2

UCRL-92304
PREPRINT

CONF-850809--33

NRC SEISMIC DESIGN MARGINS PROGRAM PLAN

G.E. CUMMINGS
J.J. JOHNSON
R.J. BUDNITZ

This Paper Was Prepared for Submittal To
8th International Conference on:
Structural Mechanics in Reactor Technology

Brussels, Belgium

August 19 - 23, 1985

Lawrence Livermore National Laboratory

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

UCRL--92304

TI85 008969

NRC SEISMIC DESIGN MARGINS PROGRAM PLAN+

G.E. Cummings*, J.J. Johnson**, R.J. Budnitz***

Abstract

Recent studies estimate that seismically induced core melt comes mainly from earthquakes in the peak ground acceleration range from 2 to 4 times the safe shutdown earthquake (SSE) acceleration used in plant design. However, from the licensing perspective of the U.S. Nuclear Regulatory Commission, there is a continuing need for consideration of the inherent quantitative seismic margins because of, among other things, the changing perceptions of the seismic hazard. This paper discusses a Seismic Design Margins Program Plan, developed under the auspices of the U.S. NRC, that provides the technical basis for assessing the significance of design margins in terms of overall plant safety. The Plan will also identify potential weaknesses that might have to be addressed, and will recommend technical methods for assessing margins at existing plants. For the purposes of this program, a general definition of seismic design margin is expressed in terms of how much larger that the design basis earthquake an earthquake must be to compromise plant safety. In this context, margin needs to be determined at the plant, system/function, structure, and component levels.

+ "This work was supported by the United States Nuclear Regulatory Commission under a Memorandum of Understanding with the United States Department of Energy."

---

* Lawrence Livermore National Laboratory, Livermore, CA 94550
** Structural Mechanics Associates, Inc., San Ramon, CA 94583
*** Future Resources Associates, Inc., Berkeley, CA 94704

1. Introduction

a. General

Recent studies such as the Seismic Safety Margins Research Program (SSMRP) [1] estimate that seismically induced core melt frequencies come from earthquakes in the peak ground acceleration range from 2 to 4 times the safe shutdown earthquake (SSE) acceleration. Other studies indicate that Seismic Category I structures and PWR primary coolant piping have similar high margin against seismically induced failure. The performance of conventional power plants in past earthquakes confirms the existence of substantial seismic capacity in nuclear power plants. However, from a licensing perspective, there is a continuing need for consideration of the inherent quantitative seismic margins because of, among other things, the changing perceptions of the seismic hazard. A sound, practical seismic margins program, utilizing margins to failure analysis and seismic probabilistic risk assessment techniques would serve to minimize the need for changing regulatory requirements and licensing actions as estimates of the seismic hazards change. In addition, it can provide a sound basis for confidence in the seismic capacity of nuclear power plants and serve to indicate, if necessary, places where seismic risk should be reduced.

The Seismic Design Margins Program (SDMP) discussed in this Plan is for the use of the U.S. Nuclear Regulatory Commission (NRC) staff. The Plan will provide the technical basis for assessing the significance of design margins in terms of overall plant safety and will identify potential weaknesses that might have to be addressed. This, in conjunction with past studies and ongoing validation and fragility efforts, should be effective in resolving the quantification of seismic design margins issues.

A general definition of seismic design margin (SDM) is expressed in terms of how much larger than the design basis earthquake an earthquake must be to compromise the safety of a plant. Margin is defined at the plant level and at the level of function/system, structures, equipment and components.

b. Regulatory Needs

The staff of the U.S. Nuclear Regulatory Commission has identified the following regulatory needs in the area of seismic design margins:

(1) There is a need to understand how much SDM exists. Margin in this context is expressed in terms of how much larger than the SSE an earthquake must be to compromise the safety of the plant.

(2) There is a need to create a seismic margin framework that can filter, and to some extent absorb, the effects of changing knowledge and hypotheses in geology and seismology. This framework is needed to provide an engineering perspective and to avoid, when possible, overreaction to these changes.

(3) There is a need to understand the influence of design and construction errors, systems interactions and effects of operator behavior on the seismic response of plants.

(4) There is a need for research to understand the behavior of plants under loads induced by low-magnitude earthquakes characterized by high frequencies, short duration, and highly localized ground motion. It is recognized that the response of the plants may be qualitatively different for these earthquakes than for those for which the plants are designed. There is also a need to put into perspective the significance of increased high frequencies (above 10 Hz) for larger earthquakes.

(5) There is a need to provide additional assurance concerning the validity of the models and input data now used in seismic probabilistic risk assessments (PRAs) so as to increase confidence in the validity of PRA results.

The hierarchy is that the first need is the most important and the remaining four are secondary.

The central regulatory issue is that the safe shutdown earthquake (SSE) used for the design of plants can be exceeded with finite probability. This exceedance is due to a variety of reasons: 1) the SSE has a finite return period and thus larger earthquakes are expected but with longer return periods and 2) the shape of design spectra can be exceeded. The basis for the adequacy of the seismic design of plants thus cannot rest on the size of the SSE alone and must also rest on there being adequate SDM.

The criteria used for plant design are known to embody SDM which in most cases is believed to be large. However, this SDM primarily arises from prescriptive procedures rather than performance requirements that specify the various margins quantitatively. This means that the existence and sources of SDMs are generally known but their quantitative values are generally unknown. Since quantitative SDMs are unknown, a natural regulatory question is: "What minimum level of earthquake will compromise plant safety and where are the weakest links?"

