Regulatory perspective on seismic PRA and margin studies

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1 INTRODUCTION

Since the completion of the Reactor Safety Study (RSS, WASH-1400) (U.S. NRC 1975), probabilistic risk assessment (PRA) techniques have been applied to several nuclear power plants to evaluate the risks resulting from their operation. The treatment of external events was extremely simplistic in the RSS. The first PRAs evaluated risks due to internal events only. The need for considering external events (particularly the risks due to seismic events) in PRAs has been recognized for some time because of the common cause effects of the external events which compromise the redundancy of safety systems. Beginning in 1978, the U.S. Nuclear Regulatory Commission (NRC) sponsored a research program - the Seismic Margin Safety Research Program (SSMRP) - to develop and apply a seismic risk analysis procedure to an operating plant. The seismic risk of the Zion Nuclear Power Plant was evaluated in the SSMRP, and a simplified procedure was developed based on these results. Currently, LaSalle, a boiling water reactor, is being analyzed using simplified SSMRP methodology.

Based on earlier studies (Newmark 1974, Ang and Newmark 1977, Cornell and Newmark 1978) and beginning with the Oyster Creek Probabilistic Safety Study (Kennedy et. al. 1980), the U.S. nuclear industry also developed an approach for seismic risk evaluation. In recent years, PRAs for a number of plants have included seismic risk evaluation (See Table 1). Currently, studies are underway to evaluate seismic risk of other plants, including a U.S. west coast plant and several boiling water reactors. From these studies, the NRC staff has gained significant insights about seismic risk and the systems and components that most significantly affect this risk.

In addition to the seismic PRAs, the NRC, through contractors, and the U.S. nuclear industry, through the Electric Power Research Institute (EPRI), have also undertaken development of methodologies to evaluate the seismic margin (i.e., to quantify the ability of a nuclear plant to withstand earthquakes greater than the design bases). Seismic margin studies, in contrast to seismic PRAs, are more directly focused on identifying plant vulnerabilities to seismic events rather than specific evaluation of the seismic risk resulting from operation of a plant. Margin studies are made with reference to discrete review level earthquakes; earthquake frequency of occurrence is not estimated and used in the evaluation. Thus, the complication of large uncertainties, which arise in results of the seismic PRA's due to difficulties in the hazard estimates, is avoided in the seismic margin studies.

This paper describes results of several seismic PRAs and margin studies, engineering insights gained from them, and the impact of these studies on the regulatory decisionmaking process.

2 INSIGHT GAINED FROM SEISMIC PRAs AND MARGIN STUDIES

Table 1 lists results from some of the recent PRAs which have been published. Some of the additional plants for which seismic PRAs or margin studies have been performed or are in progress include Midland, Diablo Canyon, Browns Ferry, Big Rock Point, Oyster Creek, Maine Yankee (margin), and Catawba (margin) plants. From the examination of Table 1 it is evident that a number of seismic PRAs have been conducted for PWRs with large dry containments, sited east of the rocky mountains.

Typically, for PWRs, the major accident sequences leading to core-melt and offsite release in seismic events include loss-of-offsite power due to low capacity of ceramic insulators, loss of service water/component cooling water, and/or loss of on-site power leading to a core-melt and late failure of containment due to overpressurization. However, note that component failures leading to this and other seismic sequences are different from plant to plant and system interactions, spatial interactions, local site conditions, and operator response play a major role. Other sequences of even lower frequencies causing releases which could contribute to the risk of early fatalities are very plant specific and unique (e.g. crane wall failure at Millstone 3, containment building failure at Indian Point 2).

For PWRs, the Nuclear Supply System (NSSS) by itself does not appear to be a leading consideration in dominant accident sequences; however, NSSS supports failures (which may affect some NSSS designs more than others) have shown up in some cases as one of the failure mode contributing to seismic risk. Distortion of reactor internals has also appeared as a potential failure mode preventing insertion of control rods. Balance of Plant (BOP) features, such as service water system, electrical power system, tanks, and spatial interactions (e.g. block walls next to safety related equipment at Oconee, relative motion between the buildings at Zion (SSMRP Study)) appear to be more critical failure modes. It is likely that older plants might be more sensitive to severe seismic events because of relatively weaker components than recent plants.

Although, the components leading to seismic induced events are plant-specific, plant functions which are essential to prevent plant damage can be deduced from PRAs. For PWRs, this approach was used in the seismic margin program and it was determined that, largely based on Westinghouse plant PRAs, reactor subcriticality and early emergency core cooling were critical functional failures leading to the core-melt. Mitigating actions such as use of the feed and bleed concept will be a function of NSSS design. The studies are currently underway to identify critical functions for Boiling Water Reactors (BWRs) from the plant damage point of view.

