✓
MASTER

UCID- 17824 REV. II

Lawrence Livermore Laboratory

SEISMIC SAFETY MARGIN RESEARCH PROGRAM - PROGRAM PLAN, REVISION II

P. D. Smith
F. J. Tokarz
D. L. Bernreuter
G. E. Cummings
C. K. Chou
V. N. Vagliente
J. J. Johnson
R. G. Dong

August 11, 1978

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the laboratory.

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

DISSEMINATION OF THIS DOCUMENT IS UNLIMITED

SEISMIC SAFETY MARGIN RESEARCH PROGRAM
PROGRAM PLAN - REVISION II

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, makes contract, all subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Frank J. Tokarz, LLL Program Leader

Paul D. Smith, LLL Principal Investigator and Deputy Program Leader

James E. Richardson, NRC Program Manager

Prepared as an account of work sponsored by the U.S. Nuclear Regulatory Commission under the auspices of the U.S. Department of Energy, Contract No. W-7405-ENG-48.

28

TABLE OF CONTENTS

DESCRIPTION	Page
1.0 INTRODUCTION -----	1
2.0 OBJECTIVE -----	2
3.0 END PRODUCTS -----	3
4.0 APPROACH -----	4
4.1 Introduction -----	4
4.2 System Overview -----	6
4.3 Transfer Functions-----	10
4.4 System Network -----	15
5.0 TASK DEFINITION -----	27
Task I Plant/Site Selection -----	28
Task II Seismic Input -----	31
Subtask II.1 Expanded Data Base -----	34
Subtask II.2 Source Modeling -----	37
Subtask II.3 Attenuation -----	40
Subtask II.4 Alternate Descriptions of Motion -----	42
Subtask II.5 Develop Seismic Input -----	44
Task III Soil Structure Interaction -----	46
Subtask III.1 Soil Structure Interaction Review -----	47
Subtask III.2 Analytical Development (I) -----	50
Subtask III.3 Transfer Functions -----	51
Subtask III.4 Nonlinear Soil Structure Interaction -----	53
Task IV Structural Building Response -----	55
Subtask IV.1 Structural Building Response Review -----	56
Subtask IV.2 Analytical Development (I) -----	58

	Subtask IV.3	Structural Damping -----	59
	Subtask IV.4	Transfer Functions -----	61
	Subtask IV.5	Nonlinear Structural Response --	63
Task V		Structural Sub-System Response -----	65
	Subtask V.1	Subsystem Response Review -----	66
	Subtask V.2	Analytical Development (I) -----	68
	Subtask V.3	Subsystem Transfer Functions ---	69
	Subtask V.4	Nonlinear Subsystem Response ---	70
Task VI		Fragility -----	71
	Subtask VI.1	Component Identification -----	72
	Subtask VI.2	Test Data Collection -----	74
	Subtask VI.3	Component Fragilities -----	75
	Subtask VI.4	Loading Combination -----	77
	Subtask VI.5	Structural Fragilities -----	78
	Subtask VI.6	Design Loading Combination -----	79
Task VII		System Analysis -----	82
	Subtask VII.1	Experimental Validation of Failure -----	83
	Subtask VII.2	System Analysis Methods -----	84
	Subtask VII.3	Specification of Computational Approach -----	85
	Subtask VII.4	Probabilistic Computation Techniques -----	87
	Subtask VII.5	Event/Fault Tree Development ---	88
	Subtask VII.6	Develop Computational Procedure-	90
Task VIII		Phase II Task Definition -----	95
	Subtask VIII.1	Estimate the Conservatism in the Standard Review Plan (SRP) Seismic Design Methodology -----	96

Subtask VIII.2	Phase I Model Improvement -----	97
Subtask VIII.3	Extend the Developed Methodology to other Plants such as BWR and Western Plants -----	98
Subtask VIII.4	Develop an Improved Seismic Design Methodology Based on Probability -----	

LIST OF FIGURES

1.	Figure 1	Methodology Overview -----	20
2.	Figure 2	Typical Seismic Hazard -----	21
3.	Figure 3	Typical Output Displays -----	23
4.	Figure 4	Details of Transfer Function 1 -----	24
5.	Figure 5	Details of Transfer Function 2 -----	25
6.	Figure 6	Simple System Model -----	26

1.0 INTRODUCTION

This document has been prepared pursuant to the second meeting of the Senior Research Review Group of the Seismic Safety Margin Research Program (SSMRP), which was held on June 15,16, 1978. The major portion of the material contained herein is descriptions of specific subtasks to be performed on the SSMRP. This is preceeded by a brief discussion of the objective of the SSMRP and the approach to be used.

