Seismic IPEEE Results and Their Use in Risk-Informed Applications

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ABSTRACT

The NRC has recently indicated "Risk-Informed" assessments should be used as the technical basis for future decisions. Accordingly, the NRC is currently changing 10CFR50 and other regulations to introduce the use of risk-informed, performance-based (RI/PB) criteria. Their objective is to focus resources on those areas which are most significant to plant risk and to maintain a comparable level of safety performance as compared to the current licensing basis. Risk Informed Regulations are intended to increase regulatory flexibility while maintaining safety performance, and allow utilities to more effectively and efficiently utilize their resources. In general, the nuclear industry fully supports the NRC RI/PB initiatives. These risk-informed criteria require inclusion of all internal and external event risks, including seismic. Three major considerations in this regard will be internal events, seismic and fire. Internal and fire events have industry programs to address the "risk-informed" process, while seismic currently does not. The seismic portion of the Individual Plant Evaluation for External Events (IPEEE) is a major building block for the development of seismic risk-informed methods since the industry has already spent considerable resources towards characterizing plant seismic risk via either a seismic margin study or a seismic PRA.

INTRODUCTION

There are two types of issues where utilities are expected to use risk-informed methods in the future, reactive and proactive:

1) Reactive – NRC asks/requires an assessment of the seismic risk effects related to specific information/data that they have been made aware:
   - Part 21 Notifications
   - Information Notices
2) Proactive – Utilities may use the "risk-informed" assessments to provide the basis for cost-effective changes
   - Power Uprates
   - Interval Increases for In-Service Inspections
   - Interval Increases for In-Service Testing
   - Graded QA for Seismic
   - Eliminate Seismic Qualification for Components not important to risk (e.g., fuel pool cooling, SFAS, containment boundary)
   - Decrease in Design Ground Motion
   - Operability Evaluations (JCO's)
   - Temporary Loads Assessment

The purpose of this paper is to document the results of the Seismic IPEEE Program and to present the elements of the EPRI research program for seismic risk-informed methods.

BACKGROUND: SEISMIC IPEEE PROGRAM

The USNRC issued Supplement 4 to Generic Letter 88-20 [1] in June 1991 requesting each licensee perform an Individual Plant Examination for External Events (IPEEE) to identify vulnerabilities, if any, to severe accidents and report the results together with any licensee determined plant improvements and corrective actions to the Commission. The NRC's stated purpose of the IPEEE program was for each licensee to:

- Develop an appreciation of severe accident behavior,
- Understand the most likely severe accident sequences that could occur at its plant under full power operating conditions,
- Gain a qualitative understanding of the overall likelihood of core damage and radioactive material release,
- Reduce the overall likelihood of core damage and radioactive material releases by modifying hardware and procedures that would help prevent or mitigate severe accidents (if necessary).

EPRI conducted a research project to study the insights gained from the seismic portion of the IPEEE program [2]. The scope of that study was to review the vast amounts of both NRC and licensee documentation from the IPEEE program and to summarize the resulting seismic IPEEE insights, including:

- Results from the Seismic IPEEE submittals
- Plant improvements/modifications as a result of the Seismic IPEEE Program
- NRC responses to the Seismic IPEEE submittals

The seismic IPEEE program was a significant undertaking by each licensee to understand the effects of a large (beyond design basis) earthquake to overall plant safety. Key results of the seismic IPEEE Programs include seismic core damage frequencies, dominant risk contributors, seismic margin levels, plant improvements, and critical components governing either plant seismic risk or plant seismic margin. Information obtained from these seismic IPEEE programs may now also prove useful to plant licensees in addressing future issues based on "risk-informed" techniques. However, it must be recognized that the IPEEE seismic reviews were conducted in a variety of ways and, in some cases, with different end objectives. Some reviews were conducted primarily to satisfy the NRC request while others were done with objectives beyond IPEEE in mind. The results obtained from the review of all available NRC documentation demonstrate that the program accomplished its intended goals defined above; however, for use in the future, such as risk-informed and performance-based applications, the NRC has identified specific areas wherein the seismic IPEEE results will likely require upgrading for some nuclear plants. EPRI's program to address both the pertinent NRC recommendations together with strategies and methods for seismic risk-informed applications are summarized within this paper.

