REGULATORY HISTORY AND INTENT FOR PROBABILISTIC FAULT DISPLACEMENT AND SEISMIC HAZARD ANALYSIS (PFD&SHA)

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1 INTRODUCTION

There is no direct mention of probabilistic fault displacement and seismic hazard analysis (PFD&SHA) in Federal regulations, statutes or responses to comments made by the U.S. Nuclear Regulatory Commission (NRC) staff during the development of their regulations. There are, however, numerous references to requirements for investigating earthquakes and faulting which could influence the performance of a high level waste (HLW) repository site. There are also references which require that uncertainties be addressed, that probability distribution functions be used and that expert opinions will be required.

There is a requirement in the Nuclear Waste Policy Act (NWPA) that NRC regulations, if developed first, be made compatible with Environmental Protection Agency (EPA) regulations whenever they are developed. To this time, all attempts at developing applicable EPA regulations have been based on probabilistic expressions of the allowable amounts of radionuclides reaching the biosphere over a given period of time. In order to calculate these probabilities, the occurrence and effects of natural hazards, such as earthquakes and faulting, would appear to be required in probabilistic form.

Probabilistic seismic hazard analysis (PSHA) was proposed in principle by Cornell (1968) and implemented in a computer code by McGuire (1976). Similar efforts were made by Algermissen (1969), and by Milne (1969) in Canada using extreme value statistics. The procedure was augmented to include the incorporation of expert opinion and uncertainties in those opinions, by the Lawrence Livermore National Laboratory (LLNL) for the NRC Office of Nuclear Reactor Regulation (NRR), e.g. Bernreutter et al. (1984, 1989). The purpose of this development was to determine seismic hazard, on a probabilistic basis, for existing nuclear power plants in the eastern U.S. where association of earthquakes with faults or other tectonic structures was not well understood. The LLNL PSHA methodology combines the statistics of data with the statistical analysis of individual expert opinions and a self appraisal by each expert of the uncertainty in the expert's opinion.

A similar method was developed by the Electric Power Research Institute (EPRI) for the majority of eastern U.S. nuclear power plant owners, the Seismic Owners Group (SOG), EPRI (1988). A principal difference between the LLNL and the EPRI approaches is the way in which expert opinions were elicited. The LLNL procedure relied on the Delphi method (e.g. Dalkey, 1969) concept, that experts be queried in writing, and that the combined statistics of responses be returned to the experts prior to further elicitation. The EPRI procedure assembled several teams of experts with the various specialties required to produce a hazard analysis. It appears that only one ground motion attenuation function was permitted, in contrast to the LLNL procedure which elicited expert opinions on the topic. The EPRI teams were then provided with the hazard results of the other teams, differences were discussed, and the teams were again elicited. Further discussion concerning the development of PFD&SHA is given by the National Research Council (1988). Some implications for the application of PFD&SHA to a HLW repository are discussed in Hofmann (1991).

Computer codes were developed by both LLNL (Bernreutter, 1984) and EPRI (EPRI, 1988) to statistically analyze variations in data and expert opinion to produce a probabilistic seismic hazard curve about which distribution functions could be estimated. These methods are under continued development. Details change as new studies progress.

The NRC Division of High Level Waste Management (DHLWM) requested the Center for Nuclear Waste Regulatory Analyses (CNWRA) to investigate the feasibility of using or modifying these methods to determine the probabilistic risk posed by faulting and earthquake ground motion at a potential HLW repository in Nevada. The probability of faulting can be determined directly from paleo-faulting (age dating of ancient fault offsets) or indirectly from historic earthquake data by using recently proposed theoretical models of the dynamics of earthquake fault movement (seismic source theory), e.g. Hanks and McGuire (1981). Expert opinion, where data is not sufficiently available and/or indisputable, would be processed to obtain hazard curves using PSHA processes like those developed by LLNL and EPRI.

The much longer period of performance for a HLW repository relative to a nuclear power plant (200-300 times) may preclude applying current PSHA methods without modification or additional considerations. A concern is that uncertainties in the analyses may produce such large standard deviations at the low probability levels required for a HLW repository analysis, that meaningful results may not be obtained. The LLNL and EPRI codes are complex and expert opinion elicitation procedures are themselves subject to differences in opinion. The level of effort that will be required for a thorough assessment of PSHA methods and their possible application to a HLW repository is not likely to be trivial. Consequently, a discussion of regulatory history and intent with respect to issues concerning PFD&SHA, was requested by NRC's DHLWM staff to demonstrate the relevance of such efforts to regulatory requirements, and to ensure that guidance which may be subsequently developed is consistent with NRC intent.

To develop a clear understanding of the regulatory intent, excerpts from the NWPA, applicable regulations, and NRC and EPA staff statements or responses to comments made during the development of their regulations are presented and discussed, which are relevant to the following topics:

- Earthquakes or faulting
- Probabilistic analyses
- Expert opinions and
- Uncertainties.

Taken together, these excerpts suggest that a methodology like PSHA may be necessary to show compliance with the composite of applicable regulations.

The following regulatory history and intent is provided as a basis for carrying out investigations into the applicability of PSHA procedures to the post closure requirements of a HLW repository. It may be noted that the use of PSHA for relatively short lived facilities, i.e. nuclear power plants, sets a precedent that suggests that such methods might also be applied to preclosure aspects of a HLW repository.

History and intent for each topic is separately discussed in chronological order to the degree possible. Many of the excerpts address more than one topic. Consequently there are exceptions to the chronological order of presentation.

2 STATUTORY BASIS

Federal statutes establish the highest-level requirements and intent of the regulatory framework. In the following discussion, the statutory basis for both regulating faulting and earthquake hazard aspects of a HLW repository and conducting the associated probabilistic assessments are addressed.

The NWPA of 1982, as amended, is the principal statute that addresses issues relevant to PFD&SHA methodology. EPA authority to regulate radionuclide releases and the responsibilities of the NRC and Department of Energy (DOE) are established in the Atomic Energy Act of 1954, as amended, and Reorganization Plan No. 3 of 1970.

The NWPA is the enabling legislation for siting, licensing, constructing, and operating geologic HLW repositories. It also prescribes EPA and NRC involvement. Section 121(a) references EPA standards and Section 121(b) references Commission Requirements and Criteria. These sections indicate that regulations of both the EPA and the NRC are applicable. Section 121(b)(1)(C) further states that

> "If the Administrator promulgates standards under subsection (a) after requirements and criteria are promulgated by the Commission under paragraph (1), such requirements and criteria shall be revised by the Commission if necessary to comply with paragraph (1)(C)", which states that "Such requirements and criteria shall not be inconsistent with any comparable standards promulgated by the Administrator under subsection (a)."

Therefore, NRC regulations must be consistent with EPA regulations whose performance criteria are stated in probabilistic terms. Calculation of probabilistic performance criteria requires, as input, the probability of failure or degradation of natural or engineered barriers, which in turn, requires that siting and design analyses (including analyses of the hazards that the designs mitigate), also be in probabilistic terms. This is the primary basis for the desire to use PFD&SHA in assessing fault and seismic hazards at a HLW repository.