This document describes specific subtasks to be performed in Phase I of the SSMRP. Phase I activity will take approximately 20 months to complete.

2.0 OBJECTIVE

The overall objective of the SSMP is:

To develop mathematical models that realistically predict the probability of radioactive releases from seismically induced events in nuclear power plants.

These models will be used for four purposes:

1. To perform sensitivity studies to determine the weak links in seismic methodology. The weak links will then be improved by research and development.
2. To estimate the probability of release for a plant. It is believed that the major difficulty in the program will be to obtain acceptably small confidence limits on the probability of release.
3. To estimate the conservatism in the Standard Review Plan (SRP) seismic design methodology. This will be done by comparing the results of the SRP methodology and the methodology resulting from the research and development in 1).
4. To develop an improved seismic design methodology.

The Phase I objective is to develop mathematical models which will accomplish the purposes #1 and #2 with simplified assumptions such as linear elastic analysis, limited assessment on component fragility, considering only accident sequences leading to core melt and simplified safety system.

3.0 END PRODUCTS

There are four major categories of end products of the

SSMRP:

1. The mathematical models developed to evaluate important systems in nuclear power plants and the results of their use in terms of the probability of release.
2. The methodology developed in order to produce the models in 1). While the models in 1) will be specific to a particular nuclear power plant, the methodology, once developed, will make it a relatively straight-forward process to develop similar models for other nuclear power plants by modifying the plant unique portions.
3. The individual (rather than overall system) studies performed to obtain the inputs for the mathematical system models in 1). These studies will focus on areas such as seismic input, soil structure interaction, structural response and structural and component failure. These studies will provide short term results prior to the overall system results. In some cases, only a relatively small additional effort will be required in order to develop a product more useful for immediate NRC needs. For example, in addition to obtaining soil structure interaction results using a best estimate methodology, this will also be obtained using SRP methodology. The two sets of results will then be compared to obtain a preliminary evaluation of the SRP methodology.
4. The evaluation of the conservatism in the SRP seismic methodology using the system model.

4.0 APPROACH

4.1 Introduction

The mathematical models to be developed and then used to predict the probability of radioactive releases will include all important features of seismic and failure methodologies, including:

1. Seismic input
2. Site response
3. Soil structure interaction
4. Structural response
5. Seismic stress/strain
6. Nonseismic stress/strain
7. Combination of seismic and nonseismic stress/strain
8. Allowable/failure stress/strain/load
9. Local failure
10. Event/fault tree evaluation of overall failure in terms of the probability of release.

In order to realistically predict the probability of release, each of the above methodologies could first be characterized as rigorously as possible. This approach, however, has two major disadvantages:

1. It would require research and development along a broad front. This could mean that test programs in the areas of soil structure interaction, large structure, subsystem, and component failure, major and subsystem structural response, etc., would have to be simultaneously undertaken.
2. It would delay obtaining estimates of the probability of release until the research results were obtained.

A more cost effective approach is to determine priorities on the research and

development in the various seismic/structural methodologies and perform the most important research first, and this is the approach which has been adopted for the SSMRP.

These priorities will be determined in terms of the basic objective of the SSMRP (probability of release). That is:

1. An overall system seismic failure model of a specific plant will be developed.
2. Each of the contributing methodologies will be characterized in terms of a best estimate and associated uncertainties.
3. Methodologies which contribute most significantly to excessive uncertainties on the probability of release will be the ones selected for research and development first.

This also means the mathematical models will be refined as the program progresses. These models will have increasingly accurate representations of the contributing methodologies as the research and development results are obtained.

The Phase I effort will be simplified in a number of ways, including:

1. Linear, rather than nonlinear methods will be used for the major soil-structure interaction and structural and subsystem response results.
2. Soil-structure-to-structure interaction will not be included.
3. The safety systems to be evaluated will be simplified.

4.2 System Overview

The purpose of this section is to describe in more detail the systematic mathematical model to be developed pursuant to the major objective of the SSMRP.

As a first step, a highly simplified version of the method to be used in the SSMRP will be discussed, (Figure 1).