SDMP is intended to take the next step. It will quantify the earthquake levels that could compromise plant safety as part of the process of assessing SDMs. To the extent possible this will be done by quantitative studies that will be planned to develop results with generic implications. To the extent that this generic work may fall short, SDM screening guidelines will be developed. These guidelines will be used to assess the adequacy of SDMs through various types of plant-specific reviews. Although some quantitative results on SDMs do exist, they are not based on sufficiently broad and varied studies to meet NRC needs adequately.

c. Strategy and Assumptions

The overall strategy for the SDMP relies upon a preliminary set of conclusions that seem to be a consensus in the community of knowledgeable experts familiar with seismic design margin issues. Perhaps the most important consensus is a confidence that reactors designed, built and operated according to the NRC's current regulations in most cases possess significant margin above the SSE levels for which they have been designed -- stated another way, there is a high degree of confidence that earthquakes must be significantly larger than the SSE before they will compromise the safety of the plants.

This confidence, which the SDMP hopes to confirm through specific studies (but is prepared to fail to confirm depending on how the studies turn out), has been taken into account in the development of the Plan. There is a conviction not only that such margin exists, but that it should be possible to demonstrate the existence of this margin quantitatively. Moreover, the strategy of the Plan is based on the assumption that it is possible to group the ensemble of plants into a manageable number of sub-groups, characterized by similar properties, such that statements about SDM will be feasible for each sub-group separately.

If these consensus opinions and convictions are borne out by the studies contemplated, then the result will be statements about how much SDM exists for each sub-group of plants. It is recognized that the statements about SDM resulting from this work cannot be comprehensive -- that is, they cannot cover all issues involved in the plants' seismic responses. In particular, there are a few issues (discussed separately below) for which new research is needed before their effect on margin can be stated confidently. Nevertheless, there is the expectation that there will be groups of plants, and groups of plant attributes (such as groups of structures or groups of equipment types), where statements about SDM can be made confidently.

The Plan also rests on several assumptions made as a starting point for the Plan's development. These assumptions may change as the work of the Plan evolves, and as the input of other knowledgeable parties is factored into the Plan.

(1) We assume that both deterministic and probabilistic techniques will be used to analyze how much SDM exists, and as tools in the SDM screening guidelines to be developed as part of the Plan. We also assume that plant risk, using the traditional risk end-points of PRAs (core-melt frequency, offsite risk,

etc.) will be used as the figure-of-merit for determining that plant safety is compromised in the SDM Analyses.

(2) We assume that plants, systems and components can be grouped usefully for the purpose of studying SDM.

(3) We assume that guidelines will be required to conduct plant reviews in the event SDM adequacy cannot be resolved in a generic manner.

(4) We assume that requiring plant-specific seismic PRAs as the principal vehicle for analyzing SDM at various plants is not a desirable solution to the task of finding a screening method for SDM. We assume that an approach can and will be found involving less extensive analysis, although it is possible that seismic PRAs may be needed for some plants to provide a piece of the required technical information.

(5) We assume that those accident sequences that are principal contributors to the seismic part of plant risk can be identified in a generic way insofar as there is any pattern identified among the plants.

(6) We assume that during the execution of the SDMP the validity of seismic PRAs will be established sufficiently to permit confidence in the conclusions based on their use.

2. Objective

The objective of the Seismic Design Margin Program (SDMP) is to develop the technical basis to resolve SDM issues. This will be accomplished through specific studies using both deterministic and probabilistic techniques. The SDMP has several goals:

- To define hierarchical relationships of margin at the plant, function, system, structure, equipment and component level.

- To assess the amount of SDM.

- To identify generic attributes related to SDM.

- To determine the adequacy of SDM's.

- To develop SDM screening guidelines.

This SDMP Plan is to provide a comprehensive approach (set of tasks) to address the SDMP objective and goals.

3. Scope of Work

The scope of the SDMP has been developed in two parts. Part I encompasses the body of the Program within six tasks. Part II tentatively identifies eight tasks which will provide information to help resolve SdMP issues. Part I is split into three phases. The first phase is an intensive effort of about six months duration leading to a preliminary assessment of margin adequacy and a set of trial guidelines. In Phase II trial reviews of two plants will be accomplished. Phase III continues with further plant reviews and studies dependent on the results of Phases I and II.

Part I: Assess Margin - Develop Guidelines - Trial Review of Plants

Phase I

Task I.1	Assess Existing Information
Task I.2	Estimate Existing Margins
Task I.3	Identify Generic Attributes
Task I.4	Assess Margin Adequacy
Task I.5	Develop Screening Guidelines and Methods for their Application

Phase II

Task I.6	Conduct Trial Plant Reviews

Phase III Implementation of Plant Reviews and Continuing Studies

Part II: Identification of Information Needs

Task II.1 Assess Failure Data

Task II.2 Assess Margins Information

Task II.3 Relate Capacity and Performance of Relays and Breakers During Strong Motion to Margin Issues

Task II.4 Relate the Behavior of Operators During and Immediately After Strong Motion to Margin Issues

Task II.5 Assess the Contribution of Design and Construction Errors to the Compromise of Safety