Seismic IPEEE Results

The review results for 110 units are contained in EPRI Report TR-112932 [2]. Out of the seventy-five (75) submittals reviewed, 28 submittals (41 units) used seismic PRA methodology; 42 submittals (62 units) performed EPRI seismic margin; 3 submittals (3 units) performed NRC seismic margin evaluations; and 2 submittals (4 units) used site-specific seismic programs for IPEEE submittals as shown in Figure 1.

Seismic Core Damage Frequency Results

NUREG-1407 states that for the seismic IPEEE, it is not necessary to carry out complete uncertainty quantification defining a distribution of core damage frequencies in order to identify vulnerabilities. Mean point estimate using a single hazard curve and a single fragility curve for each component is sufficient to get insights into potential seismic vulnerabilities. The point estimate approach is valid only because the IPEEE objectives are to identify dominant sequences and components and, where possible, rank them. A histogram of mean annual seismic core damage frequencies (CDFs) of the 28 seismic PRA submittals that were reviewed in the EPRI study are shown in Figure 2. The CDFs range from 10^{-7} to 2.26×10^{-4}. Most of the plants' CDF values fall within the range of 10^{-6} to 6.0×10^{-5}. Figure 3 presents a histogram showing the ratio of seismic CDFs to internal events CDFs. About 20% of the units reported seismic CDF to be equal or greater than the internal events CDF.

Dominant Risk Contributors

The documentation guidelines of NUREG-1407 requires a description of dominant functional/systemic sequences leading to core damage along with their frequencies and percentage contribution to overall seismic core damage frequencies. All seismic PRA submittals reviewed provided descriptions of systems/sequences that contributed significantly to the overall seismic core damage frequencies. The system losses most frequently identified as being involved in the dominant sequences included the loss of offsite power, the failure of the emergency diesel generators (either seismic-induced or non-seismic), loss of the AC power system, loss of auxiliary feedwater systems, instrumentation and control system loss, and failure of NSSS.

Typically, the seismic IPEEE submittals identified individual components that were the dominant risk contributors. Figure 4 presents a histogram showing these dominant risk contributors identified in the seismic PRA submittals. The components that are most often identified as dominant risk contributors are: electrical cabinets, tanks, surrogate elements, and building structures. Seismic interactions, transformers, battery chargers, and diesel generators are the next most significant risk contributors in the submittals. Chillers/HVAC, fans, pumps, relays, cable trays, block walls, NSSS components, heat exchangers, valves, and piping rarely are seen to be dominant seismic risk contributors.