In this figure, four significant aspects of seismic/failure methodologies are included:

1. Free-Field Earthquake. This is a description of the earthquake environment at the nuclear power plant site in the absence of any constructed works. This environment might be described in terms of response spectra, fourier amplitude spectra, power density spectra, time histories, or even something as simple as peak velocity or acceleration.
2. Transfer Functions. Transfer functions describe how the free-field earthquake is translated into local system responses such as stress, displacement, or acceleration. In traditional seismic engineering terms, these transfer functions include the effects of soil-structure interaction, major structure and local system structural dynamic response. Transfer functions are discussed in more detail in Section 4.3.
3. Fragility Curves. Fragility curves define for the component or subsystem the probability of failure as a function of the local system response to the free-field earthquake environments.
4. System Network. The system network is a functional description which specifies the series/parallel failure relationship between components of safety related systems. The system network in

Figure 1 is a simple one having four components in series.

The system network is described in more detail in Section 4.4. Not shown in this figure is the manner in which release quantities will be obtained.

One of the most important features of the system method to be used in the SSMRP is the treatment of uncertainties in predicting the probability of release. Of the above four system inputs, only the system network must be known deterministically. The method acknowledges and accommodates finite uncertainty in modeling transfer functions, component fragilities, and earthquake environments. Uncertainty in the earthquake environment is due to our lack of knowledge of the earthquake process and inadequacies in the data base. Uncertainty in transfer functions is often due to the lack of adequate analytic or empirical models for dynamic response. For component fragilities, uncertainties are primarily a consequence of insufficient data on components at levels near or beyond failure.

Two categories of uncertainties are recognized, called random and systematic. The fundamental difference between them is that a systematic uncertainty represents potential errors of models (methodologies) and extends uniformly over a population of nuclear power plants; whereas, random uncertainties extend nonuniformly from one plant to another. Random uncertainties tend to average out over a large population of nuclear power plants, but systematic uncertainties do not. Systematic uncertainties may usually be reduced by test or analysis programs which improve models of the phenomenology and system behavior. The manner in which systematic uncertainties propagate through the model of the nuclear power plant will determine the uncertainties on the probability of release. Sensitivity studies will then be used to determine the methodology whose uncertainties contribute most significantly to excessively

large uncertainties on the probability of release. This methodology will be selected for research and development first.

The component fragility curves in Figure 1 can be used to further illustrate the differences between random and systematic uncertainties. In each of the four cases shown, the solid line represents the best estimate of failure. For example, for component 3, the critical input causing failure has been determined to be the vertical acceleration. If a number of similar components are tested, the acceleration at which they fail will vary. This is due to unintentional differences in manufacturing processes, material properties, tolerances, welding, or other factors. The best statement we can obtain in such a case, even with a large testing program, is something like, "if this component experiences a 2 g environment, about 20% of the components will fail." These results are then plotted to develop the best estimate shown by the solid line. On the other hand, for example, the test loading is only an approximation of the real environment the component will experience in service. This test loading may be known to be a conservative representation of the real environment. This is an example of a systematic uncertainty. All the systematic uncertainties are then reflected on the component failure curve by the dashed lines shown. These lines might represent 10% and 90% confidences.

Random and systematic uncertainties can occur in other areas as well. For example, consider the seismic hazard curve shown in Figure 2. This curve represents the annual probability of an earthquake occurring which could exceed a given acceleration level. Here again, the solid line is the best estimate and the dashed lines represent the uncertainty. In addition, for a given acceleration we might consider the many different time histories which could occur, all with the specified peak acceleration, to be an example of a random uncertainty.

The Monte Carlo simulation method is used to perform the release calculation. For each simulated earthquake the transfer functions are applied to predict local responses within the plant, which, in turn, are compared with the fragility curves to establish the probability of failure for each of the components. The probabilities of failure are then combined in system event/fault trees to obtain the system failure probability and then the probability and size of release. At each stage of the calculation, the free-field earthquake environments, transfer functions, and fragilities are drawn from appropriate distributions of random and systematic uncertainties.

The results of the calculations will be displayed in various formats as illustrated in Figure 3. One important display is that of plant probability of release, together with associated uncertainty, as a function of earthquake size, for example, acceleration (see the upper left of Figure 3). In the upper right of this figure is plotted the median value of the probability of release of the plant and its subsystems, as functions of acceleration. This output format will be valuable for identifying subsystems which are weak links.

The other three diagrams of the figure each show the median probability of failure of a critical subsystem, together with medians of the components, all as functions of acceleration. This format will be useful in identifying components that are weak links in a subsystem. The remaining sections will describe selected portions of the approach in more detail.

4.3 Transfer Functions

One of the four key elements of the system methodology to be used in the SSMRP (Figure 1) is the transfer function between the free-field earthquake environment and the local component or system response. Only four such transfer functions are shown in Figure 1, but a number of transfer functions will be required. This number is dependent on the number and coarseness of failure paths (event/fault trees) in the system model network.