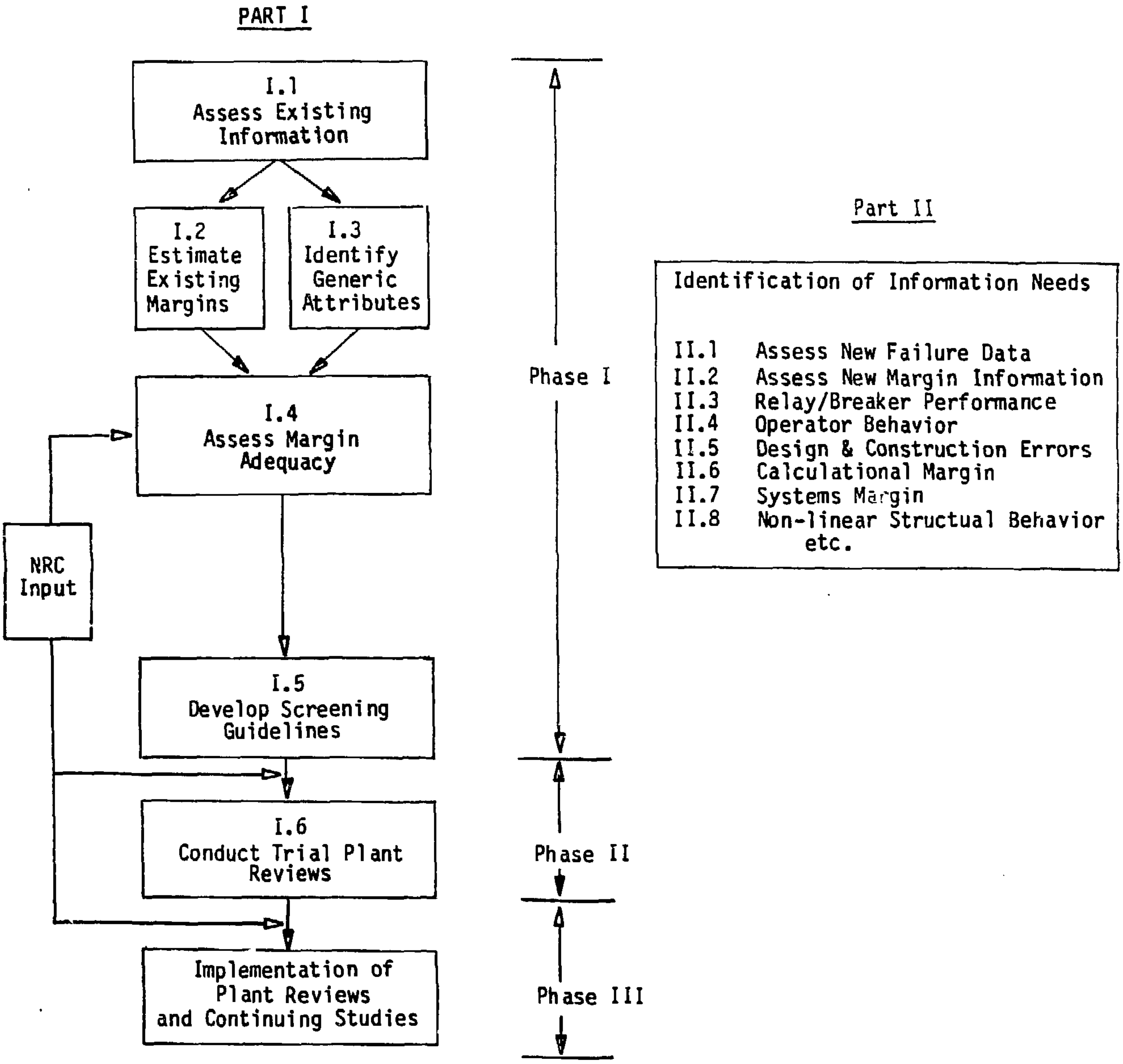
Task II.6 Assess Inherent Calculational Design Margin (best estimate vs. design code)

Task II.7 Assess the Impact of System Changes on SDM

Task II.8 Assess the Impact of Non-linear Structural Behavior on Margin Issues

The relationship between these various tasks is illustrated in the SDMP Flow Chart shown in Figure 1. The timing is aimed at resolving NRC concerns about seismic design margins in three years. To do this effectively, two trial plant reviews will be done during the first year with further work to be defined following these trial reviews.

FIGURE 1:
SDMP FLOW CHART



4. Task Descriptions

Part I: Assess Margin - Develop Guidelines - Review Plants

Phase I

Task I.1: Assessment of Existing Information.

Background. Significant information is currently available relating to SDM issues although it is known that gaps in knowledge do exist. To make sure that relevant existing information is utilized it is necessary to identify a task to assess this information. The information exists in a variety of sources although it is believed that the information most relevant to SDMP will be found in seismic PRAs. Nevertheless, all sources need to be reviewed.

Results from existing programs may give qualitative if not quantitative insights into the margins issues. Decisions and supporting studies from the Systematic Evaluation Program (SEP) [2] may help in this regard. Also, existing fragility and equipment qualification data need to be assessed. These data may give insights related to existing margin on equipment and components if not for system and plant margin. Existing earthquake experience data must be reviewed to give insights about margins in structures as well as equipment.

Over fifteen seismic PRAs will have been performed on plants in the near term. These PRAs are usually an adjunct to an internal events PRA and are a likely source of information for the determination of the adequacy of SDMs in risk terms. These plants and their PRAs are also a likely source of information for the development of SDM screening guidelines.

