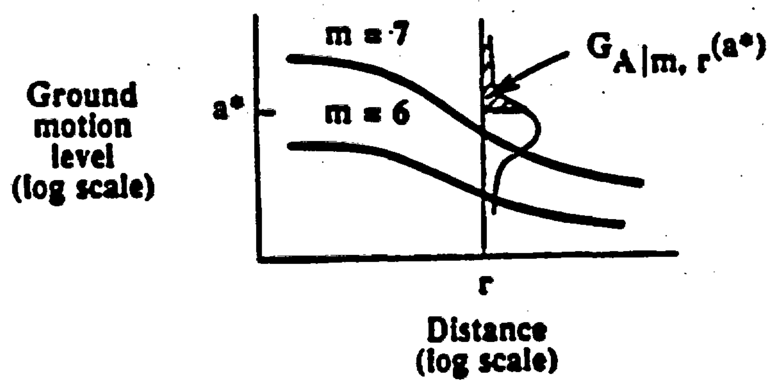
B. Magnitude distribution and rate of occurrence for Source i:

$f_M(m), v_i$



C. Ground motion estimation:

$G_{A|m,r}(a^*)$



D. Probability analysis:

$$P[A > a^* \text{ in time } t]/t \cong \sum_i v_i \iint G_{A|m,r}(a^*) f_M(m)\, f_R(r|m)\, dm\, dr$$

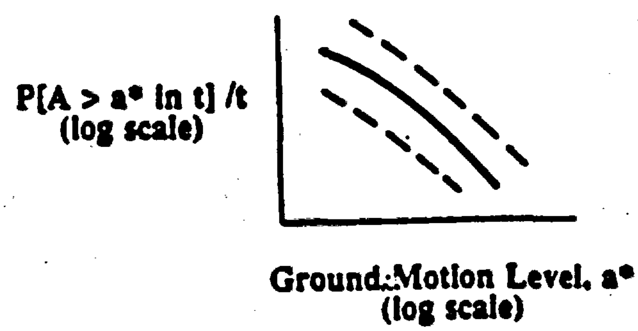


Figure 2 (From McGuire and Arabasz, 1989)

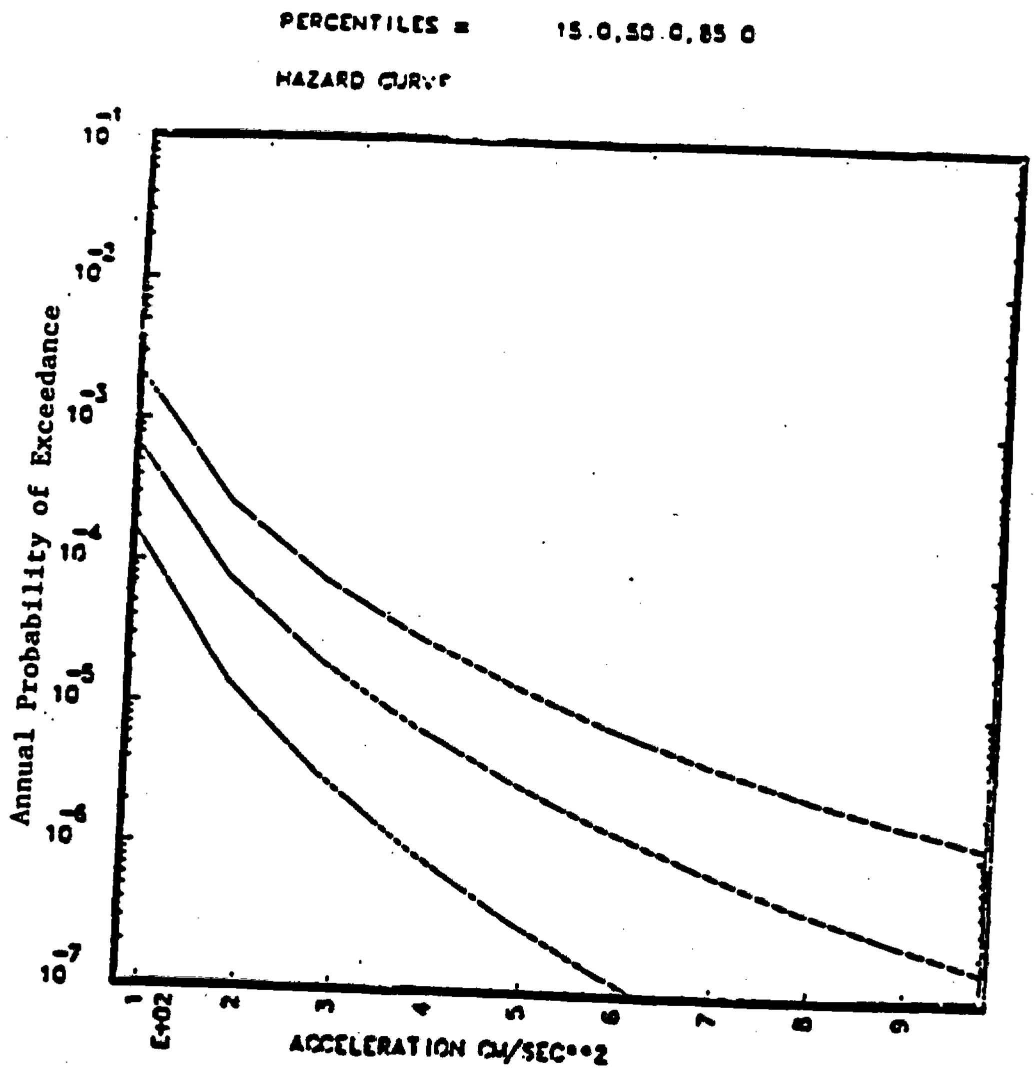


Figure 3 (From Bernreuter and others, 1989)

