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SEISMIC QUALIFICATION OF EQUIPMENT BY MEANS OF PROBABILISTIC RISK ASSESSMENT*

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ABSTRACT

Upon the sponsorship of the Equipment Qualification Branch (EQB) of NRC, Brookhaven National Laboratory (BNL) has utilized a risk-based approach for identifying, in a generic fashion, seismically risk-sensitive equipment. It is anticipated that the conclusions drawn therefrom and the methodology employed will, in part, reconcile some of the concerns dealing with the seismic qualification of equipment in operating plants.

The approach taken augments an existing sensitivity analysis, based upon the WASH-1400 Reactor Safety Study (RSS)[1], by accounting for seismicity and component fragility with the Kennedy model[2] and by essentially including the requisite seismic data presented in the Zion Probabilistic Safety Study (ZPSS)[3]. Parametrically adjusting the seismic-related variables and ascertaining their effects on overall plant risk, core-melt probability, accident sequence probability, etc., allows one to identify those seismically risk-sensitive systems and equipment.

This paper describes the approach taken and highlights the results obtained thus far for a hypothetical pressurized water reactor (PWR).

Overall, the basic features of a seismic risk analysis must be comprised of the following elements: seismicity (seismic intensity/frequency curve) and component fragility evaluation, along with plant logic, accident sequence

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analysis, and finally consequence evaluation. Although much of the seismic-related information and attendant analysis required could have been culled from the in-depth study performed within the Seimic Safety Margins Research Program (SSMRP)[4], the existing BNL sensitivity codes were structured to preclude the easy implementation of information and techniques derived therefrom. As such, the following approach was judged more adaptable.

Seismicity and component fragility built into the code are essentially those presented in the ZPSS study. In some circumstances where component fragility data were lacking, recourse to the local fragility parameters supplied in the SSMRP subsystem fragility report[5] were incorporated after they were transformed into information related to peak ground acceleration. The composite fragility curves, as described by Kennedy, et al, were also implemented into the code.

The system-fault trees and accident sequence-event trees used in this study are similar to those of the RSS representative plant (Surry), with some modifications to include the failures of passive components and major structures. Three different sizes of Loss of Coolant Accidents (LOCAs) and Transients that lead to a reactor scram are considered as the seismic-induced initiating events. Seven different release categories are defined. It is assumed that the consequence of a release category translated to late and early fatality is the same for seismic, as well as non-seismic, initiating events. Also, the relative weighting factors rather than absolute values of the release consequences are used[6].

The common-cause nature of earthquakes are accounted for based on engineering judgement when the redundant components are oriented in the same direction and located at the same elevation (compartment). For the sake of conservatism, tight coupling is assumed, namely, the fragility curve for multiple failures is assumed to be the same as the fragility curve for single failure.

With all the foregoing modifications and information, the systems analysis code calculates the probability of relative risk for each of several ranges in peak ground acceleration. Within each range, the results generated allow one to identify those seismic risk-sensitive systems/components. Once identified, their seismic resistance is selectively changed by multiplicative factors, and a sensitivity analysis is performed to determine how those changes in component performance, during a seismic event, can impact on total risk.

The following are a select sample of results thus far obtained from this study.

Comparison between the seismic-induced effects calculated herein with the non-seismic induced effects given in RSS respectively indicates that although the core-melt frequencies and the estimated risk are about 9% and 23% of that of RSS results, the risk contribution of various release categories are quite different. The seismic-related core-melt accidents have a higher probability for leading to releases in categories 3 and 2 respectively.

Figure 1 typifies a computer-generated plot which depicts the variation in total core melt probability and total relative risk with peak ground acceleration. Consideration of seismicity in conjunction with the trends indicated allows one to draw the aforenoted conclusions.

Corresponding figures, which show the variation in overall fragility with peak ground acceleration, are also used to identify equipment, systems, and structural failures that contribute substantially to seismic risk.

A summary of results obtained thus far is provided in Table 1 which shows in a qualitative fashion the relative importance, i.e., the relative contribution of a system fragility to the increment in risk, for five ranges in peak ground acceleration. The last column in this table gives a hierarchy of system or structural failure based upon their contribution to seismic risk for the entire range in peak ground acceleration.

Investigations are proceeding for evaluating the impact associated with upgrading safety equipment on total seismic risk and for improving the overall approach.

Preliminary assessment of the results obtained thus far appear reasonable. It is anticipated that the methodology described can be utilized, along with deterministic approaches, for identifying those systems and equipment which are more seismically risk sensitive and which, therefore, may require re-qualification and upgrading. The impact associated with the degree of up-grading must be related to the benefit achieved as a result in the overall reduction in risk. However, before one can truly assess the value/impact of equipment upgrading, it would seem that the analysis should be extended to reflect the effects of uncertainties.

REFERENCES

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TABLE 1

Ranking of Systems/Structural Failures
Based on Their Relative Per Cent Contribution to Seismic Risk

	Range of Peak Ground Acceleration					
System or Structural Failure	(0.08,0.17)	(0.17,0.25)	(0.25,0.5)	(0.5,0.9)	(0.9,1.2)	(0.08,1.2)
Failure of Diesel Generator Systems	L	L	H	M	M	H
Failure of HPIS, HPRS	L	L	M	M	L	M
Failure of CHRS	L	L	M	L	L	M
Failure of AFWS	L	H	M	L	L	M
Interpiping Rupture Beneath Reactor	L	L	L	H	L	M
Auxiliary Bldg. Shear Wall Failure	L	L	L	M	L	L
Containment Duct/Roof Failure	H	L	L	L	H	L
Collapse of the Crib House	L	L	L	L	L	L
Failure of Masonry Wall	M	L	L	L	L	L
Failure of Ceramic Insulator (LOSP)	M	H	L	L	L	L
Failure of CSIS and CSRS	L	L	L	L	L	L
Failure of LPIS and LPRS	L	L	L	L	L	L

HPIS: High Pressure Injection System
HPRS: High Pressure Recirculation System
CHRS: Containment Heat Removal System
AFWS: Auxiliary Feed Water System

CSIS: Containment Spray Injection System
CSRS: Containment Spray Recirculation System
LPIS: Low Pressure Injection System
LPRS: Low Pressure Recirculation System
H: High Importance; M: Medium Importance
L: Low Importance

Fig. 1. Variation in total core melt probability and total relative risk with peak ground acceleration.