Derivation of Seismic Risk Estimates from Seismic Margin Assessments

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ABSTRACT

The objective of this study has been to ascertain whether certain risk-type safety insights can be extracted from a Seismic Margin Assessment (SMA) performed for a nuclear power plant, and to identify any limitations to the applicability of such insights. The approach has been to use as case studies the seismic analyses done by two nuclear power plants (Surry Unit 1 and Nine Mile Point Unit 2). NMP-2 possesses both an SMA and a Seismic Probabilistic Risk Assessment (SPRA), whereas Surry possesses only an SPRA. The notion tested was whether, given only an SMA, it is feasible to develop elements of a pseudo-SPRA and obtain results and safety insights typical of a full SPRA, such as seismic-initiated core-damage frequency. The conclusion of the project is that this is feasible if certain prescribed procedures are followed, but the safety insights are not as robust as could be obtained from a full SPRA. The implications of this finding for the new standard for SPRA methodology being developed by the American Nuclear Society are also explored, and requirements that might be incorporated into that standard are proposed.

INTRODUCTION

About half of the U.S. nuclear power plants satisfied the seismic requirements of the NRC's IPEEE (Individual Plant Evaluation of External Events) Program, under NRC's Generic Letter 88-20, Supplement 4, [1],[2] by performing a seismic margin assessment (SMA); the others performed a seismic probabilistic risk assessment (SPRA). An SPRA provides a full suite of risk-related results and insights that are typical of PRAs more generally - the plant core-damage frequency (CDF), the dominant accident sequences, the leading contributors to the CDF, and so on - but an SMA does not. Briefly, the objective of this study cosponsored by the American Nuclear Society and the U.S. Nuclear Regulatory Commission was to ascertain whether certain risk-type safety insights can be extracted from an SMA, and to identify any limitations to the applicability of such insights.

The project has been completed, and a full report is available [3]. This paper provides background information and summarizes the methodology and results of the project.

BACKGROUND - STATEMENT OF THE PROBLEM

When the SMA methodology was developed in the mid-1980s, the objective of the development team [4] was a method capable of providing a robust and conservative estimate of the ability of a nuclear power plant to shut down safely after an earthquake somewhat larger than the earthquake for which the plant was designed. The "bottom-line" result of an SMA is in the form of a conservative estimate of the plant's seismic capacity, the so-called "HCLPF" capacity (the capacity at which there is a High Confidence of a Low Probability of Failure). To perform the analysis, a "review level earthquake" (RLE), somewhat larger than the plant's design-basis earthquake, is selected and then used as the point-of-comparison for the plant's seismic capacity. The SMA methodology is also designed to identify whether any structures, systems, or components important for safely shutting down the plant after an earthquake have HCLPF capacities lower than the RLE. Originally, two different SMA methodologies were developed, the "NRC methodology" [4], [5] and the "EPRI methodology" [6], named after the organizations that sponsored the original work. When the NRC's IPEEE program was being carried out, most of the electric utilities that selected an SMA (rather than an SPRA) for the IPEEE program chose the EPRI methodology rather than the NRC methodology. Therefore, this study has evaluated only the EPRI SMA methodology.

Unfortunately, although the EPRI SMA methodology is well-suited to meet the objectives of the IPEEE program in that it can identify "vulnerabilities" very well, it is poorly suited for many important risk-informed applications that the utilities are now contemplating. (This is not surprising, because when the SMA method was developed, most of the applications were not envisioned.) The reason is that an EPRI SMA cannot produce a core-damage frequency estimate for accident sequences initiated by earthquakes, nor can it identify well the dominant seismic-induced accident sequences. Many risk-informed applications, both applications involving NRC regulations and applications that are not concerned with the regulatory system, require such information. (Many, fortunately, do not, and for them the results of a well-performed SMA are fully adequate.)