As noted in Section 4.2, the transfer functions shown in Figure 1 include the effects of complex methodologies such as soil-structure interaction, major structure and local system structural response, and stress/strain computation. This is illustrated in Figure 4 for Transfer Function 1 (TF 1) of Figure 1. The purpose of the transfer function in Figure 4 is to allow the calculation of major structure stresses/strains in order to estimate the probability of failure (the fragility curves in the last block of Figure 4). As shown in this figure, this requires the calculation of soil-structure interaction, large structure dynamic response, the calculation of stresses (or strains) in the structure from this response, the calculation of stresses (or strains) from non-seismic loads, and the combination of these stresses (strains). Once the combined stresses (strains) are obtained, the probability of local failure can be estimated using fragility curves. These probabilities are then combined in the system network equations to obtain an estimate of the probability of overall failure and release.

In a similar manner, Figure 5 illustrates some details of Transfer Function 2 (TF 2) of Figure 1. A comparison of these two transfer functions (TF 1 in Figure 4 and TF 2 in Figure 5) will suggest some of the similarities and differences possible between transfer functions. The two transfer functions are identical in that they both would use the same process to obtain the effects

of soil-structure interaction (basemat response). The next step (large structure response analysis) would be similar but not identical in that for TF 1 the primary quantities of interest are responses in critically stressed areas of the major structure, while for TF 2 the primary quantities of interest are motion inputs at the supports of the subsystem (for example, piping) for the subsystem structural response analysis. Only TF 2 includes the additional step of subsystem structural dynamic response. The remainder of the two transfer functions are similar in that seismic and non-seismic stresses (strains) are computed and combined, but for TF 1 this is done to evaluate local failure of the major structure while for TF 2 it is done to evaluate local failure of the subsystem.

The Monte Carlo method will be used to evaluate the probability of release. This means the transfer functions will have to be exercised many times during the course of the calculations. While many of the sub-components, for example, large structure analysis, of the transfer functions illustrated in Figures 4 and 5 are complex methodologies, the manner in which they are represented in the actual transfer function will not be in the usual straightforward manner using standard computer programs such as SAPIV. This is because of the excessive computer times that would be required. It may be possible to transfer the same information content without excessive calculation as will be illustrated in the following paragraphs.

Consider the undamped equations of motion for the large structure dynamic response analysis:

$$M \ddot{x} + K x = M L \ddot{u}_g \quad (1)$$

where M is the n by n mass matrix, K is the n by n stiffness matrix, x is the

n by 1 vector of relative displacements, L is a n by 3 matrix relating the basemat accelerations to the nodal masses, and $\ddot{u}_g$ is the 3 by 1 vector of basemat orthogonal rectilinear acceleration time histories obtained from the soil structure interaction calculation. This equation could be obtained using standard finite element procedures. Using the frequency domain approach and simple matrix condensation it can be shown that the three components of motion at any point on the large structure can be obtained by an equation of the form

$$\tilde{x} = A \tilde{\ddot{u}}_g \quad (2)$$

where $\tilde{x}$ is the 3 by 1 vector of the Fourier transform of the relative displacement (output), $\tilde{\ddot{u}}_g$ is the 3 by 1 vector of the Fourier transform of the basemat acceleration time histories (input), and A is a 3 by 3 matrix (all at some frequency ω). $\tilde{x}$ and $\tilde{\ddot{u}}_g$ are necessarily composed of complex numbers, and A is complex if damping is included. The matrix A can be pre-computed prior to the Monte Carlo simulation and thus equation 2 can be evaluated during simulation with only 9 complex multiplications per frequency point. About 100 to 500 frequencies may be required so it is seen that the amount of calculation represented by equation 2 is not excessive.

The first thing to note about equation 2 is that the complexity of the actual detailed structural model from which the matrix A is obtained does not affect the calculation during the solution of equation 2. If a three-dimensional input and output is required, 9 complex multiplications are required for each frequency point evaluated, regardless of whether the structural model has 10,000 or 100 finite elements.

Second, the calculation suggested by equation 2 is not all that is required. In addition, transforms, inverse transforms, transfer of

relative accelerations to absolute accelerations, transfer of relative displacements to stresses, etc., would be required in addition to the operations suggested in equation 2. The important feature is that the calculations represented by equation 2 would be quite formidable performed in an alternate manner such as the direct use of complex computer programs and that these calculations are the bulk of those required.