The NWPA also states, with regard to requirements and criteria promulgated by the Commission for a geologic repository, that

> "Such requirements and criteria shall provide for the use of a system of multiple barriers in the design of the repository."

By itself, this statement does not appear particularly relevant but it is precedent to the concept that multiple barriers compensate for but do not necessarily quantify uncertainties. Uncertainties are of concern in PFD&SHA.

Under Section 112(a) Guidelines of the NWPA, seismic activity is specifically addressed:

> "Such guidelines shall specify detailed geologic considerations that shall be primary criteria for the selection of sites in various geologic media." and "Such guidelines shall specify factors that qualify or disqualify any site . . . including . . . geophysics, <u>seismic activity</u> . . . " [underline added].

The 1987 amendment to the NWPA, Section 404(f) Evaluation of Sites (1) states:

> "In preparing an environmental assessment under subsection (a), the Secretary shall use available geophysical, geologic, geochemical and hydrologic information . . ."

Seismic and faulting information are categories of geophysical and geological information.

The presence of faults, fault movements and earthquakes is of regulatory interest in the context of performance of the geologic component of this multiple barrier disposal system. The following excerpts from Section 217 of the NWPA are in reference to a test and evaluation facility which could be built and operated to gather data to ensure that the site meets established criteria prior to a decision to construct a HLW repository. Because the following excerpts from Section 217 apply to a Test and Evaluation Facility and not directly to the repository, they are considered secondary references indicating the general approach and intent of the Commission regarding investigation and analysis of the geologic setting and associated uncertainties.

> Section 217(a) "The purpose of such a facility shall be-- (6) to supplement siting data, the generic and specific geological characteristics developed under section 214 relating to isolating disposal materials in the physical environment of the repository".

Faulting and earthquakes are geological characteristics which relate to isolating disposed materials in the physical environment.

Seismic activity, which is caused by fault movement, is singled out in the NWPA. Under Research and Development on Disposal of High-Level Radioactive Waste, it is stated that an *in-situ* testing program shall begin at the test facility with the purpose:

> ". . . to determine the effects various credible failure modes, including- (i) seismic events leading to the coupling of aquifers through the test and evaluation facility" [Section 217(c) Operation (F)] .

This use of the term "seismic" suggests that authors of the NWPA considered that fault movement attendant to the generation of vibratory ground motion is a component of seismic events (earthquakes and possibly nuclear test events).

The enabling statute, therefore, clearly intends that earthquakes (seismic activity) and faulting be addressed in evaluating any HLW repository site. The statute further requires that NRC regulations be compatible with EPA regulations. Because the containment requirements in the EPA regulation are in probabilistic form, by inference, there is a requirement that data and analyses required as input to the assessment of performance also be in probabilistic form. However, this analysis indicates that there is no clear, direct statutory requirement addressing PFD&SHA, nor would one expect there to be since statutes do not generally address methods for demonstrating compliance with their requirements.

3 REGULATORY HISTORY

The responsible agencies have developed a number of regulations based on the previously described statutes. These provide precedent for concern with the natural hazards of earthquakes and faulting with respect to nuclear facilities. For nuclear power plants, 10 CFR Part 100, Appendix A, which contains technical details of fault and earthquake investigations, has been in effect since the early 1970's. 10 CFR Part 72 for Independent Storage of Spent Nuclear Fuel and Radioactive Waste addresses earthquake and faulting hazards. For the western U.S., the latter defers to 10 CFR Part 100, Appendix A. 10 CFR Part 60 for a High Level Nuclear Waste Repository also discusses hazards from faulting and seismic activity. However it does not refer to 10 CFR Part 100, Appendix A. Following issuance of the NRC's 10 CFR Part 60 and the EPA's 40 CFR Part 191, the DOE generated 10 CFR Part 960 General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories, which also addresses faulting and earthquakes. Although the words "probability" or "probabilistic" do not appear in 10 CFR Part 60 or 10 CFR Part 960, both regulations reference the EPA standard, which provides its containment requirements in probabilistic terms.

This section discusses the regulatory history and intent derived from the published record of development of NRC regulations concerning earthquake and faulting hazards, their probabilistic assessment and the employment of expert opinion in such assessments. Because PFD&SHA is not a direct topic of regulations, but rather a proposed mechanism by which compliance may be demonstrated with their various requirements, its history and intent is addressed by the principal topics of which it is comprised. Those topics are, (i) earthquakes and faulting, (ii) use of probabilities, (iii) use of expert opinion and (iv) uncertainties.

The words "probabilistic" or "probability" do not appear in the current 10 CFR Part 60. However, 10 CFR 60.111(a) states "The geologic repository operations area shall be designed so that . . . radiation exposures . . . will at all times be maintained within limits specified in Part 20 of this chapter and such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency." Furthermore, 10 CFR 60.113(b)(1) states ". . . the fastest path of radionuclide travel to the accessible environment shall be at least 1000 years or such other travel time as may be approved or specified by the Commission." "Among the factors that the Commission may take into account are: (1) Any general applicable environmental standard for radioactivity established by the Environmental Protection Agency". These clearly relate the NRC regulations to the probabilistic containment requirements of 40 CFR Part 191. Therefore, input to performance assessment (PA) scenarios regarding natural hazards also must be in probabilistic terms. Earthquakes and faulting are two of several natural hazards of concern.

PFD&SHA appears to be a methodology which could be adapted to satisfy requirements of the regulations and the intent of those who developed them, and applied to the problem of determining whether EPA probabilistic containment requirements have been met. The following excerpts from regulations and related documents are pertinent to defining regulatory intent as it relates to the components PFD&SHA.

In 40 CFR Part 191, the EPA states:

> (a) Disposal systems for spent nuclear fuel or high-level transuranic wastes shall be designed to provide reasonable expectation, based upon performance assessments, that

the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
(1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A).
(2) Have a likelihood of less than one chance in 1000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).
(b) Performance assessments need not provide complete assurance that the requirements of 191.13(a) will be met. Because of the long time period involved and the nature of the events and processes of interest, there will inevitably be substantial uncertainties . . . what is required is a reasonable expectation, on the basis of the record before the implementing agency, that compliance with 191.13(a) will be achieved" (Section 191.13).

The EPA states in the Federal Register notice which promulgates 40 CFR Part 191:

> "Determining compliance with § 191.13 will also involve predicting the likelihood of events and processes that may disturb the disposal system. In making these various predictions, it will be appropriate for the implementing agencies to make use of rather complex computational models, analytical theories, and prevalent expert judgement relevant to the numerical predictions. Substantial uncertainties are likely to be encountered . . . implementing agencies may choose to supplement such predictions with qualitative judgements as well." "The Agency assumes that compliance can be determined based upon "best estimate" predictions, (e.g., the mean or the median of the appropriate distribution, whichever is higher)" (Section 50 FR 38088-182).