This limitation with the SMA approach has been known since the SMA methods were first developed about fifteen years ago. About a decade ago some ideas about how to overcome it were developed by M. K. Ravindra of EQE and Robert C. Murray of Lawrence Livermore National Laboratory [7]. However, the ideas were never pursued. Then in 1996, Richard Sherry of the staff of NRC's ACRS published a paper that formalized a slightly different approach [8]. Finally, in mid-1999 Robert P. Kennedy took Sherry's idea and the Ravindra-Murray ideas a major step further by publishing a specific proposal for a step-by-step methodology that is designed to extract an approximate CDF from an existing SMA [9]. However, until this project, the Kennedy proposal was untested. The main purpose of this project was (i) to test whether an approximate CDF, which we here call a "pseudo seismic CDF", can be extracted from an existing SMA, and (ii) to identify any limitations in the CDF information and related risk-type information that can be extracted.

BACKGROUND - THE ANS STANDARD ON EXTERNAL EVENTS PRA

The American Nuclear Society is developing a standard [10] for use of probabilistic risk assessment (PRA) techniques applicable to external events for licensed commercial nuclear power plants. The standard is being coordinated with another new standard being developed by ASME for Level 1, internal events PRA [11]. The new ANS standard is in the public-comment-period stage as this is being written (January 2001); the expectation is that it will be released in final form by summer 2001.

The new ANS Standard defines the requirements for conducting a quality PRA for external events. These include among others earthquakes, high winds, external flooding, and man-made events such as aircraft impact, nearby transportation accidents, and accidents involving nearby industrial facilities. PRAs that meet this standard will be capable of developing a reasonable estimate of baseline risk from earthquakes and other external events, as measured by criteria such as core damage frequency (CDF) and large early release frequency (LERF). The standard contains the requirements for an external event PRA that is adequate to meet the needs for risk informed decision making. A second objective of this project was to develop the basis for new requirements in the ANS External Events PRA Standard for the extraction of risk information from an SMA.

TECHNICAL APPROACH -- CASE STUDY METHODOLOGY

The approach in this project was to use two existing SPRAs as case studies. The project was fortunate to have obtained the cooperation of the staff at two nuclear plants (Surry, a PWR operated by Dominion Generation, and Nine Mile Point 2, a BWR operated by Niagara Mohawk Power Corporation). The reports from these two plants provided the technical basis for the project's work [12], [13]. An important benefit to point out is that the NMP-2 plant performed both an SPRA and an SMA when it was satisfying the IPEEE requirement, so that the back-extraction of the SMA from the SPRA was not necessary for that plant, which simplified the work.

As background, it is relatively easy to back-extract an SMA and the corresponding SMA results from an existing SPRA by some straightforward calculations. This is because nearly all of the information needed to perform an SMA is contained in an SPRA. The project plan involved doing this back-extraction using the SPRAs for the two case-study nuclear plants, and then to take the SMA information and use Kennedy's method [9] to derive a "pseudo seismic CDF" for each plant. This was then compared with the seismic CDF estimate developed more fully (more "correctly") by the SPRA. (Note that the inquiry here was limited to level-I-PRA risk insights, such as CDF. Extracting information about LERF – Large Early Release Frequency – from an SMA is much more difficult, and was not within the study's scope.

SUMMARY OF INSIGHTS --GENERIC INSIGHTS FROM THE NMP-2 AND SURRY-1 CASE STUDIES

The following three important insights, derived from the NMP-2 and Surry-1 case studies, are considered to be generic insights:

A) If in the SMA all HCLPF capacities are found to exceed the RLE screening level, and if non-seismic failures and human errors are in fact unimportant for the two SMA success paths, then a pseudo- seismic CDF will produce a reasonable and useful bounding result. Specifically, the pseudo-seismic CDF will be conservative, because the HCLPF capacities are conservatively calculated. (This is based on the NMP-2 case study.)

B) By extension: If a few important HCLPF capacities are found in the SMA to be less than the RLE screening level, then a pseudo-seismic CDF will produce a reasonable and useful result, provided (as above) that non-seismic failures and human errors are in fact unimportant for the two SMA success paths. However, the pseudo- seismic CDF may not be conservative, although the differences will likely not be large, for two possible reasons: first, contributions to the CDF from seismic failures with HCLPF capacities above the RLE are not included, and second, the fragility curves generated from the HCLPF capacities using generic β_c values may also not be conservative. (This is based on the Surry-1 case study.)