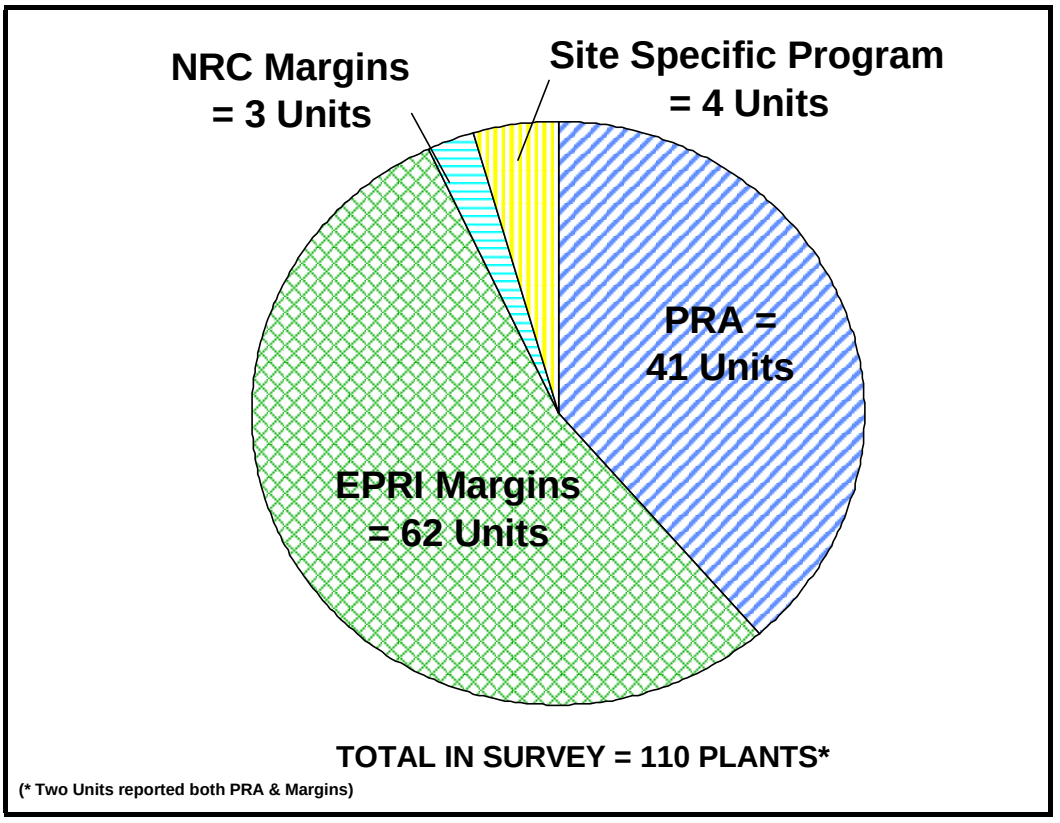

Fig. 1 Seismic IPEEE Approach Used by U.S. Utilities

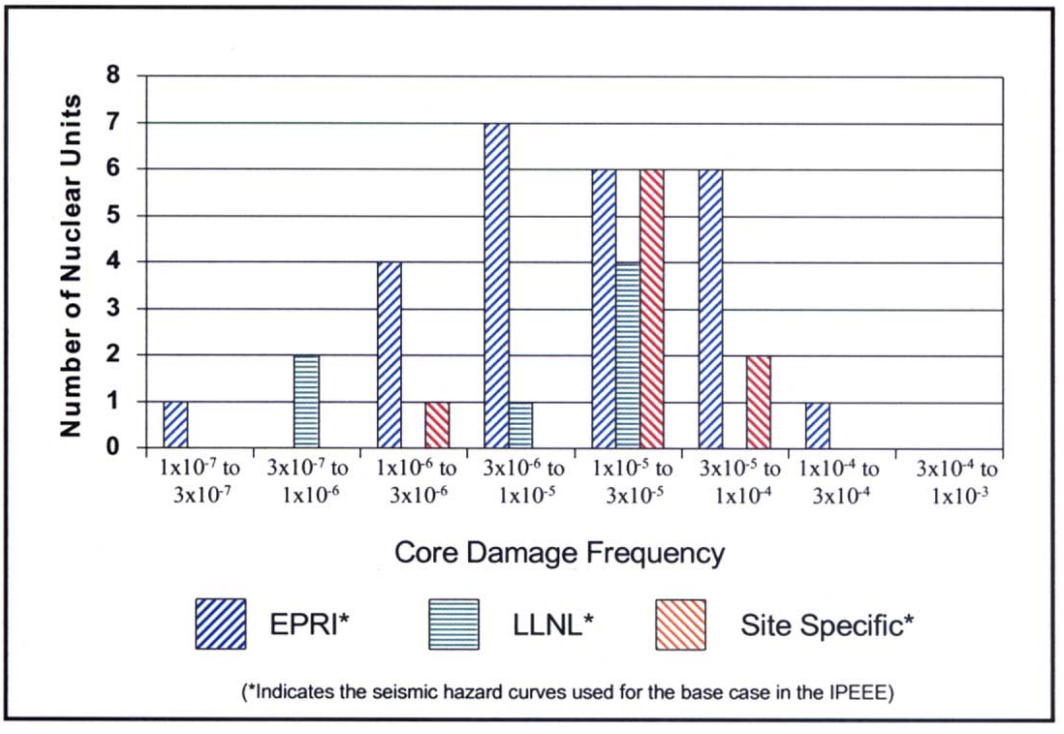

Fig. 2 Mean Seismic CDF

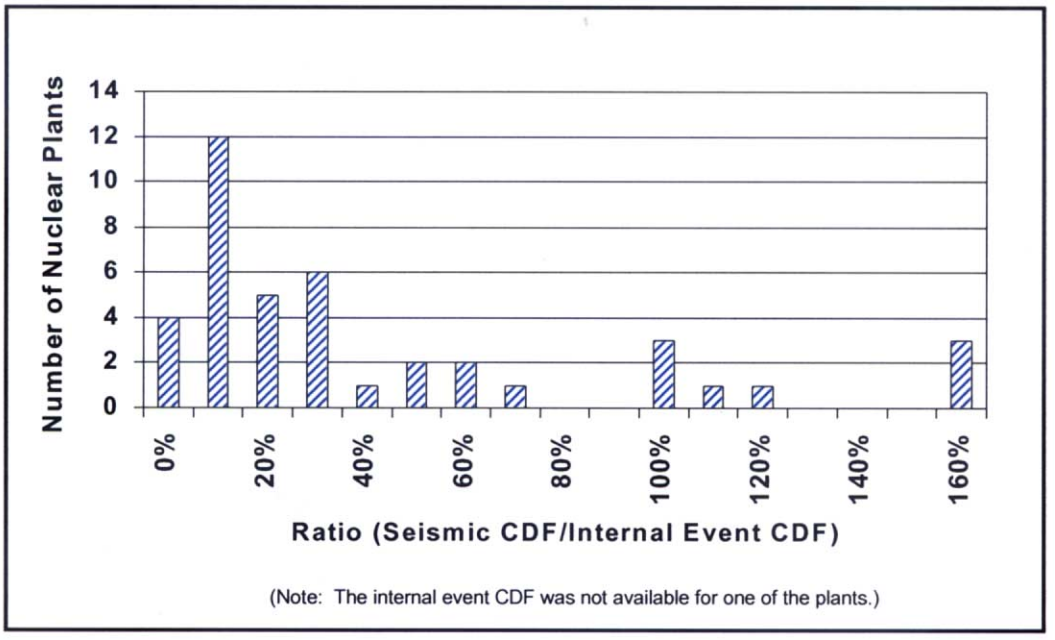

Fig. 3 Seismic/Internal Event CDFs

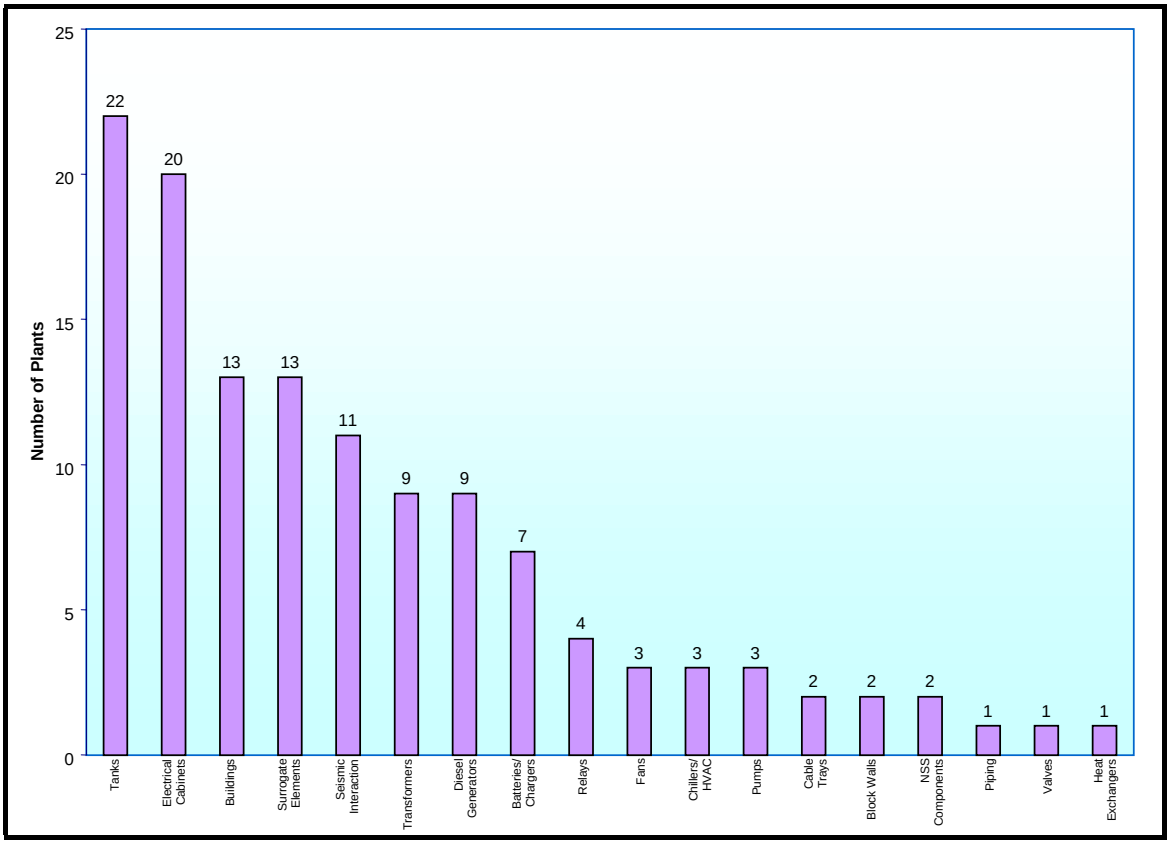

Fig. 4 Dominant Risk Contributor Components Seismic IPEEE

Seismic Margins

For those plants which chose to perform seismic margin evaluations for seismic IPEEE, either the EPRI SMA or the NRC SMA methodology was used to calculate a plant level High Confidence Low Probability of Failure (HCLPF) capacity. Both methods use the EPRI seismic walkdown procedures but use different system analysis philosophies. The NRC method is based on an event/fault tree approach to delineate accident sequences. It involves determination of the HCLPF