The SDMP approach requires a consistent set of quantified seismic PRA results. At a minimum we anticipate the use of NRC, utility and Electric Power Research Institute (EPRI) developed seismic hazard functions which will require re-quantification of the existing seismic PRA results. The sensitivity of PRA results to this hazard function will have to be tested. We also anticipate the need to examine closely the development of the plant logic models and fragility and uncertainty descriptions and the possible need to modify some of these relative to their characterization in the existing seismic PRAs. Any modifications will lead to a need for some requantification. Also, the development of SDM screening guidelines will require a close interrogation of the existing seismic PRAs in the form of sensitivity studies, uncertainty analyses and the evaluation of various alternate configurations. One of the seismic PRAs to be reviewed will be the SSMRP Zion Study [3] since this is the most comprehensive analysis and was conducted with NRC instead of utility funds. Thus, information from this study is not only the most detailed but also the most readily available. Utility seismic PRAs such as were done on Millstone 3 [4], Seabrook [5], Limerick [6], Oconee [7] and Indian Point 2 and 3 [8] will also give useful insights.

<u>Objective.</u> This task will evaluate existing information to extract that information useful to SDM issues and has two main objectives:

1. To provide information to be used to identify generic attributes, determine margin adequacy, and develop screening guidelines (Tasks I.3, I.4 and I.5).

2. To provide information to help in estimating existing margins (Task I.2). Results from Task I.2 will be used to establish what we know and don't know about existing margins.

<u>Approach.</u> The approach will be to review as much information as possible during the first phase of this Program. Further review including requantification of the existing seismic PRAs may be required later depending on Phase I findings. For Phase I, results of all studies including PRAs will be taken as stated with limited interpretation and no requantification. With this in mind, the steps in the review process will be as follows.

1. Review existing studies relating to SDM issues.

2. Review existing fragility and equipment qualification data.

3. Review existing earthquake experience data.

4. Review existing information on hazards analysis.

5. Review existing seismic PRAs (approximately 6). In Phase I, quantities of interest will be tabulated and compared on a plant, system/function, and component basis. Such quantities would include core-melt frequency, important accident sequences, systems/functions, components and structures, and earthquake level at the median failure point. This assessment will be based on the PRA results as presented with any necessary requantification determined after Phase I.

6. For each of the reviews the applicability of the results to each of the Part I tasks needs to be assessed and the findings documented in a way useful to each task.

Task I.2: Estimation of Existing Margins

Background. There is a need to establish to the extent possible what the SDM is in existing plants and particularly to establish where the uncertainties appear too great or where gaps in knowledge occur. Based on the information in Task I.1 an early determination of what these margins are will be made by this task to establish a base of knowledge from which the remainder of SDMP can be conducted.

Objective. The objective is to estimate the margins present in existing plants by estimating what size earthquake is necessary to compromise plant safety. It is desired to estimate SDMs for the plant as a whole, as well as at the system/function level, the structure level, and the component level.

Approach.

1. Identify candidate plants based on Task I.1 results for which sufficient information is thought to exist to enable an estimate of SDMs.

2. Review the analysis for each candidate plant, and develop additional specific information as needed.

3. Determining how SDM will be defined in an operational sense for the purposes of this Task, in terms of specific ground motion characteristics or other physical parameters. The definition of SDM given in the introduction to this SDM Plan is quite general: "SDM is expressed in terms of how much larger than the design basis earthquake an earthquake must be to compromise the safety of a plant".

4. Determine the SDMs for each candidate plant, including an estimate of the uncertainties in the determination. The SDMs are to be estimated at the plant level and/or the level of functions/systems, structures and components as feasible.

5. Determine, through existing sensitivity studies or new sensitivity studies to be carried out where needed, the extent to which the SDMs calculated above depend on various assumptions, models, and generic data. Particular attention must be paid to the sensitivity of the results to the shape of the hazard curve or response or fragility function curves.

6. Document the results.

Results of the Task. The results of this task will be estimates of the SDMs existing for each of a small group of candidate plants chosen because sufficient information is available upon which to base such a set of estimates. The SDMs are to be expressed where feasible at the plant, system/function, structure, and component levels. The uncertainties in the SDM estimates are to be presented and discussed, along with insights through sensitivity studies as to where the SDM estimates most depend on various assumptions, models, and generic data.

Task I.3: Identification of Generic Attributes

Background. To make the assessment of SDM as efficient as possible, generic attributes need to be identified. This will help group plants or plant systems so that further review can be better focused.

Objective. The objective of this task is to identify those generic attributes of the plants studied that seem to be important contributors to plant strength, and those that appear to contain important vulnerabilities to earthquakes. Focus should also be on identifying systems, structures and components which can be eliminated from further investigation.

This is to be accomplished, insofar as feasible, for broad groups of plants, and/or broad groups of functions, and/or broad groups of systems and components. The specific groupings are to be one result of this effort.

Approach.

1. Identify candidate generic attributes that emerge from the studies in Task I.1 and I.2.

2. For each identified candidate generic attribute, determine the extent to which the attribute is present in each of the plants studied. The focus of this effort is to achieve a rough grouping of plants and/or attributes.