Taken together, the statements in 40 CFR Part 191, 10 CFR Part 60 and the Federal Register Summary of 40 CFR Part 191 imply that a probabilistic approach to defining hazards and their consequences is necessary to determine compliance with EPA's containment requirement. The EPA regulation has been remanded by the Federal Court system, however, and is not currently in effect. Resolution of the issues posed by the Federal Court's decision may result in substantive changes to the current 40 CFR Part 191.

3.1 STATEMENTS RELEVANT TO EARTHQUAKES AND FAULTING

3.1.1 The Proposed Rule

A General Statement of Policy concerning the licensing of HLW Repositories was proposed by the NRC in 1978. It was followed by the procedural part of the proposed rule in 1979 [44 Fed. Reg. 70408 (1979)], which contains the statement in Section 60.21(c)(1) that ". . . the assessment shall contain an analysis of the geology, hydrology, geochemistry . . . of the site . . ." Although this was not the technical part of the rule, which was proposed later, there was a clear intent that an analysis of geologic data would be a requirement. Earthquakes and faulting are interpreted here as elements of the geologic analysis.

3.1.2 First Public Draft of Technical Criteria

The first public draft of the technical part of the proposed rule was published in 1980 (45 FR 31393). The EPA had not yet generated a draft of its standard. Probability or probabilistic methods were not mentioned, although a 10,000 year criterion as a period of concern for repository performance and numerous references to uncertainty and to expert opinion were made in anticipation of EPA's rule. Earthquakes were specifically addressed and there were several statements of implied concern including the following.

> "Stability"--means the rate of natural processes affecting the site during the geologic past are relatively low and will not significantly change during the next 10,000 years."
>
> "(4) *Performance of the geologic environment.* (i) The Department shall provide reasonable assurance that the degree of stability exhibited by the geologic environment at present will not significantly decrease over the long time term."
>
> "The Department shall investigate and evaluate the natural conditions . . . that can be reasonably expected to affect design construction, operation and decommissioning of the geologic repository operations area. The natural conditions include geologic, tectonic . . . processes".
>
> "(2) *Potentially adverse natural conditions--geologic and tectonic.*
> (iv) The geologic repository operations area lies within the near field of a fault that has been active since the start of the Quaternary Period.
> (v) There is an area characterized by higher seismicity than that of the surrounding region or there is an area in which there are indications, based on correlations of earthquakes with tectonic processes and features, that seismicity may increase in the future."

These draft statements were all eventually modified or deleted. However, they indicate early concern with earthquake, faulting and probability issues which continues through current versions of 10 CFR Part 60.

3.1.3 Proposed Amendments to Draft Technical Criteria

After public comments were received on the draft technical criteria, proposed amendments issued in 1981 began to shape the final rule (46 FR 35280). In the preliminary discussion under "Disruptive Processes and Events" the NRC stated:

> "If the process or event is unlikely, then the overall system must still limit the release of radionuclides consistent with the EPA standard as applied to such events. An example of an unlikely event would be reactivation of a fault within the geologic setting which had not exhibited movement since the start of the Quaternary period."

Therefore, it appears that reactivation of faults that are geologically old, among other unlikely natural events, is intended to be considered in design to ensure adequate long term performance of the repository.

3.1.4 Final Proposed Rule

A final rule was proposed in 1981 and comments were solicited (NRC, 1981b). In response to the comments and their consideration by the Commission, this version was revised and reissued for comment in 1983. The purpose of citing these excerpts is to indicate the intent and concerns of the Commission in its deliberations in developing the final rule.

Section 60.21 Content of application (c)(1) states:

> "A description and analysis of the site . . . with appropriate attention to those features which might affect facility design and performance. The assessment shall contain an analysis of the geology, geophysics hydrology . . .".

Section (c)(3) states:

> "A description and analysis of design and performance requirements for structures, systems and components . . . important to safety. The analysis and evaluation shall consider (i) the margins of safety under normal conditions and under conditions that may result from unanticipated operational occurrences, including those of natural origin; (ii) the adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of the consequences of accidents, including those caused by natural phenomena . . . ".

The emphasis on natural phenomena clearly includes earthquakes and fault movement. Under 10 CFR 60.24 Updating of application and environmental report, the concern with these issues is reiterated:

> "The DOE shall update its application in a timely manner so as to permit the Commission to review, prior to issuance of a license:
> (b)(1) Additional geologic, geophysical, geochemical and meteorologic and other data obtained during construction."

A similar statement regarding the operations phase of the repository is under 10 CFR 60.51 License amendment to decommission (a)(3):

> "Geologic geophysical, geochemical, hydrologic, and other site data that are obtained during the operational period pertinent to the long term isolation of radioactive emplaced wastes.

In 10 CFR 60.112, Required characteristics of the geologic setting, further emphasis is placed on stability of the geologic setting:

> "(a) The geologic setting shall have exhibited structural and tectonic stability since the start of Quaternary period."

These excerpts indicate the depth of concern with dynamic geological processes as evidenced, for example, by earthquakes and fault movements.

In addressing favorable conditions of potential sites, the Commission noted in 10 CFR 60.122:

"(a) The nature and rates of tectonic processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate waste."

"(b) The nature and rates of structural processes that have occurred since the start of the Quaternary Period are such that, when projected, they would not affect or would favorably affect the ability of the geologic repository to isolate waste."

These statements further express concern over such processes and their manifestations, e.g. earthquakes and faulting. In 10 CFR 60.123, parallel language is provided for potentially adverse conditions, expressing these concerns in additional detail.

"(a)(4) Earthquakes which have occurred historically that if they were to be repeated could affect the geologic repository significantly."

"(a)(5) A fault in the geologic setting that has been active since the start of the Quaternary Period and which is within a distance from the disturbed zone that is less than the smallest dimension of the fault rupture surface.

"(b)(7) Potential for creating new pathways for radionuclide migration due to the presence of a fault or fracture zone irrespective of the date of last movement."

"(b)(8) Structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period."

"(b)(9) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located."

"(b)(10) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase."

3.1.5 Staff Analysis of Public Comments on Proposed Rule

The following commentary and responses from the Staff Analysis of Public Comments on Proposed Rule (NRC, 1983a) reinforce prior statements by the staff that there are several phenomena associated with active faulting that should be evaluated.

Comment No. 127: U.S. Geological Survey (85)

"In the unsaturated zone, the presence of fractures or faults help to drain the repository horizon, rather than serve as possible short circuits to the biosphere as would be the case in the saturated zones" [Page 35290, Col. 2, paragraph 2 - (f) (2) and (3)].

"The existence of a fault that has been active during the Quaternary Period." "This may not necessarily be an adverse condition in the unsaturated zone" [Page 35290, Col. 3, (b) (6)].