The high confidence, low probability of failure (HCLPF) capacities (mathematically, HCLPF capacities, in terms of earthquake levels, are approximately equal to a ninety five percent confidence on not exceeding about a five percent probability of failure) listed in Table 1 indicate that for most eastern U.S. plants, there is generally high confidence that the plant can survive earthquakes in the range up to about 0.3g with a low probability of failure leading to melting of the reactor core. Additionally, for the eastern plants (with the design basis earthquake below 0.25g), the contributions to core melt frequency are dominated by earthquakes in the range of about 2 to 4 times design levels. Based on some preliminary information on plants located in the high seismic area (e.g. Diablo Canyon), it is likely that a simple extrapolation of some of the insights obtained from the study of eastern plants, such as dominant risk contributors and the ground motion levels at which they occur, may not be appropriate.

Because of large uncertainties on the hazard estimates and fragility estimates, there exist large uncertainties about the mean core-melt estimates. For example, the NRC staff estimates (Kelly et. al. 1986) of mean seismic core damage frequency for Millstone 3 ranged from 6.0E-6 per year using the utility's (Northeast Utilities 1985) hazard curves to 1.0E-4 using an alternate set of hazard curves (Bernreuter et. al. 1984). The important point here is that there is a large amount of uncertainty (sometimes several orders of magnitude) associated with absolute estimates of hazard and any decision making based solely on these numerical measures is extremely difficult and, in some cases, misleading. Additionally, insights gained from going through the PRA process such as identifying plant vulnerabilities and procedural improvements, can be obtained without actual plant risk quantification, thus avoiding dealing with large uncertainties to some extent. As discussed in the introduction, such consideration led to the development of the seismic margin program.

The above is a very brief discussion of the insights gained from the seismic PRAs and Margins studies. Extensive discussions on insights can be found in Budnitz et. al. 1983, Ravindra and Kennedy 1983, Ravindra 1987, and Reed 1986.

3 USE OF PRAs AND MARGIN STUDIES IN LICENSING

The use of PRAs in evaluating cost/benefit ratios, technical specification changes, prioritization and other activities are well known. Here, two case studies dealing with the use of a seismic PRA and a margin study in licensing are briefly described.

3.1 Diablo Canyon - Use of a Seismic PRA

During the review of the operating license (OL) application for the Diablo Canyon Power Plant (DCPP), the Advisory Committee on Reactor Safeguard (ACRS) recommended in 1978 that "...the seismic design of Diablo Canyon be reevaluated in about 10 years taking into account applicable new information." In addition, differing interpretations of the geologic setting of the region near the plant have been put forth during the past several years. As a result, a License Condition was added to the operating license for DCPP (NRC 1984). This license condition required that the licensee of the DCPP shall: 1. evaluate all relevant geologic and seismic data, information, and interpretations that have become available since 1979 in order to update the geology, seismology, and tectonics in the region of the DCPP; 2. reevaluate the magnitude of the earthquake used to determine the seismic basis for the Diablo Canyon Nuclear Plant using the information from 1; 3. reevaluate the ground motion at the site based on the results obtained from 2 with full consideration of site and other relevant effects; and 4. assess the significance of conclusions drawn from the seismic reevaluation studies in 1, 2, and 3, utilizing a probabilistic risk analysis and deterministic studies, as necessary, to assure adequacy of seismic margins.

Currently, both the deterministic studies (items 1, 2, and 3) and the probabilistic studies are underway. The important licensing consideration here is to use the PRA to provide the perspective on the new information obtained from the deterministic studies. While the seismic PRA will utilize the updated seismic information and techniques to assess the seismic risk at DCPP, extending the scope of PRA from a seismic risk assessment to full-scope risk assessment (which includes internal events and other external events) provides some perspective on the role of seismic risk with respect to other contributors.

3.2 Millstone 3 - Use a of Seismic Margin Study

The seismic design basis approved for Millstone 3 (located in the state of Connecticut) at the construction permit stage was a Newmark type response spectrum anchored at 0.17g (U.S. NRC 1985). However, there was sufficient uncertainty associated with the causes of the 1982, body-wave-magnitude 5.75, New Brunswick earthquake that the NRC staff made a limited evaluation of the ground motion resulting from reoccurrence of that size of earthquake in the vicinity of Millstone 3. In order to address the uncertainty caused in the design basis by the New Brunswick event, the NRC staff required the applicant to utilize the results of the Millstone 3 Probabilistic Safety Study (PSS) to document the seismic capability (seismic margin study) at acceleration up to 0.25g, with high confidence of low probability of failure for individual controlling failure modes of structures and equipment.

The results of the margin study (Ravindra et. al. 1986) were reviewed by the NRC staff to address the uncertainty associated with the design basis. The study contained information on the following aspects: 1. identification of dominant contributors to seismic risk; 2. evaluation of the high-confidence, low-frequency-of-failure accelerations for critical structures and equipment; 3. evaluation of the high-confidence, low-frequency-of-failure accelerations for the dominant plant damage states; 4. evaluation of the frequencies of occurrence of significant plant damage states from seismic events; 5. evaluation of the contributions of various acceleration ranges to the frequencies of occurrence of significant plant damage states; and 6. investigation of the sensitivity of the results of the Millstone 3 PSS to variation in the assumption or analytical models employed for the seismic fragility and hazard development.