3. Group the plants and/or attributes, taking into account the extent to which each plant group or attribute group possesses a high, medium, or low degree of correlation and consistency. Determine the extent to which the groupings seem 'natural' or 'forced' -- that is, whether the groupings seem to arise from some generic property of the plants or attributes that might be present in other similar plants not studied, or whether the groupings seem not to arise from any identified generic property.

4. Estimate the extent to which the groups of plants or groups of attributes might be extendable to include other plants or attributes not specifically present within the analytical information set studied.

5. Estimate the extent to which the conclusions in (3) and (4) above depend on (are sensitive to) differences in assumptions, models, or data used. Particular attention must be paid to whether the insights are sensitive to the hazard curves used or shapes of the fragility or response function curves.

6. Estimate the overall confidence in the groupings arrived at (high, medium, or low confidence, for example), based on the analyses in (4) and (5), and on the confidence thought to be present in the overall groupings.

Results of the Task. The results of this task will be identified generic attributes of plants studied that seem to be important contributors to plant strength, and that seem to be important aspects of plant vulnerability to earthquakes. For each identified generic attribute, the task will identify and discuss the sensitivity of the conclusions to assumptions, models, and data used. An overall confidence rating will be given to the groupings specified.

Task I.4: Assessment of Margin Adequacy.

Background. Based on the results of the preceding tasks, an assessment of margin adequacy needs to be made to determine the necessity for proceeding on to final guideline development or the plant review stage. It may be that margins will be found adequate at this stage or found adequate for some classes of plants, systems or components. Such a finding would eliminate or minimize the need for further effort. Close coupling with NRC will be necessary in this task since the final judgment as to adequacy of SDM must be made by the NRC. Any required additional studies are included in this task rather than in the preceding tasks.

Objective. The objectives of this task are:

1. To assist NRC by providing results for their decisions on the adequacy of SDMs.

2. To provide inputs to the development of SDM screening guidelines. (Whether or not this objective is needed will dependent on NRC decisions on whether SDMs are adequate.)

Approach.

1. Interact with NRC to finalize an approach to determine adequacy based on the experience gained in the preceding tasks.

2. Review and summarize the reports from the preceding tasks.

3. Revise this Summary or perform special studies as a result of the review in (2), as required by NRC.

4. Interact with NRC on their decision on adequacy of SDMs, as required by NRC.

Task I.5: Development of Screening Guidelines.

Background. The purpose of screening guidelines is to help determine how to proceed with plant-specific reviews and to help assess the adequacy of SDMs in these reviews. The need to develop screening guidelines necessarily rests on NRC conclusions on the technical results developed in Task I.4.

It may be necessary to revise some of the efforts that were performed in Task I.4 to reflect NRC insights that resulted from their decision process on SDM adequacy or to answer various NRC questions that arise. The primary goal of SDMP at this point is to identify screening guidelines that can be used to support an NRC finding that SDMs are adequate or inadequate at a plant for which no seismic PRA exists. It is anticipated that plants which do pass the guidelines will be judged to have adequate SDM, but those plants that fail may or may not have inadequate SDM. Additional effort will be required to determine if the SDM is not adequate, e.g., a risk assessment.

Assuming some areas are found of questionable adequacy, the key NRC decision will be the priority that will be assigned to further plant or topic reviews. Possible decision areas are plants located at sites expected to have local site amplification, plants with current or earlier seismic criteria, geographical location of plants, Westinghouse versus other PWRs, PWR versus BWR, magnitude of the risk estimates in the existing PRAs, and so forth.

There are two major factors that impact the devclopment of SDM screening guidelines:

- NRC insights as a result of Tasks I.1, I.2, I.3 and I.4 and their decision process on the adequacy of SDMs.
- A close examination of the differences between the plants or parts of plants that were and were not found to have adequate SDMs.

Close coordination with NRC will be required in this task since they play the dominant role in one of these two factors. For example, it is possible to develop guidelines relating to the adequacy of SDMs as follows:

"The seismic loads used in the design of structures shall be shown to be a factor of 2 or more times the median loads that are expected to occur assuming the occurrence of realistic earthquakes with a peak acceleration equal to the SSE."

and/or:

"The median capacity of a structure (including consideration of inelastic energy absorption) shall be shown to be 5 or more times the best estimate loads that are expected to occur assuming the occurrence of a realistic earthquake with a peak ground acceleration corresponding to the 5 x 10^{-4} per year probability level."

It is important to specify areas and forms of guidelines as completely as possible before the SDMP technical efforts in this task begin. This is because:

- The area (structural response or capacity in the above example) of applicability of the guideline must be viewed as necessary and acceptable to NRC.

- The form of the guideline (factor of 2 or 5, etc., in the above example) must also be acceptable to NRC as an appropriate one for determining adequacy of SDMs in the specific area (structural response in the example).

Note that in the above examples an additional complication arises. Specifically, most seismic design and PRA information available does not include the best estimate seismic loads for the structures. These loads would need to be calculated if NRC desired a guideline of this type.

A key issue to consider in developing guidelines is current versus earlier seismic design criteria. This is because the SDMs for plants designed to current criteria are thought to be larger than for plants designed to earlier criteria. Global guidelines are appealing as they would simplify the plant-specific SDM reviews significantly, independent of the original criteria used.