C) Earthquake-initiated accident sequences that involve both seismic failures and non-seismic failures/human errors are not systematically identified in an SMA. Hence, when deriving a pseudo-CDF from such an SMA, these sequences would not necessarily be captured unless a special effort is made to evaluate them using procedures designed to do so. (This is based on the Surry-1 case study.)

There is a way to avoid these pitfalls, which is summarized next.

CHARACTERISTICS OF AN ACCEPTABLE METHODOLOGY FOR DERIVING SPRA-TYPE RISK RESULTS FROM AN SMA

Seismic margin assessments can be thought of as falling into three categories:

1. The plant HCLPF capacity is found to be less than the RLE, and the SMA has explicitly identified one or more SSCs on the success paths having HCLPF capacities less than the RLE.
2. The plant HCLPF capacity is found to be higher than the RLE, and all of the SSCs on the success paths are screened out with HCLPF capacities greater than the RLE.
3. A so-called "reduced scope" SMA was performed using the plant's SSE as the RLE. See references [1][2] for discussions of the reduced scope approach.

For each of these categories, what follows is a step-by-step approach to deriving useful risk-type insights. This step-by-step approach comprises the principal "results" of this project.

For the First Category:

a) Assume that the SMA screening has been done conservatively, and that the screened-out SSCs do not contribute to seismic-induced CDF.

b) Use the Hybrid Method [9] to calculate the seismic CDF. Specifically, use the mean seismic hazard curve and the mean fragility curve estimated from the plant HCLPF capacity and a generically assigned β_C. It is to be noted that the CDFM-calculated HCLPF capacity is the so-called $HCLPF_{84\%}$ because the input ground motion spectrum is the 84% non-exceedance spectrum. For the seismic CDF calculation, the $HCLPF_{50\%}$ corresponding to the median ground motion spectrum should be used. This is obtained by dividing the $HCLPF_{84\%}$ by a factor between 1.22 and 1.45 [14]. Furthermore, the SMAs have been done using the NUREG/CR-0098 median spectrum for rock or soil site [15]. This shape, derived from California earthquakes, may be too conservative for the typical Eastern US site. Therefore, the $HCLPF_{50\%}$ capacity obtained above should be scaled up to reflect the difference between the RLE spectral shape and the median ground motion spectrum appropriate to the site.

c) If the calculated CDF is less than 1 E-6 per year, then the seismic contribution to the plant risk is judged to be low from a risk-informed-decision perspective. If the calculated seismic CDF is larger than 1 E-6 per year, a more realistic estimation is needed. We recommend the following (d through h):

d) For each screened-in SSC, perform a seismic fragility evaluation, following the methods described in [14] or equivalent methods, to obtain A_m, β_R and β_U or equivalently, the full family of fragility curves. Information collected in the SMA walkdown, supplemented with the median response analysis results, can be used effectively to develop these fragility curves. Typically, the number of SSCs in this group is less than 20.

e) By examining the transient event tree taken from the internal-events PRA, identify the cutsets that contain the seismic failures identified in the success paths of the SMA. The cutsets can be grouped into two different categories: Some seismic failures could lead directly to core damage (i.e., cutsets without any non-seismic failures or human errors), whereas other seismic failures may appear in cutsets that contain additional non-seismic failures and/or human errors.

f) Using the specific seismic fragilities and the non-seismic unavailabilities and human-error probabilities, quantify these cutsets. (i) For the cutsets that contain only seismic failures, the quantification will yield a family of plant-level seismic fragility curves. (ii) For each cutset containing non-seismic failures and/or human errors, the quantification will yield a different family of seismic fragility curves that is specific to that cutset.

g) We judge that the existing seismic hazard studies for the site -- usually either the updated LLNL hazard study [16] or the EPRI hazard study [17], or perhaps both -- represent the state-of-the-art and fully depict the uncertainty in the hazard estimates (i.e., the uncertainty is given). The results of one or the other of these hazard studies should be used.

h) The next step is to convolve the family of seismic hazard curves with the family of (core damage) fragility curves from (f) above to obtain the seismic CDF, which is the sum of the CDF contributions from each cutset. (The seismic CDF will be in the form of a probability distribution representing the uncertainty.)