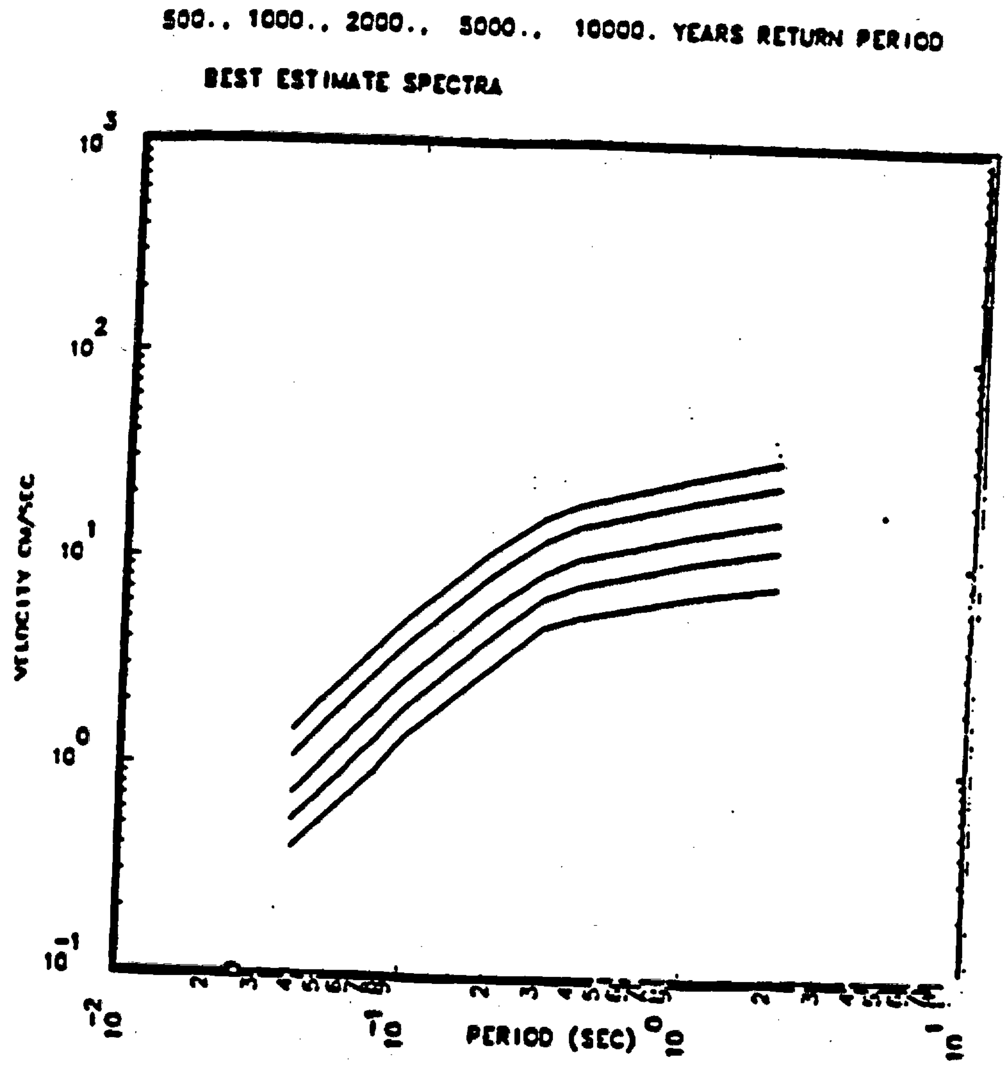


Figure 4 (From Bernreuter and others, 1989)