values for individual components and the examination of Boolean expressions for accident sequences initiated by a seismic event and ending in core damage to determine the HCLPF capacity for the plant. The EPRI method is based on a systems "success path" approach. The approach defines and evaluates the capacity of a subset of components required to bring the plant to a stable condition and maintain that condition for at least 72 hours using the success path chosen. Several possible success paths may exist. Two success paths are required for the EPRI seismic margin evaluation. The plant level HCLPF capacity is defined as the lowest component HCLPF capacity in the more rugged success path.

Most of the focused or full scope plants reported plant HCLPF capacities equal to or greater than the plant review level earthquakes (e.g., 0.3g) after the resolution of USI A-46 outliers or implementation of plant improvements. Twelve (12) out of a total of 75 submittals reviewed reported plant HCLPF capacities less than the plant Review Level Earthquake (RLE). Among these, two reported plant HCLPF capacities less than the design SSE level. The significance of these values was addressed in each of the two submittals and necessary actions or improvements were taken by the utilities. For reduced-scope plants, the IPEEE evaluation is performed based on the plant's seismic margin over design SSE as would a focused or a full-scope SMA. Figure 5 presents a histogram of plant HCLPF capacities of 69 SMA units reviewed in this study. Several plants who conducted PRAs and reported plant HCLPF capacities have also been included.