Third, each of the dynamic response methodologies could be represented in a manner similar to equation 2. This includes soil-structure interaction, large structural response, and subsystem structural response.

Fourth, the calculation suggested by equation 2 is entirely equivalent to and will give exactly the same numbers as a calculation using the complex computer code. The reason calculations are not performed according to equation 2 is that for ordinary (non-simulation) applications it would require excessive computation. For example, matrix inversion is required in order to obtain the matrix A in equation 2 and this is not the most efficient way to solve equation 1.

Fifth, in order for the calculational method suggested by equation 2 to be feasible in a Monte Carlo setting, the uncertainties in the elements of matrix A must be characterized using sensitivity studies prior to the simulation calculations. This will be the major effort required in developing the transfer functions.

Finally, the precise definition of transfer functions provided by equation 2 is for the purposes of illustration only, and the actual detailed nature of the various transfer functions for SSMRP use has yet to be determined.

As a final effort at illustrating how the computation might proceed during a representative simulation, the calculational steps will be listed for TF 2 (Figure 5):

1. Random selection of free-field earthquake time histories.
2. Fourier transform of time histories.
3. Soil-structure interaction response (selection of the 9 parameters of the matrix A and the application of an equation like 2 to the transforms in 2).
4. Large structural dynamic response (selection of the 9 parameters of the matrix A and the application of an equation like 2 to the transforms resulting from 3). This will have to be done for a number of cases depending on the number of subsystem supports.
5. Calculation of absolute acceleration response at subsystem supports and then Fourier transform.
6. Subsystem structural dynamic response (selection of the 9 parameters of the matrix A and the application of an equation like 2 to the transforms resulting from 5). This will have to be done for a number of cases depending on the number of subsystem supports and number of critical locations.
7. Inverse Fourier transform of the results of 5 to obtain displacement time histories.
8. Calculations of stresses using the results of 6.

4.4 System Network

A second key element of the system methodology to be used in the SSMP (Figure 1) is the system network. The system network shown in Figure 1 is quite simple (a series of four components) but more complex networks will be required in the nuclear power plant evaluation.

A somewhat more complex model of a system network for a specific failure is shown in Figure 6. This example is taken from a recent paper by Cornell and Newmark. This model is a simplified version of a more detailed one in the Reactor Safety Study for PWRs.

The reasoning behind this model is as follows:

The earthquake will likely lead to the loss of off-site power and this in turn will probably lead to a transient. The main feed water system is not seismically designed and is thus likely to be lost at high seismic levels. Loss of containment by over pressure can then occur if the auxiliary feed water system fails.

The model in Figure 6 assumes the auxiliary feed water system fails if (1) all three of the three stored water facilities or (2) all three pumps fail. One pump is driven by turbine and the other two by electricity. The accident sequence assumes the loss of off-site power and thus the electrically driven pumps depend on one of the two diesel generators operating. We stress that this model is a simplified one presented for the purposes of illustration only. It is simplified in a number of ways including (1) it is a part of only one sequence leading to a release, and (2) much detail (piping, valves, control systems, etc.) has been omitted.

It will be useful to illustrate how failure probabilities are calculated using diagrams like those in Figure 6. For a subsystem with only

components in series, a failure of any one of them will cause subsystem failure. Thus, if a subsystem SS1 is composed of only two components in series, C101 and C102, and the probability of failure of these components is P_{101} and P_{102} , respectively, then the probability this subsystem fails is

$$P_{SS1} = 1 - (1 - P_{101})(1 - P_{102})$$

For a subsystem SS2 with two components in parallel, C201 and C202, the probability of its failure assuming independence of events is

$$P_{SS2} = P_{201}P_{202}$$

Using these relations, the probability of failure of the system shown in Figure 6 is

$$P_{SS6} = 1 - \left\{ 1 - \left\{ 1 - (1 - P_{G1}P_{G2}) (1 - P_{EP1}P_{EP2}) \right\} P_{TP} \right\} \left\{ 1 - P_{ST1}P_{ST2}P_{ST3} \right\} \quad (3)$$

where P_{SS6} is the probability of failure of the system shown in Figure 6, P_{G1} and P_{G2} are the failure probabilities of the two generators, P_{EP1} and P_{EP2} are the failure probabilities of the electrically operated pumps, P_{TP} is the failure probability of the turbine pump, and P_{ST1} , P_{ST2} and P_{ST3} are the failure probabilities of the three stored water facilities.