Although desirable, we anticipate that it may not be possible to develop acceptable global guidelines. One of the reasons for this is there are many site- and plant-specific features that have a significant impact on seismic risk even when the plants are designed to the same criteria. This is a widely recognized consideration in PRAs for internal-initiated events and seems likely to be true for seismic PRAs also. If this consideration is a significant factor in seismic PRAs then it means that design practice is as important or more important than design criteria. Data on the performance of non-nuclear facilities in past earthquakes tends to confirm the importance of design practice in seismic vulnerability. However, global guidelines may help in grouping plants for consideration and/or for determining which systems in plants of a certain vintage or vendor should be considered.

We thus anticipate that it may be necessary to develop SDM screening guidelines that are less global and more technical. One problem with such guidelines is that they may require significant efforts by the assessor as part of the plant-specific review. Recall that compliance with our example guideline would require the assessor to perform best estimate response analyses. Also, the uncertainty and variability within and between plants needs to be taken into account. If, for instance, the structures do not satisfy the guidelines but the piping does, then additional guidelines or a risk analysis may be required.

To reduce the ultimate burden on the assessor, the guidelines should be developed in such a way that they offer a spectrum of options and/or levels. For example, for structures, one sequence of such guidelines might be the following:

1. Structural response margins (as in the example).
2. Margin against structural yielding.
3. Margin against structural failure.

NRC staff and utility efforts in (1) could be used in (2) if the guidelines in (1) were not satisfied and those efforts in (1) and (2) could be used in (3) if the guidelines in (1) and (2) were not satisfied. All of this technical effort would be of use in a seismic PRA if the guidelines in (3) were not satisfied.

Objective. The objective of this task is to develop SDM screening guidelines.

The purpose of these guidelines is to assess the adequacy of SDMs in plant-specific reviews and to help structure the type and priority of such reviews.

Approach.

1. Develop a trial set of screening guidelines to be used in subsequent plant reviews and evaluations. The area and form should be specified in the guidelines as appropriate.

2. Develop a procedure for applying these screening guidelines for postulated plant reviews. It may be that certain classes of plants need no or minor review (for instance, post-1973 plants), it may be that only certain parts of plants need reviews (reactor coolant loop piping may have adequate margin), or it may be that plants can be grouped into broad classes (by vendor, architect/engineering firm, age, etc.).

3. Elicit NRC guidance on the proposed guidelines and method of implementation. This may involve further work in Tasks I.2, I.3, and steps (1) and (2) of this task.

4. Finalize guidelines.

5. Document guidelines and review methods.

Phase II

Task I.6: Conduct Trial Plant Reviews

Background. To meet the Regulatory Needs concerning SDM issues, it may be necessary to review plants individually or on some sort of selective group basis. The SDM reviews will be necessary if uncertainty exists concerning SDM adequacy after the completion of Task I.4. It is now believed such uncertainty will exist because current seismic risk assessments and SEP studies show that unique plant features frequently dominate risk and therefore would need to be looked at to assure margin adequacy. To test this review concept trial plant reviews will be conducted with further reviews implemented in Phase III if found necessary by NRC.

The screening guidelines and recommendations for their use from Task I.5 will be used to conduct these reviews. Detailed interaction with the NRC staff will be required not only in establishing the guidelines but in implementing the reviews. The reviews could be done in conjunction with the utilities as was done in the Seismic Qualification of Auxiliary Feedwater Systems Program.

Objective. The objective of this task is to conduct trial plant reviews and report the results so that the adequacy of margin is established.

Approach.

1. Use data from Task I.3, I.4 and I.5 to establish a plant review process (walkdowns, PRAs, systems/components to be included, plant groupings, etc.).

2. Catalog the important components and characteristics of each plant to be reviewed with annotation.

3. Do a rough assessment of each plant to establish priorities. Factors to be taken into consideration include generic attributes and work related to other NRC efforts.

4. Do more detailed reviews if required or until NRC feels the margins issue is resolved.

5. Document findings.

Phase III: Implementation of Plant Specific Reviews and Continuing Studies

At completion of the first two phases of SDMP it is anticipated that further work will be defined possibly including some further plant reviews. Although it may be necessary to do a rough assessment of all plants, detailed reviews on a representative set should be sufficient. Phase III of SMP is the conduct of further work including the implementation of additional plant reviews, as necessary, over a two year period. Details will be determined during Phase I and II. This work might include further guideline development, risk assessment or further review of those existing risk assessments including some requantification and similar work to that done in Phase I.

Part II: Identification of Information Needs

The following tasks are identified as being important to establishing actual seismic design margin including performance of the plant and operator immediately after the occurrence of an earthquake. These tasks are executed concurrently with those of Part I and provide input to the end product, i.e. the ability to make statements about seismic design margin for a specific plant or for groups of plants. Their execution may fall under a different program either within the NRC or the industry. However, they are presented here to emphasize their importance to the end objective.

Task II.1: Assessment and Development of Failure Data.

Description. Considerable seismic qualification testing has been performed using shake tables. Some informal descriptions exist of weaknesses or failures that were observed during testing. This is contrasted with the data on the observed performance of equipment in past earthquakes where few if any failures have been reported. Obtaining these qualification test results may be difficult since they may be considered proprietary. In addition, other NRC and industry programs are gathering and generating useful data concerning fragility, e.g., Component Fragility Program, Structural Fragility Program.

The objective of this task is to obtain general information on failure modes and failure levels of equipment and structures as an input to NRC decisions on the adequacy of SDMs.