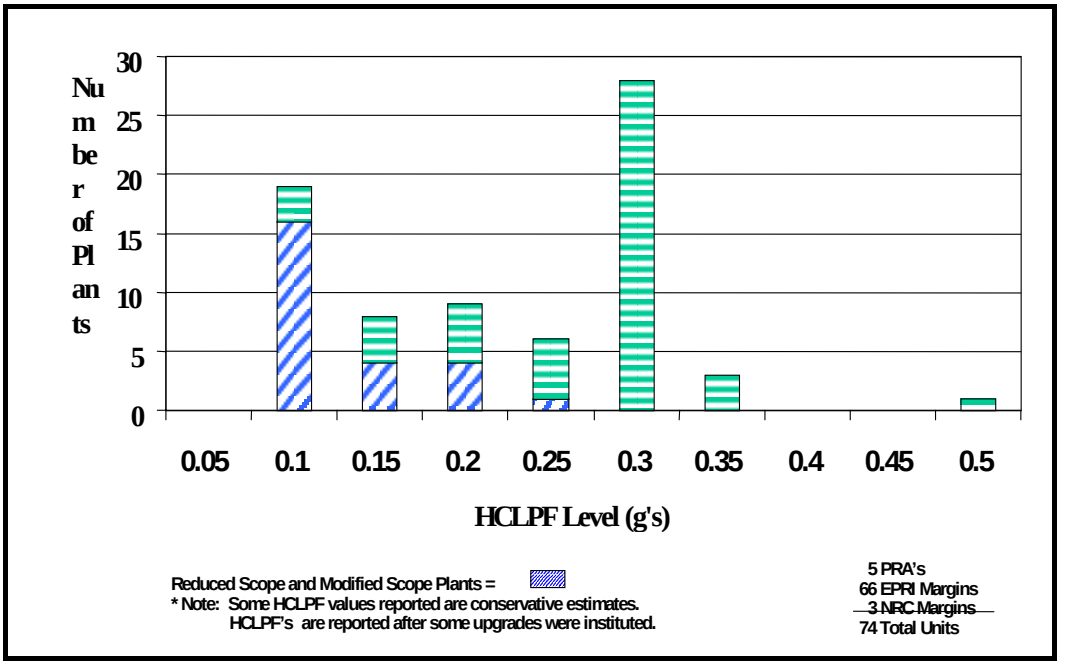

Fig. 5 Plant HCLPF Capacities of Margin Plants and Selected PRA Plants

NRC Technical Evaluation Reports

The NRC (and their contractors) performed the reviews of the Tier 1 seismic IPEEE submittals and issued RAIs for clarifications and further evaluations of specific issues. Upon reviewing utility responses to the RAIs final Technical Evaluation Reports (TERs) were issued and attached to the NRC's Safety Evaluation Reports (SERs). The following seismic IPEEE submittal weaknesses identified by the NRC are summarized from a review of 31 TERs within the EPRI program. These weaknesses are listed in the descending order of the number of times they were identified in the TERs. It is to be noted that the identified weaknesses are not necessarily intended to indicate a significant deficiency of the study with respect to the IPEEE program. Many of these weaknesses were identified with regard to using the Seismic IPEEE results for future "risk-informed" applications. A summary of the significant site-specific issues identified in the final TERs are as follows:

- Non-seismic failures and human actions were not adequately addressed, especially in the area of operator actions. Unsubstantiated assumptions regarding human error rates were used that may obscure finding on risk contributors and produce unreasonable CDF estimates. For submittals that used EPRI's seismic margin approach, non-seismic failures and

human actions were treated in a qualitative manner. Only a few submittals used screening criteria as recommended by NUREG-1407.

- Seismic/fire interaction was not adequately addressed, specifically in the areas of seismic-induced inadvertent actuation of fire protection systems and loss of fire fighting capability coincident with an earthquake.
- Seismic-induced flooding was not adequately treated, specifically on potential impacts to safety-related equipment from seismic-induced failures of non-safety tanks and piping other than firewater piping.
- Surrogate elements were used in several seismic PRA submittals to replace screened components. In some submittals, a surrogate element was found in the dominant accident sequences and, as such, it masked the resulting dominant accident sequences and risk contributors.
- The NRC felt that weaknesses resulted from plants changing the IPEEE commitment from 0.3g focused-scope to reduced-scope based on lower seismicity reported in the revised LLNL seismic hazard study.
- The spectral shapes employed in many eastern U.S. plants (SPRA submittals), which used site-specific uniform hazard spectra, resulted in the HCLPF capacity spectrum below the plant design ground response spectra such that plant seismic margin beyond the design basis cannot be demonstrated.
- Since a consistent spectral shape was not used, it would be inappropriate to directly compare capacities among PRA studies or between PRA and SMA studies. The NRC felt this was an issue with the overall seismic IPEEE criteria, not with specific plant implementation.