We will illustrate how the Monte Carlo simulation might proceed using a simple example:

1. We will assume that the only random distribution from which Monte Carlo trials will be selected is the free-field earthquake time history. That is, at any given acceleration level, say 0.2g, the realistic time histories of the earthquake that might occur

could be any one of a large set of time histories. Each of the time histories in this set would vary in specific details, such as spectral content at a given frequency, but each would have a peak acceleration of 0.2g.

2. We will illustrate the calculation for only one acceleration level, viz 0.2g, and we will assume the best estimate value of the probability for an earthquake of this acceleration level is 10^{-4} per year (solid line in Figure 2).
3. For each time history selected, transfer functions like those illustrated in Figures 4 and 5 would be used to obtain local component loads and then the probability of failure of these components. The variation in the probability of failure due to random variations in time histories alone is not expected to be small. For example, we estimate the details in time histories of this type to lead to about an order of magnitude variation in floor spectra at various frequencies. This implies a similar variation in component loads is possible. These probabilities are then combined as in equation 3 to obtain system failure probability.
4. The probability of system failures calculated in 3 is then multiplied by 10^{-4} (the probability of the earthquake).
5. For each time history selected we calculate a probability of failure in 4 and these probabilities are used to estimate a mean probability of failure which we will assume to be 10^{-6} per year. If a large enough set of time histories are used, (sufficient Monte Carlo trials) the traditional confidence limits on this mean could be quite small, for example, we may

have results suggesting the mean failure probability to be 0.99 to 1.01 times 10^{-6} per year with 90% confidence.

6. The difficulty with confidence limits of the type suggested in 4 is that they are misleading. The major factor that has been ignored is the uncertainty in the probability of the earthquake (the dashed lines in Figure 2). If we include this uncertainty in the calculation we might end up with a best estimate of the probability of failure at 10^{-6} per year (as before) with 90% confidence this probability is in the range of 10^{-3} to 10^{-9} . This range of probabilities indicates how the uncertainties in the seismic input propagate through the system seismic/failure model.

This example is highly simplified in that only one element (the seismic input) has been assumed to have both random and systematic uncertainties. As noted above, other elements (such as transfer functions and fragilities) will also be assumed to have these uncertainties in the models used in the SSMRP. Sensitivity studies will be used to determine which of these uncertainties most affect probability ranges such as those in 6 above in order to determine priorities for research and development.

In the example given (uncertainties only in the seismic input), the uncertainties in the earthquake probability entered in the calculation in a particular simple multiplicative way. In the more comprehensive and realistic models to be used in the SSMRP, the propagation of these uncertainties will not be as simple.

If in addition to the above sequence of steps we also vary the peak acceleration, we will then obtain the probability of failure over the acceleration range of interest.

Finally, the SSMRP method will go one step further than illustrated in the above example. That is, the probability and size of the radioactive release will also be estimated.

Fig. 1. System methodology overview.

Fig. 2. Typical seismic hazard format.

Fig. 3. Typical output displays.

Fig. 4. Details of transfer function 1.

Fig. 5. Details of transfer function 2.

Fig. 6a. System block diagram.

Fig. 6b. System fault tree.

Fig. 6. Simple system model.

5.0 TASK DEFINITION

Eight separate tasks are included in the program. They are:

- I. Plant/Site Selection
- II. Seismic Input
- III. Soil-Structure Interaction
- IV. Structural Building Response
- V. Structural Subsystem Response
- VI. Fragility
- VII. System Analysis
- VIII. Phase II Task Definition

Each of these eight tasks are described in the following paragraphs. Note that while these tasks are comprehensive in that they generally describe all major areas of effort in the entire program, the subtasks described below are not complete. That is, the subtasks included herein define work to be accomplished over the next 20 months or so. As work on the program progresses, additional subtasks will be defined as required.

5.1.0 Task I Plant/Site Selection

The selection of a plant and site for the SSMRP effort is critical. A specific plant will be selected by the JIC in the near future. However, this task is still required in order to develop information to place this selection in context with other potential plants, assist the selection of a back-up plant, should one be required, and begin the definition of the precise types of data required for the plant ultimately selected for the SSMRP.

5.1.1 Task I - Plant/Site Selection

A. Objective

The objective of this task is to select the specific plant and site on which detailed evaluations will be performed. The early phase of this task is to select the first such plant and site and later phases will select subsequent plants and sites.

B. Background

There are a myriad of details to be considered in a realistic seismic assessment of a nuclear power plant such as being performed on this program. As a first step, rather than attempting to define a generic plant and site and provide a basis and defense for each decision, it is much simpler and adds realism to choose a specific plant and site.