The approach is to engage testing laboratories to develop reports summarizing general information on weaknesses or failures of components observed during testing. Typical information sought would be year of test, general description of component, description of failure or loss of function, excitation description, and mounting conditions. The information from all testing laboratories would be assembled for like components and added to the existing fragility data base. Candidate components for additional testing would be identified. Note that significant effort would be expended to assure confidentiality of the data and its source.

Task II.2: Assessment of Margins Information.

Description. The state of knowledge in the fields of seismic risk analysis, component and structural fragility, and systems behavior is evolving at a rapid pace. Many research programs and additional seismic PRAs are underway, or planned, with results expected in the next two to three years. These programs will provide valuable input to the seismic design margin issue and need to be explicitly recognized and included in the SDMP. The timing of their results is not compatible with the schedule for Task I.1, hence, an additional task is identified.

The objective of this task is to assess newly developed information related to seismic design margin on an ongoing basis and provide input to Tasks I.4 and I.5 of the SDMP. To do so requires identifying and monitoring research programs and other studies which are likely to provide information pertinent to the assessment of seismic design margins.

Task II.3: Assessment of the Effect on Margins of Relay and Circuit Breaker Performance During Strong Motion.

Description. Recent studies have shown that seismically-induced circuit breaker failures may inhibit the proper operation of safety systems during and after strong motion. These failures may be caused by relay chatter in the circuit breaker electrical systems. For example, inadvertant operation of the anti-pumping relays may lock out the circuit breaker. Failure of manual and test switches in these circuits may also be a problem. Such failures have been ignored in most seismic risk assessments to date, yet relay chatter can be caused by a relatively low intensity of ground motion. Therefore, the effect of relay chatter during strong motion may have a pronounced effect on system and plant SDM.

Since some circuit breakers, relays and circuits may be affected by this type of failure, the number of these and the generic implications need to be assessed.

The objective of this task is to estimate the influence on plant and system SDM of circuit breaker misoperation caused by relay chatter or switch malfunctions. An examination of nuclear power plant systems will be made to determine how prevalent are circuit breaker system designs subject to strong motion failure. If large populations of systems are susceptible to these problems, effort needs to be expended on developing their fragility functions and the consequences of their failures on plant safety.

Task II.4: Assessment of the Behavior of Operators During and Immediately After Strong Motion.

Description. Concern exists that reactor operators or the displays they monitor may be so affected by the ground motion that they will be unable to perform their required functions. Recent experimental data from Japanese tests suggests the operator may be prevented from reading and reacting to his displays at ground motions above 0.2 to 0.4 g. These tests indicate the actual level is influenced by chair design, chairs with casters being the better performers. Other efforts to assess the effect of earthquakes on operator performance are being undertaken by the NRC Office of Nuclear Regulatory Research as part of their human factors research program.

Information from these efforts as well as results from the revisits of seismic PRAs need to be assessed. From this assessment, a feeling for the relative effect of seismic induced operator error compared to various hardware and structural failures needs to be made. The overall impact of operator behavior during and after earthquakes to SDM issues can then be understood.

Task II.5: Assessment of the Effect of Design and Construction Errors on SDM Issues.

Description. The amount of seismic design margin at a plant is dependent not only on the design as envisioned but also as constructed in the field. Design and/or construction errors can play a significant role in this issue. Several reports in the literature have demonstrated the large effect that design errors can have on seismic risk and consequently on SDM. To date, however, no generally accepted, practical means of including the effects of design and construction errors in a risk calculation is available. Further, no methodology or procedure exists to identify design and construction errors outside of the current QA programs. Because design or construction errors many times lead to surprises in the performance of facilities when subjected to an earthquake, this issue needs to be addressed in the format of SDMs.

Task II.6: Assessment of Inherent Calculational Design Margin.

Description. Over the past 15 years, a significant evolution has occurred in seismic analysis and design procedures. In most cases, the evolution has been to increased design requirements introduced by the methods of seismic analysis and specification of the hazard and system parameters. Examples include:

- Seismic design ground motion defined by U.S. NRC Regulatory Guide (RG) 1.60 -- three components of motion and broad-band response spectra. [9]
- Damping values defined by U.S. NRC RG 1.61. [10]
- Control point definition at foundation level -- U.S. NRC Standard Review Plan (SRP) 3.7.2. [11]

- Broadened in-structure response spectra for equipment and piping system qualification defined by U.S. NRC RG 1.122. [12]

- Envelope procedure for analyzing multi-supported systems such as piping systems -- U.S. NRC SRP 3.9.3. [13]

- Modal combination rules for closely-spaced modes -- U.S. NRC RG 1.91. [14]

These and other requirements were introduced due to legitimate concern regarding uncertainties in analysis methods and parameter values. However, they were introduced with little consideration of their ramifications on subsequent elements in the seismic analysis chain. It is well-recognized that conservatisms compound as one moves from the seismic input - to soil-structure interaction - to structure response - to equipment and piping response. This compounding was not explicitly considered in developing new requirements. It is a major source of seismic design margin. Quantifying these margins contributes to our ability to make definitive statements concerning seismic design margin on a plant-by-plant basis or for groups of plants. In addition, it is items such as these that may be potential screening guidelines.

An effective approach to this task is first to assemble existing information on quantification of calculational margin. Also, one must identify candidate seismic design criteria (methodologies, parameter values, etc.) which introduce substantial conservatism in calculated values of response. To quantify these conservatisms, one must perform comparative calculations with best estimate technology, the result being the margin introduced by the specified calculational procedure.