Staff Response to Comment No. 127:

"The staff agrees with the USGS that the existence of a fault that has been active during the Quaternary may not necessarily be an adverse condition in the unsaturated zone. However, the staff believes that other phenomena that may be associated with active faulting could adversely affect a geologic repository. Therefore, the staff believes that active faulting still constitutes a potentially adverse condition that should be evaluated. 60.122(f)(2) and (3) are responsive to the USGS comments on the paragraphs."

Comment No. 446: Div. of Emergency Government, State of Wisconsin (77)

"60.112(a). How will tectonic stability be demonstrated? There is no U.S. historical record longer than 200 years?"

Staff Response to Comment No. 446:

"The reference to "tectonic stability" has been deleted."

This comment and response appear to indicate that tectonic stability is a topic of concern to the NRC but that the NRC staff recognizes the difficulty in defining and determining it with the technology available. Responses to the following comments also support this concept. Quantification of tectonic stability in terms of its manifestation in fault movement and earthquakes is a product of PFD&SHA.

Comment No. 523: Penberthy Electromelt International (61)

"The foregoing System of packaging the radwaste in a glass of high integrity and clad with an inert glass makes it quite unimportant whether there is a collapse of the tunnel due to an earthquake. Nothing will happen to the waste."

Staff Response to Comment No. 523:

"For many, perhaps all, design concepts, the nature of the tectonic processes operating on the site can be an extremely important condition."

Comment No. 526: J. Adam (34)

§ 60.122 Favorable Conditions.

The following favorable condition should be added:

"(k) A uniform and massive, both in depth and extent, geologic unit at repository depth.

Staff Response to Comment No. 526:

"All host rock will exhibit some evidence of fracturing, faulting or other inhomogeneities that would make implementation of the suggested change unworkable in practice. Therefore, we decline to make the change. We consider, however, that a host rock which was identified to be relatively uniform and massive would be found to possess favorable characteristics already identified in other provisions of the final rule."

Comment No. 545: U.S. DOE (48)

10 CFR 60.123(a)(5)

Recommended Revision:

"Add: Or, where the length of the smallest dimension is unknown, a fault in the geologic setting that has been active since the start of the Quaternary Period and whose active segment is within 1 km of the disturbed zone."

Rationale:

"The potential structural condition described is unclear. First, definition of the smallest dimension of the fault rupture surface is difficult. Does the Commission use last movement or total length as the critical dimension? Secondly, there appears to be no direct correlation between the nature of the fault rupture surface (earthquake fault plane) and the magnitude of an earthquake. Once the magnitude of an earthquake is defined, the peak acceleration as a function of distance can be more credibly extrapolated. We are not sure that this adverse condition, as defined, is beneficial in defining the waste isolation characteristics of the repository."

Contrary to the rationale stated above, there are currently proposals to use a relationship between fault dimensions and earthquakes to estimate the magnitude of prehistoric earthquakes. The method would extend seismic history to time spans as long or longer than that of repository performance concern. Confidence would be less than for the past few decades of instrumental recording, however. The staff did not include this criterion in the 1983 rule but has the option of addressing it later in other ways, e.g. in a staff technical position.

Staff Response to Comment No. 545

"Paragraph 60.123(a)(5) has been deleted from the final rule because it was unclear."

Comment No. 546: N. K. Olson, S.C. Geological Survey (70)

Para 60.123, subpara (a)(5)

"Last words, "that is less than the smallest dimension of the fault rupture surface" are somewhat confusing and too permissive. Compare with Subpara (b)(8) which follows. Suggest rephrasing to avoid ambiguity."

Staff Response to Comment No. 546:

"See Response to Comment No. 545."

Comment No. 558: U.S. DOE (48)

10 CFR 60.123(b)(9)

NRC Proposed Wording:

"More frequent occurrence of earthquakes of higher magnitude than is typical of the area in which the geologic setting is located."

Recommended Revision:

"Delete the section."

Rationale:

"Whether there is "more frequent occurrence of earthquakes" is irrelevant; what matters is whether the frequency and/or intensity of earthquakes is at an acceptable level."

Staff Response to Comment No. 558:

"The staff considers "more frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical . . ." to be a potentially adverse condition; whether or not their frequency or intensity is acceptable is the kind of judgement to be made as a result of the analysis required under § 60.122(a)."

Comment No. 584: C. Walske, Atomic Industrial Forum (50)

"Item 60.130(b)(2) . . . (i) applies to interference with normal operation during the period important to safety. . . . (ii) applies to failure to achieve performance objectives in any relevant time period. Therefore, (ii) would appear to encompass all of the requirements of Item (i)." ". . . is it the NRC intent that important-to-safety items required for the operations period be designed to retain their safety function for a 100-year earthquake, and that the engineered barriers used for long-term protection be designed to withstand a 10,000-year earthquake?"

Staff Response to comment No. 584:

". . . Sections 60.130(b)(2)(i) and 60.130(b)(2)(ii) have been combined into one paragraph." "In the final rule, "important to safety" is defined to be applicable prior to permanent closure of the repository."

In summary, the staff responses to these comments indicate that, regardless of details of consideration, the nature of tectonic processes operating on a site, e.g. earthquakes, can be an extremely

important consideration. The staff conceded that a level of detail requiring determining the smallest dimension of a fault to be determined was inappropriate in a regulation. Their intent, however is to indicate that such details are considered important. The staff did not choose to clarify whether important-to-safety items should be designed to retain their safety function for a 100 year earthquake but did clarify that such items were defined to be applicable prior to permanent closure, thereby implying that probabilistic criteria for pre- and postclosure time periods were likely to differ.

In Part C, Rationale for the Performance Objectives in 10 CFR Part 60, the NRC staff discuss items germane to technical intent, some of which relate to PFD&SHA (NRC, 1983a).

> "The characteristics customarily used to describe the geologic environment relate to its mechanical and thermal properties, its mineralogy, and its geologic structure. The processes which affect these characteristics include climatic changes, surface erosion/deposition, diagenesis, and tectonic processes such as uplift, folding and faulting" (Ch. V. (c)(i); NRC, 1983a).

> "There are plausible scenarios in which the geologic barrier is breached. One such scenario assumes a fault through the underground facility extending through the overlying aquifer. We assume the fault offers no hydrologic resistance to vertical flow to the overlying aquifer" (Ch. V.; NRC, 1983a).

That the staff chose to discuss the particular scenarios in the above quotations, suggests that these scenarios are of particular significance. In-as-much as "scenario" is a word used in PA, the implication is that the topics discussed, e.g. tectonic processes which include faulting and earthquakes, and faulting through the underground facility and an aquifer, should be treated probabilistically. Inputs to PA scenarios must be defined in probabilistic terms.

3.1.6 Proposed Conforming Amendments to Rule

Categories of events are defined in the proposed amendments to 10 CFR Part 60 (NRC, 1986) pg. 60-PR-2 as:

> "The term "categories" is used to refer to general classes of processes and events, such as faulting, volcanism or drilling. Subsets of these categories, such as drilling which intersects a canister or fault displacement of a specific magnitude, may need to be retained . . ."