C. Problem Definition

The existing fault-tree work on the Reactor Safety Study (and Diablo Canyon for PWRs) makes the selection of one of these plants an attractive choice for the initial plant selection. The evaluation will require a significant amount of effort in addition to fault tree work, so the simplification of fault tree development tasks by choosing one of these plants should be carefully weighed against subsequent task requirements.

Our preliminary decision is to select a PWR rather than a BWR plant but this decision requires more careful consideration.

Considerable detailed information on the plant will be required and the willingness of a utility to provide such information is necessary.

NRC support and assistance in obtaining utility cooperation is required.

We must define the amount, type, and quality of the information required for each potential plant/site.

D. Approach

Our approach to this task is the following:

1. Define type, quality, and quantity of desired data (site data, seismic data, structural data, design specifications, test data, system descriptions, etc.).
2. Review and screen existing and proposed plants (telephonic or written communication and meetings with NRC, A&Es, EPRI, and consultants; review of docketed material).
3. Revision of 1.
4. Preliminary selection of candidate plants and sites.
5. Detailed discussions between NRC, LLL, and selected utilities.
6. *Final selection of specific plant(s) and site(s).*
7. Definition of specific sub-contracts to obtain required information.

5.2.0 Task II Seismic Input

The objective of this task is to develop a probabilistic statement of the seismic hazard. For example a typical definition of this hazard would be a curve relating the annual probability of an earthquake occurring with a peak acceleration exceeding a given value (Figure 2). The first requirement on such curves for the SSMRP is that they are realistic (rather than conservative) and that the confidence limits on them are known and as small as practical.

It is important to define the seismic hazard accurately because all failures are conditional on the occurrence of an earthquake of a certain size, and the overall probability of release is essentially obtained by integrating the seismic hazard curve with the failure probabilities. The seismic input thus directly affects a major objective of the SSMRP, that is, the probability of release.

As noted by Cornell and Newmark, there are two important implications of this approach:

1. The design events, SSE or OBE, do not play a fundamental role. All acceleration levels are considered.
2. The "common mode" nature of the earthquake threat is automatically included.

Finally, because the seismic input occurs first in the seismic methodology chain, the uncertainties in the seismic input propagate through the entire chain and are the only uncertainties to do so. This means these uncertainties may significantly affect uncertainties in the probability of release.

We envision that a definition of the seismic hazard, including realistic time histories, will be required for nonlinear analysis. It is

not yet known if time histories will be used in Phase I. Even if time histories are not used we would still like to include the duration effects in Phase I. This is of particular significance for sites located in the eastern U.S. where smaller and shorter (than in California) earthquakes occur.

In order to set the stage for the subtask definitions, it is useful to briefly discuss the important parameters which significantly influence the seismic hazard at a site; the major sources of uncertainty; and how we plan to reduce uncertainties.

The important parameters are:

- (1) Location of the site relative to tectonic provinces.
- (2) The basic statistics which define the seismicity in each province. These include seismic activity rate, distribution of earthquake magnitudes and maximum earthquake that can occur.
- (3) Definition of the important source parameters of the earthquake such as magnitude, focal depth, stress drop (both dynamic and static) and source size.
- (4) The relation between earthquake with given source parameters and the resulting ground motion as a function of distance.
- (5) The statistics giving the dispersion of the data about the mean of each of the various parameters.

Many of the parameters contained in items (1) and (2) are not well known for the East. The importance of these parameters is site dependent. We have not defined subtasks for these parameters as factors for these items are under study as part of our Site Specific Spectra Project (SSSP) for DOR.

If required, after the SSSP is completed, we will develop additional subtasks.

Item (3) could be included as part of item (2) in that basic field data is required. However, parameters such as the dynamic and static stress drops, and source dimension often cannot be directly measured but are deduced from theory. The interrelation of the basic parameters and earthquake magnitude is not well understood. Work is needed to better define the relationships and how to estimate the parameters of interest from the available data.

Item (4) is the keystone -- namely, what is the ground motion from a given earthquake? A number of studies have attempted to relate the ground motion parameters to earthquake magnitude and epicentral distance. These and other studies suggest that magnitude alone is not sufficient to define the expected ground motion. We have to develop improved correlations including other source parameters to better relate the ground motion to the postulated earthquake. In addition, because the data set used is incomplete (little near-field data from any size earthquake) and strongly biased to one region (Southern California with no data from the regions of interest) corrections are needed for both the mean and the dispersion of data.