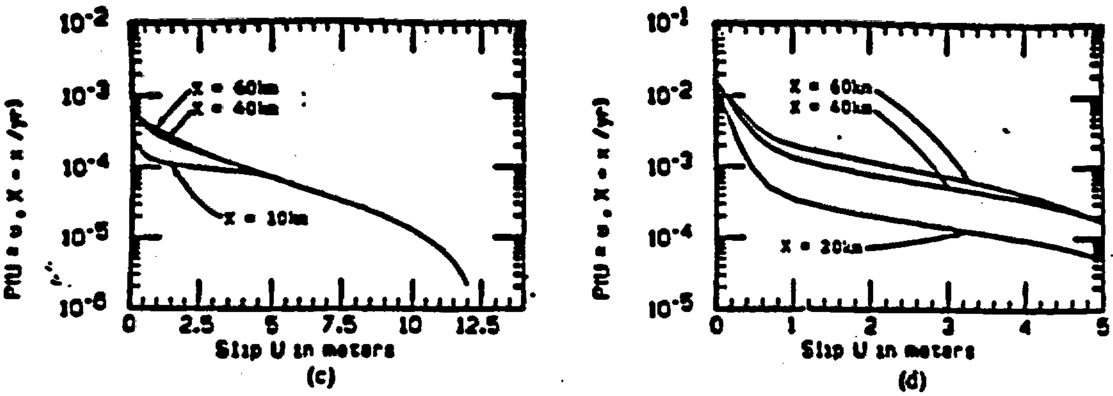


Figure 5 (From Kiremidjian, 1984)

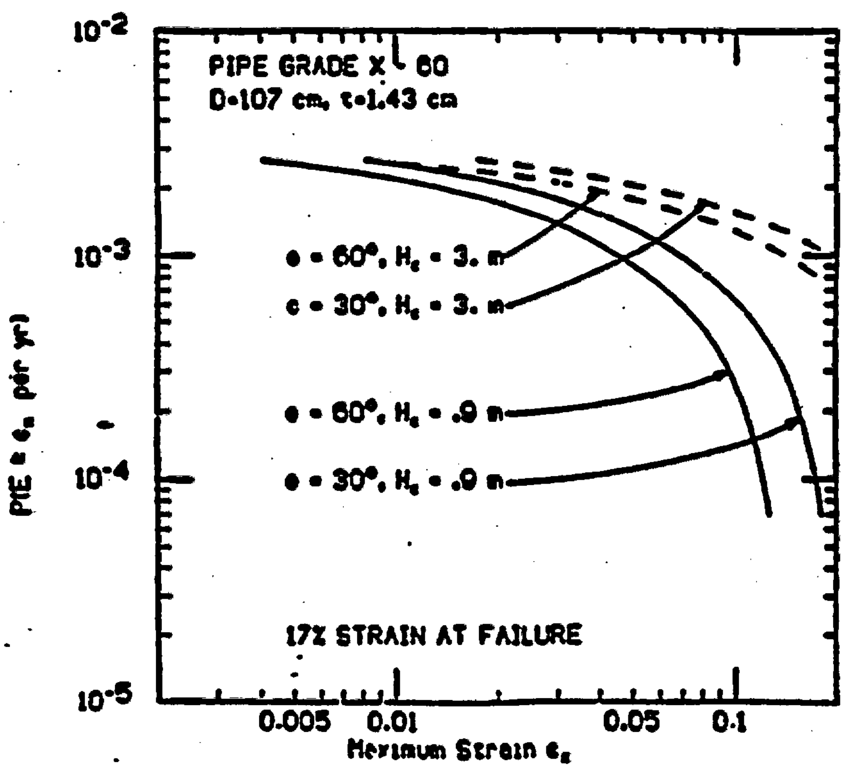


Figure 6 (From Kiremidjian, 1984)

APPENDIX

A. Glossary

(From EERI Committee on Seismic Risk, 1989)

Annual Probability of Exceedance: The level of probabilistic seismic hazard or seismic risk associated with an exposure time of one year.

Attenuation Relationship: A mathematical equation that defines the relationship between a ground-motion parameter, earthquake magnitude, and source-to-site distance. These equations are usually derived from the analysis of earthquake records.

Background Seismicity: Seismicity that cannot be attributed to a specific fault or source zone.

Ground Motion: A quantitative description of the vibration of the ground resulting from an earthquake, usually given in terms of an acceleration time series (an accelerogram) or a response spectrum.

Gutenberg-Richter Relationship: An empirical relationship between N, the expected number of earthquakes per year with magnitude greater than M, and earthquake magnitude, for a specified source zone.

Probabilistic Seismic Hazard: The probability that a specified seismic hazard, usually a ground motion parameter, will exceed some quantifiable level at a specific location during a given exposure time.

Return Period: The average time between occurrences of a specified level of ground motion at a specific location; it is equal to the inverse of the annual probability of exceedance.

Response Spectrum: The maximum response to a specified acceleration time series of a set of damped single-degree-of-freedom systems, plotted as a function of the undamped natural periods or undamped natural frequency of the system.

Seismic Hazard: Any physical phenomena associated with an earthquake (e.g. ground motion or ground failure) that has the potential to produce a loss.

Seismic Hazard Analysis (SHA): The calculation of probabilistic seismic hazard for a site or a group of sites, the result of which is usually displayed as a seismic hazard curve or seismic hazard map.

Source Zone: An area considered to have a uniform rate of seismicity or a single probability distribution for purposes of a seismic hazard or seismic risk analysis.

Uniform Seismic Hazard Spectrum: A response spectrum whose amplitudes represent a uniform level of probabilistic seismic hazard at all periods or frequencies.

Uncertainty: Refers to the state of knowledge concerning a physical phenomenon, it can be reduced by more detailed evaluation or gathering of additional data.