The structural/component capacities and plant damage state fragilities indicated that, except for the loss of offsite power, critical structures and components identified had high-confidence, low-frequency-of-failure accelerations in general of at least 0.3g. For the plant damage state, TE (Transient caused by loss of offsite power with failure of onsite emergency power or reactor coolant system heat removal), which is the predominant contributor to the core-melt frequency, high confidence, low probability of failure level was 0.26 (see Table 1). For the next highest contributor, plant damage state. SE (small LOCA or seismic anticipated transient without scram with failure of safety injection and containment quench sprays), the high confidence, low probability of failure level was 0.4g.

Because of the above findings, the NRC staff was able to conclude that Millstone 3 and its critical structures and components possessed significant margins beyond the design-basis level and there is a high confidence that the frequency of plant damage is significantly lower at acceleration levels less than 0.25g. Thus, the uncertainty associated with the postulated reoccurrence of an earthquake the size of the 1982 New Brunswick event in the vicinity of the plant was addressed in the licensing framework.

The above case study illustrates the use of the probabilistic concept, somewhat in a deterministic fashion, to address the licensing issue from a broader perspective and in a cost effective manner. Since significant capacity exists beyond the high confidence, low probability failure level estimate, it provides an excellent means for evaluating the impact of changing perspective on the seismic design basis. Also, the seismic margin study retains the integrated review of components, plants systems, operators actions etc.; thus it is able to provide similar insights as to the full seismic PRAs. In particular, plant vulnerabilities are identified.

4 CONCLUSIONS

1. Seismic PRAs and margin studies performed to date in the eastern U.S. indicate that aside from plant-specific outliers current deterministic design and licensing practices, in general, have resulted in seismically rugged plant with capacities well beyond design levels.

2. Although deterministic criteria result in rugged designs, true understanding of the behavior of the plant and plant vulnerabilities can only be determined by an integrated evaluation such as seismic PRAs and margin studies. In fact, seismic PRAs and margin studies have identified areas where the seismic ruggedness can and have been effectively enhanced. Further, the knowledge gained by the utility in going through this process would result in improved safety if this knowledge is disseminated within the organization.

3. Seismic PRAs and margin studies allow us to evaluate the potential benefits of a plant modification and to assess the impact of the uncertainties associated with the design basis.

4. The numerical results from seismic PRAs contain large uncertainties and without clear understanding of underlying assumptions, the direct application of these results as an absolute measure of risk could be misleading. However, the use of insights and numerical results as relative measures may be more appropriate.

5. Procedures for conducting seismic PRAs and margin studies are still evolving. Our decision making ability in face of large uncertainties needs to be improved. Rigorous analytical basis for the fragility and HCLPF calculations needs to be established. Explicit considerations of design and construction errors, aging, relay chatter effects, and operator actions under stress are beginning to get more attention. A number of studies are currently underway to address the

TABLE 1 SUMMARY OF SEISMIC PRAs

PLANT	NSS TYPE	DOMINANT CONTRIBUTORS	SEISMIC* CORE-MELT FREQUENCY	HIGH CONFIDENCE LOW PROBABILITY CAPACITY (g) (RAVINDRA, 1987)
Zion	PWR W	Service Water pumps, Aux. Bldg. shear wall, Interconnecting piping failure, pump enclosure roof, 125V DC Batteries and racks	5.7E-6	0.30
Indian Point 2	PWR W	Control Building Impact, D.G. fuel oil tank, RCS pressurizer, Unit 1 super-heater stack	1.4E-4	0.34
Indian Point 3	PWR W	D.G. fuel oil tank, RCS pressurizer	3.1E-6	0.37
Limerick	BWR,MKII	250V DC Motor control center, 125V DC distribution panel and fuse box, 4160V switchgear, reactor internals, reactor enclosure and control structure shear wall	5.8E-6	0.30
Millstone 3	PWR W	D. G. building footing, D. G. oil cooler, control building diaphragm, core geometry distortion, containment crane-wall (bypass)	8.9E-6	0.26
Seabrook	PWR W	Steam driven emergency feed pump, DC day tank, D.G.s, Random failure of D.G.s and emergency feedwater system	2.3E-5	0.30
Oconee	PWR,B&W	Condenser, Aux. Bldg. masonry walls, transformer CT4 and block house, Jocasseedam etc.	6.2E-5	Unavailable

* There exists a large uncertainties about these mean values. Alternate values also exist based on different hazard/fragility evaluations. Direct comparisons between values of different plants must be made with caution and taking large uncertainties into consideration. These values may or may not reflect plant modifications.

hazard aspects of the eastern U.S. sites.

In summary, the seismic PRAs and margin studies have already proved to be an efficient licensing tool in conjunction with other deterministic criteria. In the future, the application of PRAs and margin studies will definitely assume a larger role. For approval of a standard design the seismic PRA (along with internal and other external initiators) is already a requirement.

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