Further refinement: A further refinement to this estimate can be obtained by constructing the seismic event tree and quantifying it to obtain the frequency distribution of different seismic damage states. The procedure is to attach this seismic

event tree to the transient event tree, to obtain the core-damage accident sequences. These are then quantified using the seismic-damage-state frequency distributions and the non-seismic unavailabilities and human-error probabilities, to produce a seismic CDF. This approach is more realistic in that it treats the successes and failures of components at any given earthquake level in a consistent manner. Of course, this approach is much closer to a full seismic PRA than the former one. The Surry SPRA was performed using this approach, and that report [12] is a useful reference and guide to how it works in practice.

For the **Second Category of SMA**, in which all SSCs on the two success paths have been screened out, an approximation to the seismic CDF can be obtained by modeling the plant level HCLPF capacity as equal to the RLE. (Note that the screening may have much built-in conservatism and thus the SSCs could have HCLPF capacities much higher than the RLE.) A generic β_C is used to develop a pseudo-mean-fragility curve from the plant-level HCLPF capacity. The resulting mean plant level fragility is convolved with the mean hazard curve to obtain a conservative approximation to the mean seismic CDF. Again, if the seismic CDF is less than 1 E-6 per year, then the seismic contribution to the plant risk is judged to be low from a risk-informed-decision perspective.

If the calculated seismic CDF is larger than 1 E-6 per year, a more realistic analysis is needed. By reviewing the walkdown and screening information and the response analysis, the analyst may identify a set of SSCs that have HCLPF capacities marginally higher than the RLE, or are known to be important from past seismic PRAs. Specific fragilities for these SSCs can then be developed and a more realistic seismic CDF calculated, as described for the first category of SMA.

The **Third Category of SMA review**, the so-called "reduced scope SMA", was performed to satisfy NRC's IPEEE requirements by a few plants located in low-seismicity regions [1], [2]. One basic difference that characterizes a reduced-scope SMA is that the plant's SSE may be used as the RLE. Other differences involve the way soils are treated, the way relay evaluation is done, and the approach to containment-system evaluation.

If a reduced scope SMA review has found that all SSCs can be screened out, an approximation to the seismic CDF can be obtained by modeling the plant-level HCLPF capacity as equal to the SSE. (Sometimes 1.25 times the SSE has been used instead of the SSE.) [18] A pseudo-mean plant-level fragility curve is then derived using a generic β_C. The resulting mean plant-level fragility is convolved with the site's mean seismic hazard curve to obtain a conservative estimate of the mean seismic CDF.

If this is less than 1 E-6 per year, then the seismic contribution to the plant risk is judged to be low from a risk-informed-decision perspective. If the estimated seismic CDF is larger than 1 E-6 per year, a more realistic analysis is needed. By reviewing the walkdown and screening information, and the design analyses, the analyst may identify a set of SSCs that have seismic HCLPF capacities marginally higher than the SSE, or are known to be important from past seismic PRAs. Specific fragilities for these components can then be developed and a more realistic seismic CDF calculated, as described for the first category of SMA.

SUMMARY AND CONCLUSIONS

The objective of the study reported here was to examine whether certain risk-type safety insights can be derived from a seismic margin assessment performed for a nuclear power plant, and to identify any limitations to the applicability of such insights. The proposed methodology [9} has been applied to two case studies. It has been found that the pseudo-seismic CDF calculated using this procedure may be generally conservative. However, the methodology will not be able to capture sysematically." the accident sequences that involve both seismic failures and non-seismic unavailabilities/ human errors. An alternative procedure tailored to different categories of SMA and acceptable range of seismic CDF has been developed.

ACKNOWLEDGMENTS

The authors wish to acknowledge the Office of Nuclear Regulatory Research of the US Nuclear Regulatory Commission, which provided funding for this project through a grant to the American Nuclear Society. N.C. Chokshi of the NRC staff served as the project's technical contact. We also thank S. Coyne-Nalbach of the ANS staff, P.J. Amico (Chair of the ANS Risk Informed Standards Consensus Committee), D. Bhargava and D.M. Bucheit of Dominion Generation (Surry), and L. Kachnik and J.H. Moody of Niagara Mohawk (Nine Mile Point-2), for supporting the project, and R.P. Kennedy, R.C. Murray, and G.S. Hardy for useful review comments on an early draft of the report

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