The above indicates that faulting and its consequences, e.g. earthquakes are among the events to be considered in evaluations of performance. The text also discusses proposed methods of treating uncertainties. These are cited in Section 3.4 of this report.

3.1.7 The DOE Rule on Siting Guidelines

Following issuance of the NRC's 10 CFR Part 60 and the EPA's 40 CFR Part 191, the DOE generated the regulation 10 CFR Part 960, General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories. Faulting and earthquakes are addressed as favorable, potentially adverse, and disqualifying conditions:

"The nature and rates of faulting, if any within the geologic setting are such that the magnitude and intensity of the associated seismicity are significantly less than those generally allowable for the construction and operation of nuclear facilities" [10 CFR 960.5-2-11(b)].

"Historical earthquakes or past man-induced seismicity that, if either were to recur, could produce ground motion at the site in excess of reasonable design limits. or (3) Evidence based on correlations of earthquakes with tectonic processes and features, (e.g., faults) within the geologic setting, that the magnitude of earthquakes at the site during repository construction, operation, and closure may be larger than predicted from historical seismicity" [10 CFR 960.5-2-11(c)].

"A site shall be disqualified if, based on the expected nature and rates of fault movement or other ground motion, it is likely that engineering measures that are beyond reasonably available technology will be required for exploratory-shaft construction or for repository construction, operation, or closure" (10 CFR 960.5-2-11(d)].

Appendices I and II of 10 CFR Part 960 discuss NRC and EPA requirements for repository performance. Appendix IV, Types of Information for the Nomination of Sites as Suitable for Characterization, includes:

"The historical seismicity of the geologic setting", "Quaternary faults in the geologic setting, including their length, displacement, and any information regarding age of last movement." and "Active tectonic processes, such as uplift, diapirism, tilting, subsidence, faulting and volcanism" (10 CFR 960.4-2-7).

". . . Quaternary faults." and "Preliminary estimates of expected ground motion caused by maximum potential earthquakes within the geologic setting" (10 CFR 960.5-2-11).

3.2 STATEMENTS CONCERNING PROBABILISTIC ANALYSIS

3.2.1 Staff Analysis of Public Comments on Proposed Rule

In the opening section of the Staff Analysis of Public Comments on Proposed Rule (NRC, 1983a) "Overview, Section 3.1", the Commission discusses the relationship between "reasonable assurance" as stated in NRC regulations, and statistical processes like those addressed in PFD&SHA.

"As EPA itself recognizes, there can only be estimates rather than rigorous demonstrations of probabilities of occurrence. The Commission's translation of the EPA language into qualitative terms provides a clearer basis for judging, under the Atomic Energy Act, whether there is unreasonable risk to the health and safety of the public" (NRC, 1983a, Footnote 5).

"The Commission expects that the information considered in a licensing proceeding will include probability distribution functions for the consequences from anticipated

and unanticipated processes and events. Even if the calculated probability of meeting the Commissions's standards is very high that would not be sufficient for the Commission to have "reasonable assurance"; the Commission would still have to assess uncertainties associated with the models and data that has been considered" (NRC, 1983a, Section 5.4).

In the following comment, the state of California argues that detailed numerically specific performance criteria should be provided in 10 CFR Part 60 for the natural barrier provided by the geologic setting. The staff response cites the same arguments made to earlier comments in this regard. Specific among the concepts in the citations are concerns that their will be a high degree of uncertainty in models and results from them and that ". . . fact-finding process is an administrative task for which the terminology of law, not science is appropriate." The citations state that correctness of models of physical systems are not quantifiable by statistical methods. The tenor of these citations is that there is a limit to the degree of quantification that can be required in a regulation when the inputs to a quantitative analysis cannot, by their nature, be fully quantified.

Comment No. 53: State of California Department of Conservation (62)

"CDC's position is that maximum practical detail of performance criteria is valuable, for confidence in overall safety of any proposed site . . ." ". . . we understand that the major elements are the engineered barriers . . . and the natural barrier provided by the underground setting." ". . . we believe that the criteria for each of those elements should be made as numerically specific as practical by incorporation of the requirement of probabilistic analysis, based on the worst case scenario."

The NRC staff response references large sections elsewhere in NUREG 0804, (NRC, 1983a). Applicable parts of it are discussed in the immediately preceding paragraphs. Another possibly applicable reference which is germane to the amount of quantification appropriate to the regulation follows. This statement is from the first section of NRC (1983a) but is included after several comments from Part A, to provide some background for its relevance to PFD&SHA.

Overview 2.1 Single versus Multiple Performance Standards

"The Commission's task is not only a mathematical one of modeling a system and fitting values for particular barriers into the model in order to arrive at a "bottom line" of overall system performance. The Commission is also concerned that its final judgements be made with a high degree of confidence. Where it is practical for the Commission to do so as to provide greater confidence in its licensing judgements. Accordingly, a variance between actual and assumed EPA standards will not necessarily require a change of corresponding magnitude in the individual barrier performance requirements." "The numerical criteria for the individual barriers included in the rule are appropriate, insofar as anticipated processes and events are concerned, in assisting the Commission to determine with reasonable assurance that the proposed EPA standard has been satisfied. ". . . however . . . to meet the EPA standard as it applies to Unanticipated processes and events, higher levels of individual barrier performance may be required."

This statement is one of several which points out NRC requirements (in this case, barrier performance criteria) which are in addition to overall performance criteria to enhance confidence in performance, considering uncertainties in system modeling. That quantitative requirements for barrier performance are given to compensate for uncertainties should be taken into account when applying PFD&SHA to a HLW repository.

Comment No. 314: Calif. Dept. of Conservation (62)

". . . CDC believes strongly that all evaluations of HLW containment and releases should be based on probabilistic data which uses the worst-case scenario failure analysis.

Comment No. 323: Calif. Dept. of Conservation (62)

"CDC recommends additional tightening of the performance objectives in Subsection 60.111, to emphasize the importance of stringent criteria for the geologic setting, to assure its reliability under all failure conditions . . ."

Staff Response

"See Overview, Sections 3.1 and 5.4 . . ."

Extracts of the Overview Sections 3.1 and 5.4 are in the first 3 paragraphs of this section, above. An applicable reference is Footnote No. 5. cited following the first paragraph of this section. The staff is pointing out that the relationship between probabilities and reasonable assurance is based upon estimates and that they do not agree that a worst-case scenario-failure-analysis is appropriate. There is, therefore, a tempering attitude in the background of 10 CFR Part 60's implied usage of hard statistics to satisfy EPA containment requirements. The staff reiterates that these statistics must be based, in part, on opinions and estimates. What is important here is that the staff did not agree with the concept of imposing more stringent quantitative criteria for the geologic setting than they had proposed in the regulation. The staff concurs that statistics are necessary but because these statistics must be derived from qualitative opinions, it is not appropriate to demand adherence to criteria more stringent than those proposed.