Task II.7: Assessment of System Changes, Such as Added Redundancy and Enhanced Operational Modes, on SDM.

Description. Over the past 15 years, systems design has evolved as have seismic design criteria. Thoughts have evolved concerning redundancy of components, redundancy of safety systems, isolation of components, manual operation of portions of systems, power trains and isolation, etc. Changing NRC requirements have led to this evolution such as the implementation of fire protection regulations. Many of these changes may have overall plant safety consequences when considering the seismic hazard even though they were not implemented to enhance seismic safety as in TAsk II.6. Consequently, those plants with favorable systems aspects may be more reliable under the seismic hazard and this may lead to screening criteria for the SDMP.

The objective of this task is to identify systems aspects of nuclear power plants which lead to significant SDM and consequently constitute a screening criterion by themselves.

Task II.8: Assessment of the Effect of Uncertainty in Non-linear Structural Behavior on SDM Issues.

Description. In assessing seismic design margin, the realistic behavior of structures under earthquake loadings must be taken into account -- in particular, the non-linear behavior of structures. The performance of structures in past earthquakes has demonstrated the significant reserve capacity of ductile structures subjected to earthquake loadings and the poor estimates of behavior made by linear elastic predictive techniques. Currently, when non-linear behavior is taken into account, it is treated by very approximate techniques. The ductility modified response spectrum technique, originally developed by Newmark, is the most extensively used approach to date. It is based on numerous studies of single-degree-of-freedom systems but lacks correlation with physically realistic structural configurations.

The problem is clearly two-fold: data acquisition on the behavior of structures and analytical modeling of the behavior. Data acquisition is partially addressed by the NRC Category I Structures Program although for limited structure types and scale models. Additional data for full-scale structures and of differing construction are needed. Analytical techniques, adequately benchmarked, need to be developed to permit analysis of structures with significant non-linear behavior.

Seismic PRAs consider the range of possible earthquakes at the site and, hence, consider earthquakes substantially higher than the design level event. Seismic PRAs quantify structural failure predictions which become an important element in seismic risk analysis and in the assessment of seismic design margin. Non-linear structure behavior dominates these predictions and requires validation.

In addition to the effect on structure forces, non-linear structure behavior has a significant impact on the input environment to subsystems (piping systems and equipment). This needs to be taken into account when estimating their capacity for seismic PRA and seismic design margin analyses purposes.

The objective of this task is to identify and quantify the margin introduced by linear or approximate calculations for structures that respond in a non-linear way to strong seismic excitations. The approach to executing this task is a combination of data acquisition (existing and new) at the structure and structure element levels and analytical development and verification of non-linear analysis techniques. Benchmarking these techniques with existing data and application to physical structures completes the effort.

References

[1] P.D. Smith, et.al., "Seismic Safety Margins Research Program, Phase I Final Report", Lawrence Livermore National Laboratory Report UCRL-53021, also U.S. Nuclear Regulatory Commission Report NUREG/CR-2015, in 10 volumes (1981)

[2] U.S. Nuclear Regulatory Commission, "Integrated Plant Safety Assessment, Systematic Evaluation Program, Palisades Plant", Report NUREG-0820 (1982). There are seven other reports on other plants in the SEP series.

[3] Lawrence Livermore National Laboratory, "Application of the SSMRP Methodology to the Seismic Risk at the Zion Nuclear Power Plant", Report NUREG/CR-3428 (1983)

[4] Northeast Nuclear Energy Company, "Millstone Unit 3 Probabilistic Safety Study", unpublished (1983)

[5] Public Service Company of New Hampshire, "Seabrook Probabilistic Safety Study", unpublished (1984)

[6] Philadelphia Electric Company and NUS Corporation, "Severe Accident Risk Assessment, Limerick Generating Station", unpublished, (1983)

[7] Duke Power Company and Nuclear Safety Analysis Center, "Oconee PRA", Report NSAC-60 (1984)

[8] Consolidated Edison Company and New York State Power Authority, "Indian Point Probabilistic Safety Study", unpublished, (1983)

[9] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants", (1973)

[10] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", (1973)

[11] U.S. Nuclear Regulatory Commission, "Standard Review Plan", NUREG-0800, Section 3.7.2 (1981)

[12] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.122, "Development of Floor Design Response Spectra for Seismic Design of Floor-Supported Equipment or Components" (1978)

[13] U.S. Nuclear Regulatory Commission, "Standard Review Plan", Report NUREG-0800, Section 3.9.3 (1981)

[14] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.92, "Combining Modal Responses and Spatial Components in Seismic Response Analysis" (1976)

Acknowledgements

This paper is an abridged version of unpublished Report UCID-20247 by the same authors, available from the Lawrence Livermore National Laboratory, University of California, Livermore, CA 94550. This Program Plan was developed by the Expert Panel on Quantification of Seismic Design Margins in collaboration with Lawrence Livermore National Laboratory. Panel members are R. Budnitz (Chairman), P. Amico, C.A. Cornell, W. Hall, R. Kennedy and J. Reed. Other contributors were P. Smith, who formulated an earlier version of this Plan, and A. Garcia and D. Bernreuter who provided valuable assistance in reviewing the Plan. The work was supported by the U.S. Nuclear Regulatory Commission under a Memorandum of Understanding with the U.S. Department of Energy.