OVERALL NRC CONCLUSIONS, INSIGHTS AND RECOMMENDATIONS

- The NRC review process has confirmed that most of the seismic IPEEEs have involved substantial and thorough effort on the part of licensees.
- The review process has revealed considerable variability in the selection of methods for analysis, the underlying assumptions and inputs used, and the approach to and level of risk quantification employed (e.g., screening versus detailed quantification).
- While virtually all of the submittals have followed the general reporting outline recommended in NUREG-1407, within this framework there has been considerable variation in the approach to reporting, and the level of detail provided in the submittals.
- A seismic walkdown was performed for each plant, and in most cases, the walkdown identified conditions pertaining to anchorage, interactions, maintenance, and/or housekeeping that required further investigation. As a result, a number of plant-specific fixes have been implemented at many plants.
- Simplifications in systems analyses, assumptions regarding human error rates, and use of simplified screening fragilities have in some cases obscured findings pertaining to dominant seismic risk contributors, and as opposed to producing a realistic CDF estimate, have only resulted in a bound on the CDF result.
- In general, licensees have closely coordinated their USI A-46 and IPEEE seismic evaluations, including the implementation of related plant improvements.

New Insights

The NRC has reported the following examples of new insights that were gained during the screening reviews:

- A small, but notable fraction of eastern U.S. plants present a significant risk of core damage from seismic events, exhibiting seismic CDF values near $1x10^{-4}$/yr and higher, regardless of whether the EPRI or LLNL seismic hazard results are used for seismic CDF quantification.
- Even after plant improvements have been made, some plants have a HCLPF capacity spectrum that is less than the SSE demand over important vibration frequencies.
- The calculated seismic capacity of some plants can be extremely low. For instance, one plant included in this study had a PGA HCLPF capacity no greater than 0.05g and a median capacity of about 0.26g.
- The ranking of dominant contributors to risk has consistently shown (based on licensee submittals) to be insensitive to the use of the EPRI or LLNL seismic hazard curves.
- Cable trays have been identified as outliers or dominant risk contributors at a notable number of plants.
- Containment internals and control rod drive mechanisms cannot always be screened out from seismic evaluation.

Specific NRC Recommendations

- Conduct studies to assess the impact of surrogate element modeling on CDF results and dominant contributors.
- Improve the methods for assessing seismic impacts on Human Error Probabilities (HEPs) and develop guidelines to enhance relay chatter recovery actions.
- Formulate programs and guidance to mitigate identified weaknesses in seismic IPEEEs, particularly with respect to potential risk informed applications in the future.

The Future for Seismic Risk-Informed/Performance-Based Applications

The NRC is fully committed to the philosophy of expanded use of practical PRA methods and data for all regulatory activities in the future. The transition to a seismic risk-informed regulatory framework is expected to be incremental. Risk-informed regulations will be phased in and will gradually replace existing deterministic and prescriptive requirements. In order to derive the maximum benefit from this transition, the nuclear industry must develop methods and procedures to implement these new regulations in a cost-effective manner as they are promulgated. EPRI has initiated a new program to develop seismic RI/PB methods and procedures. An overall strategic plan has been developed, and the first three tasks of Phase 1 of this program have been completed [3].

The EPRI program is broken into 4 Phases as described below:

<u>Phase 1</u>

- Review ANS External Events PRA Standard
- Identify Weaknesses of Current Seismic PRAs Based on IPEEE Results
- Identify Issues Associated with Converting Seismic Margins to Seismic RI/PB Products
- Develop Seismic RI/PB Planning Document

<u>Phase 2</u>

- Survey the Industry and the NRC Relative to Technical Issues on Seismic RI/PB Methods and Applications
- Develop Recommendations for Improvement of PRA Methods
- Develop Methodology for Converting Seismic Margin Results into Seismic PRA-Type Data
- Develop of an Applications Document for Seismic PRA
- Develop of an Applications Document for Seismic Margins (Converting to RI/PB Formula)

<u>Phase 3</u>

- Perform Pilot Applications
- Perform Cost/Benefit Study on Seismic RI/PB Applications
- Provide Technical Papers to Industry Conferences

<u>Phase 4</u>

- Develop Database and Website for Seismic RI/PB Applications
- Integrate Seismic into Global RI/PB Methods
- Provide Industry Seminars and Training (Seismic RI/PB Methods)

The objectives of this program are to assess, develop, and promulgate seismic RI/PB methods to comply with, and benefit from, risk- and performance-based regulations; to provide the NRC and licensees with the framework for using seismic risk information.

REFERENCES

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