Comment No. 396: American Nuclear Society (20)

"Section 60.111(b)(2)(i) requires that waste packages contain all* radionuclides for the first 1,000 years after permanent closure." "The use of "all" could be interpreted that no waste package failure could be allowed in 1,000 years. Using probabilistic design analyses, it must always be concluded that some chance of failure exists. Consequently, percent of failure allowed must be defined if any fixed life is to be required for the waste package."

Staff Response to Comment No. 396:

"See Overview, . . . Section 3.4, Containment, for the use of the word all."

This section reads:

> "The commenters failed, in part, to recognize that under the specified standard of proof . . . the applicant would not be forced to carry an impossible burden. Nevertheless, since the Commission does not expect proof that literally all radionuclides will be contained, the performance objective now requires design so that containment of HLW within the high level waste packages will be "substantially complete" for the specified period."

This comment suggests that although probabilities are to be used, limits should remain undefined but are not absolute, and the criteria should be implementable; i.e., not be "an impossible burden". Therefore, any application of PFD&SHA to a HLW repository is intended by the NRC staff to be technologically implementable. This poses the problem of creating statistics concerning expert opinions to augment data. It may be an impossible burden to obtain a complete set of data to perform probabilistic analyses which demonstrate compliance with the EPA containment requirement. This concept may apply to the possible use of greater than the mean or median of data, e.g. a standard deviation, which when applied to expert opinions may produce excessively conservative answers. Although the EPA has stated that only the mean or the median of a probability distribution need be used to demonstrate compliance (EPA, 1983), the concern expressed by the NRC regarding uncertainties (NRC, 1983a) may lead to the use of standard deviations or other measures of variability in an attempt to quantify uncertainties. This is an important concept to keep in mind when developing technical criteria for PFD&SHA as applied to an HLW repository.

A final relevant comment is:

Comment No. 407: California Department of Conservation (62)

CDC recommends the following Changes to the proposed rules:

"Subsection 60.111(b)(2)(ii)(A): Control of releases

"(A) For HLW, the engineered system shall be designed with sufficient redundancies and with probabilistic failure analysis using the worst-case scenario so that . . ."

Staff Response to Comment No. 407:

"See Overview, Sections 3.1 and 5.4, . . ."

Extracts of NRC's response are in Section 3.4, Uncertainties, of this report. This suggested change in wording was not incorporated into the final rule, but indicates NRC staff intent that uncertainties be addressed but that this task may not be amenable to mathematical quantification.

3.2.2 Final Rule

Most changes to the rule that are relevant to PFD&SHA were discussed in the NRC Staff Responses to Comments reviewed in the previous section of this report. However, some of the discussion preceding the final rule (NRC, 1983b) has a bearing on the use of probabilities. Pertinent, examples include the following:

> "The Commission intends that a judgement whether a natural process or event is anticipated or unanticipated be based upon a careful review of the geologic record. Such processes or events would not be anticipated unless they were reasonably likely, assuming that processes operating in the geologic setting during the Quaternary Period were to continue to operate but with perturbations caused by the presence of emplaced waste superimposed thereon." "Identification of anticipated and unanticipated processes and events for a particular site will require considerable judgement and will not be amenable to accurate quantification by statistical analysis, of their probability of occurrence.[5]"

The footnote "5" referenced above, is quoted as follows:

> "[5]The Commission views the proposed EPA standard as being directed to the evaluation of releases arising out of the categories that we have defined as "anticipated processes and events." As EPA itself recognizes, there can only be estimates rather than rigorous demonstrations of probabilities of occurrence."

> "Complex quantitative models will need to be employed, and a wide range of factors considered in arriving at a determination of whether there is reasonable assurance, making allowance for the time period and hazards involved, that the EPA standard will be met." ". . . the performance assessment which has been performed must indicate that the likelihood of exceeding the EPA standard is low." ". . . the Commission must be satisfied that the performance assessment is sufficiently conservative, and its limitations are sufficiently well understood, that the actual performance of the geologic repository will be within the predicted limits."

These statements, taken together, require that judgement which is not amenable to statistical analysis be somehow combined with quantitative assessments to produce a reasonable assurance that the EPA standard will be met. PFD&SHA is a class of analyses which attempts to accommodate these requirements in such a manner that analysis of fault displacement and seismic hazard can effectively be input to PA in such a manner that reasonable assurance is provided.

> "Thus its [the Commission's] interest in specifying that the geologic setting shall have exhibited "stability" since the start of the Quaternary Period was to assure only that the processes be such as to enable the recent history to be interpreted and to permit near-term geologic changes to be projected over the relevant time period with relatively high confidence."

3.2.3 Proposed Amendments to Rule

Although the proposed amendments to 10 CFR Part 60 (NRC, 1986) were not implemented, they indicate the intent of the NRC to accommodate the EPA standard and expand upon how they proposed to interpret and implement the rule. The Commission specifically took note that:

> ". . . EPA's reference to estimating the cumulative releases caused by all significant processes and events, to be incorporated in an overall probability distribution of cumulative release to the extent practicable, does not modify the principles underlying Part 60. As was observed when NRC's final technical criteria were published in 1983 (48 FR 28204) the Commission expects that the information considered in a licensing proceeding will include probability distribution functions for the consequences of anticipated and unanticipated events."

This suggests that serious consideration was given by the NRC to a requirement that statistical distributions, which imply a knowledge of standard deviations, be employed to quantify uncertainty.

3.2.4 Update to Final Rule

In 1989, the NRC published a final rule updating 10 CFR Part 60 (NRC, 1989) to adopt ". . . procedures for implementation of the National Environmental Policy Act." These changes involved a requirement for inclusion of an environmental impact statement in the application and some changes for filing and distribution of an application. This rulemaking did not affect provisions which could be considered to apply to PFD&SHA.

3.3 STATEMENTS RELEVANT TO EXPERT OPINION

3.3.1 Staff Analysis of Public Comments on Proposed Rule

With respect to the use of expert opinion or expert judgement, the Staff Analysis of Public Comments on Proposed Rule contains two pertinent commentaries (NRC, 1983a).

> Comment No. 263: Div. of Emergency Government, State of Wisconsin (77)
>
> Page 35288, second column, "reasonable assurance" and where else it appears in the proposed rule.
>
> ""Reasonable Assurance" is a non-legal term that has evolved from the Waste Confidence Rulemaking. We are concerned that this phrase is a very subjective value judgement on the part of the Commission."
>
> Staff Response to Comment No. 263:
>
> "In dealing with risk assessments, such as those required when licensing HLW facilities, it is appropriate to provide a "reasonable assurance" standard. This indicates that the decisionmaker will not demand rigorous step-by-step proof of cause and effect, but may apply expertise to draw conclusions from imperfect data.

In the "Conclusion" to Chapter VII, there is a discussion relating to the quantification of the minimum performance of an engineered barrier to compensate for geologic-media performance uncertainties.

> ". . . the 1000 year groundwater travel time requirement is an essential component of the defense-in-depth concept as applied to waste disposal. This requirement constitutes a quantifiable criterion for the geologic setting to meet, in contrast to the remainder of the siting criteria for which compliance will be determined by expert judgement."

Nonquantitative evidence and its quality are judgmental. Therefore PFD&SHA asks for a judgment of the quality of the data which is also derived from judgement in order to provide reasonable assurance in situations where quantitative data are also a part of that assurance. Although PFD&SHA provides judgments (expert opinions) in a quantitative form, it does so more to provide a means of determining collective judgement, rather than to quantify the unquantifiable.

3.3.2 Guidance for Implementation of 40 CFR Part 191

EPA addresses the role of expert judgement in its guidance for implementation of 40 CFR Part 191 (EPA, 1983, Appendix B).

> ". . . substantial uncertainties are likely to be encountered in making predictions. In fact, sole reliance on these numerical predictions to determine compliance may not be appropriate; the implementing agencies may choose to supplement such predictions with qualitative judgements as well."

Deterministic methods of assessing hazards may fall into the latter category.

3.4 STATEMENTS RELEVANT TO UNCERTAINTIES

3.4.1 Staff Analysis of Public Comments on Proposed Rule

Considerable comment and discussion were devoted to the treatment of uncertainties. Pertinent excerpts from the Staff Analysis of Public Comments on Proposed Rule (NRC, 1983a) are quoted in the following paragraphs.

> "In practice, this means that modeling uncertainties will be reduced by projecting behavior from well understood but simpler systems which conservatively approximate the system in question."

This statement suggests that analog geologic systems of mathematical models which are more easily understood than a particular repository site, might be used to model uncertainties. PFD&SHA relies on mathematical models to project earthquake or faulting recurrence at a site. The models are typically developed from suites of data from geologic systems similar to the one whose behavior is being projected into the future.

". . . the fact-finding process is an administrative task for which the terminology of law, not science, is appropriate. The degree of certainty implied by statistical definition has never characterized the administrative process. It is particularly inappropriate where evidence is "difficult to come by, uncertain or conflicting because it is on the frontiers of scientific knowledge." Ethyl Corp v. EPA, 541 F.2d 1, 28 (D.C. Cir. 1976) (NRC, 1983a).

These examples indicate the recognition of a need to quantify uncertainty with statistics and the knowledge that this process, because of uncertainty consequent to our limited state of knowledge, may not be wholly satisfactory. PFD&SHA is a possible technique for attempting to quantify data and models where evidence is difficult to find, uncertain, or conflicting with regard to fault movement and earthquakes.

The Commission also made statements that imply that uncertainties must be based on inference (NRC, 1983a, Section 5.4):

"Expressing a requisite level of confidence in quantitative terms is far more problematical." "The licensing decisions which the Commission will be called upon to make involve additional uncertainties--those pertaining to the correctness of the models being used to describe the physical systems--which were not quantifiable by statistical methods. Conclusions as to the performance of the geologic repository and particular barriers over long periods of time must largely be based on inference; . . . "

". . . the Commission will not be able to rigorously determine probability of occurrence of an outcome that fails to satisfy the performance standards."

The following comment addresses several issues relevant to PFD&SHA; hence, its location here is somewhat arbitrary. The staff response points out that estimates from the geologic record will involve considerable uncertainty and appears to agree with most of the comment. In response to this comment and others, some of the more technically specific language proposed for Part 60 was deleted. The staff appears to concur that because of uncertainties, the degree of specificity they had proposed was inappropriate. However, it is important to note their concerns in that they contribute to an understanding of intent preceding issuance of the final regulation.

Comment No. 441: Dr. T. C. Gustavson (71)

"§ 60.123

a) 4) Reference is made to the historical earthquake record. In the midcontinent, where seismicity is diffuse and the historical record is so short as to be statistically non-existent, this criteria is not valid.

5) Fault activity is not defined

b) This criteria requires investigation to 500 m below the repository level, yet the drill holes necessary for these investigations compromise the repository integrity.

6) "Fault activity" is not defined.

8) This criteria requires dating of fractures, which are certain to be present. This is undeterminable 99.99 percent of the cases."

Staff Response to Comment No. 441:

"The stability provisions of the geologic setting performance objective have been deleted."

"As noted in this comment, evaluation of many of the geological processes or features of a site will be judgmental and potentially controversial. For this reason, the Commission has adopted a multiple barrier approach which places considerable emphasis on engineering barriers during the period when wastes are the most hazardous."

This statement makes clear that multiple barriers are intended to compensate for the fact that evaluations of geological processes will, by their nature, be judgmental and potentially controversial.

"The provision for site investigation to 500 m. below the repository level has been deleted; under 60.21(c)(1) the Safety Analysis Report must reflect results of investigations extending to a depth sufficient to determine critical pathways for radionuclide migration. We have not included a definition of "fault activity," but note that DOE must demonstrate that any such fault would not compromise the ability of the site to host a geologic repository.

Although the staff deleted a numerical requirement for the depth of investigations below the repository, they reaffirmed the need for such investigation to include critical pathways for radionuclide migration. In other statements, the staff and the NWPA make clear that faulting and seismic activity are regarded as potential critical pathways for radionuclide migration. Although the staff declined to define "fault activity" in a numerical sense, they emphasize that any fault must be demonstrated to not compromise the repository. The lack of numerical specification indicates recognition of that uncertainties exist and that flexibility is needed.

"Estimates of the likelihood of a low probability geologic event that could disrupt the repository can only be made on the basis of the geologic record for a particular site, and then will involve considerable uncertainty."

Again, the staff recognized that uncertainty exists in using the geologic record to define the occurrence of low probability events that could affect a geologic repository.

The staff further discusses uncertainties in Part C - Rationale for the Performance Objectives in 10 CFR Part 60 Chapter V (NRC, 1983) under "Uncertainties Associated with Geologic Disposal of High Level Radioactive Wastes". They recognize that, although quantitative models must be used to define the geologic system that uncertainties will exist in proposed repository models and the data gathered to implement them. The staff also states that for time periods of about 10,000 years or less, uncertainties in a geologic system that has suffered little change in the Quaternary are likely to be unimportant. A corollary is that geologic systems that have changed since the beginning of the

Quaternary Period, may have important uncertainties. The defense in depth approach, using multiple barrier systems is offered as one way in which to compensate for uncertainties.

> "Assessments of the long-term performance of such a HLW repository require the use of quantitative models, and substantial uncertainties are associated with both the models themselves and with the input data necessary for their use."

2. Uncertainties with respect to transport of radionuclides through the geologic setting.

> "Regardless of the extent to which engineering is used to contain wastes or control the release of radionuclides, the geologic setting determines the environment in which the engineering must perform its intended function. Hence the geologic setting must be characterized and understood . . ."

> "Not only must conditions in the present be favorable for waste isolation, but also there must be some assurance that the processes expected in the future at the location will have no significant adverse effect." "Inferences are made from the geologic record as to the likelihood of continued or renewed activity of geologic processes." At locations which have exhibited little change since the beginning of the Quaternary, the uncertainties in predicting the effect of geologic processes on repository performance are likely to be unimportant for time periods of about 10^4 years or less, but may become significant for longer times [Ref. 5-32 (Smith and Balderman, 1982)]."

> "However, there is a residual uncertainty as to whether a process or event might occur which is not expected or considered likely on the basis of the geologic record and which will cause the engineering to fail." "Faced with this same type of uncertainty for other licensing decisions in the past, although not to the same degree, the Commission has applied a policy of multiple protective systems. This is commonly known as the defense-in-depth approach. In the case of geologic disposal of HLW, this policy would be realized as a requirement that the site and the engineering share in the task of isolating the wastes."

> "The long history of geologic conditions provided by the geologic record permits more confident evaluation of the ability of the location to maintain some level of retardation of radionuclide into the future. Hence confidence in the geologic record compensates for uncertainty in the survivability of engineering, while confidence in containment for an initial period compensates for uncertainty in geochemical retardation."

The NRC further discusses uncertainties in Part C - Rationale for the Performance Objectives on 10 CFR Part 60 Chapter VII, Impact of Numerical Requirements on Routine Releases.

> ". . . the EPA also notes its judgement that regulation of releases for a 10,000 year interval will protect the public health and safety beyond 10,000 years."

". . . uncertainties can only be expressed as a statement of reliability or probability that the criterion will be achieved."

". . . the staff continues to conclude that the requirement to limit the release rate from the engineered system to 1 part in 100,000 per year at 1000 years is reasonably achievable, particularly in view of the Commission's statement that absolute proof of compliance is not required. The staff also notes that in proceeding from the proposed rule to the final rule the performance objectives have been stated with significantly more flexibility."

These statements suggest that quantification is necessary even though uncertainties are recognized as not being quantifiable and therefore that engineered barriers are required to compensate them (e.g. see the last quoted staff response to comment 442 above). PFD&SHA, as it is currently used, attempts to quantify uncertainties by the use of expert judgements. Such estimates of uncertainty can be extremely large and would suggest possible future conditions that have not been observed in the geologic or historic records. This aspect of PFD&SHA clearly requires additional development in light of the many, sometimes apparently conflicting statements, in regulations or responses to comments concerning them.

3.4.2 Proposed Amendments to Rule

In its proposed amendments to 10 CFR Part 60, the Commission further addressed the role and impact of uncertainties (NRC, 1986).

"The Commission anticipates that licensing decisions will be complicated by the uncertainties that are associated with predicting the behavior of a geologic repository over the thousands of years during which HLW may present hazards to public health and safety. It has chosen to address this difficulty by requiring that a DOE proposal be based on a multiple barrier approach. An engineered barrier system is required to compensate for uncertainties in predicting the performance of the geologic setting, especially during the period of high radioactivity. Similarly, because the performance of the engineered barrier system is also subject to considerable uncertainty, the geologic setting must be able to contribute significantly to isolation."

"The reasonable assurance standard is derived from the finding the Commission is required to make under the Atomic Energy Act that a license activity provide "adequate protection" to the health and safety of the public; the standard has been approved by the Supreme Court. *Power Reactor Development Co. v. Electrical Union, 367 U.S. 396, 407 (1961).* This standard, . . . allows the flexibility necessary for the Commission to make judgmental distinctions with respect to quantitative data which may have large uncertainties (in the mathematical sense) associated with it."

"The Commission expects that the information considered in a licensing proceeding will include probability distribution functions for the consequences from anticipated and unanticipated processes and events. Even if the calculated probability of meeting the Commissions standards is very high . . . the Commission would still have to

assess uncertainties associated with the models and data that had been considered. This involves qualitative as well as quantitative assessments."

"It is important to keep in mind this distinction between, first, a standard of performance, and second, the quality of evidence that is available to support a finding that the standard of performance has been met."

The distinction discussed in the last quotation, appears to be a requirement defining the quality of evidence to be input to PA. It suggests that there is a distinction between the probabilistic definition of input information and the PA process which uses this information. PFD&SHA is a process by which input to PA is developed on a probabilistic basis. This discussion, therefore, is germane to PFD&SHA which directly impacts PA which, in turn, will be used to determine compliance with the EPA standard. The above discussion seems to suggest that probabilistic estimates and their uncertainties be corroborated by checks against information concerning past occurrences of a hazard. This would provide the Commission with a basis for judging the adequacy of the mean or median result required by the EPA. Following this reasoning, the DHLWM proposes a Staff Technical Position which requires both a probabilistic and deterministic assessment of faulting and seismic hazards. PFD&SHA would provide the probabilistic assessment. A deterministic assessment is based upon past observations of faulting and earthquake hazards or their extrapolation based on geologic features.

"The licensing decisions that the Commission will be called upon to make involve additional uncertainties--those pertaining to the correctness of the models being used to describe the physical systems--which are not quantifiable by statistical methods."

". . . substantial uncertainties will be involved in the analysis of long-term repository performance. These uncertainties may include (1) identification of basic phenomena and their potential effects on repository performance, (2) development and validation of models to describe these phenomena, (3) accuracy of available data, and (4) calculational uncertainties. Various methods may be used to accommodate such uncertainties including, for example, numerical estimates of uncertainties (expressed as probability distributions) or conservative "bounding" models or data. Treatment of uncertainties will rely heavily on expert judgement, both for selection of an appropriate method and for application of that technique."

The above indicates that expert opinions and statistical analysis of uncertainty are expected components of data analysis. PFD&SHA attempts to incorporate these components.

4 CONCLUSIONS

The NWPA requires that NRC regulations comport with those of the EPA and assigns to EPA the responsibility for regulating the amount of radioactive material that may enter the biosphere. NRC rules governing HLW repositories do not directly address probabilistic assessment methods like PFD&SHA, except by reference to an EPA standard which has not yet been promulgated in final form. The draft and remanded EPA standards require addressing the probability of specific amounts of radionuclides entering the biosphere during 10,000 years after HLW disposal. In addition, NRC rules dictate certain minimum requirements, outside of a probability analysis, for a HLW repository. These additional requirements, e.g. engineered barriers, serve to compensate for uncertainties in data and analyses.

Staff resolution of comments on the NRC rule (NRC, 1983a) make clear that mathematical models of potential accident scenarios will be used to address the probabilistic consequences of fault movement, whether or not it accompanies an earthquake, on the migration of radionuclides. The staff also makes clear, as does the remanded EPA standard, that qualitative judgements (expert opinions) may have to be called upon to resolve compliance issues and that probability distribution functions of data must be considered in analyses. Uncertainties are also considered to be compensated by the defense-in-depth principle, with both engineered barriers and the geologic repository sharing responsibility for waste containment and isolation. PFD&SHA incorporates these requirements in a methodology whose hazard assessment output is compatible with PA input requirements. PA is a separate topic for which a regulatory history may be derived and is not addressed here. However, the requirements for PA are rooted in the same laws and regulations which suggest the use of a procedure like PFD&SHA.

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