For (5) there are a number of factors which can influence the mean and dispersion of data; e.g., attenuation is significantly lower in the East than in California, there is more strike slip faulting in the West as compared to thrust and normal faulting in the East, and changes in the average depth of the earthquake has a significant influence on the spectral shape and level at a given site. Bounding studies will be coupled with the available data to provide a better estimate of the mean hazard at a site and the uncertainty associated with it. These studies are discussed in the various subtasks.

5.2.2 Subtask II.1 Expanded Data Base

A. Objectives

The objectives of this task are:

(1) Obtain additional available recorded time histories from earthquakes.

(2) Cross check data bases and improve or resolve the differences in the definition of site geological (soil) conditions at each recording site as well as definition of distances and earthquake source parameters for each recording using available data sources.

(3) Develop selected subsets of time histories which have been corrected for instrument response and digitization methods.

B. Background

The available data base is strongly biased to Southern California and larger earthquakes with about one-half of the data from a single earthquake (San Fernando). It would be useful to expand the Cal Tech data set even in Phase I because: (1) we feel that we will need time histories in our analysis; (2) at this time there is no methodology available to develop realistic time histories; (3) the Cal Tech data set is limited, and (4) other data is readily available. For the eastern U.S., we need to expand the data base to include smaller near-field events and earthquakes from other tectonic regions to insure that the systematic error introduced by having most of the data from a single tectonic environment is reduced or at least partially understood so that approximate corrections can be made.

There are a number of sources of data, e.g., from Europe and Japan. However, considerable care must be taken to insure that the data is not distorted because of poor instrument response, site soil conditions and instrument location in massive structures. For example, most of the Japanese

data is recorded on instruments with poor high frequency response and thus cannot be directly used.

C. Approach

(1) Obtain additional available data from agencies (e.g., USGS in the U.S. and CNEN-ENEL in Italy) which collect, digitize and correct strong motion data. Also, when available, collect copies of strong motion records which are not digitized. No effort is planned at this time to digitize these records.

(2) Cross check data blanks/sources (e.g., the data set developed for NUREG-0143, Trifunac's, and Seed's) for such information as the earthquake magnitude, epicentral and hypocentral distance, site recording conditions (in particular, size of the building housing the instrument). Where significant differences exist between sources attempt to resolve differences from original sources and/or specific checks at various agencies. In many cases it will not be possible to determine which is correct -- then the variation becomes important.

(3) Review USGS studies on the digitization approach used by Cal Tech and compare to alternative approaches to see if a systematic bias exists. If necessary, develop estimates of the amount of error existing in appropriate subsets of the various data sets (e.g., subsets based on duration of strong motion, and level). The thrust here is to determine if significant errors exist, and if so, is it restricted to certain types of records, and if approximate corrections can be used for Phase I?

(4) Using the results of (3) select subsets of records from (1) which have been reasonably corrected for instruments response and digitization errors. Other subsets should be selected which have only small

errors in the high frequency end or to which simple approximate corrections can be applied. Spectra should be developed for these subsets if not already available. In particular, regional subsets should be developed and cross-compared to determine if any regional bias is evident.

Only a very modest effort is required at this stage for this subtask. This could change if it is determined that many of the Cal Tech corrected records must be corrected or if we find that a number of very important (but small) earthquake time histories should be digitized.

5.2.3 Subtask 11.2 Source Modeling

A. Objective

The objectives of this subtask are:

(1) Use currently available methodology to perform bounding and parameter studies to provide insight into the gross effects of such important parameters as stress drop (both dynamic and static), fault length, focal depth, role of Q on spectral shape, seismic energy released and its relation to earthquake magnitude, etc., have on the ground motion recorded at a site.

(2) Using the results from (1) make approximate assessments of the division of seismic energy into various wave types, angles of incidence of various waves arriving at selected sites, etc., for input into detailed SSI calculational models.

B. Background

It is now possible to simulate the ground motion from an earthquake using computer modeling. However, few studies have yet been conducted. While such modeling might not completely capture all of the aspects of the observed ground motion, it will shed light on the role and importance of the various parameters known to be important and no doubt indicate a few new parameters. It will allow a better understanding of the empirical concept of earthquake magnitude, its relation to the seismic energy released in an earthquake, and the strong ground motion recorded. This will provide us with parameters and relations to use to develop improved correlations between the postulated earthquake and the resultant ground motion. In addition, the information from this study will assist us (in a Bayesian way) to bias the restricted data set we have for the conditions we know exist in the East. For example, we have reasonable estimates of Q in both the East and in the West.

We can assess the relative effect Q has on both the peak g value and spectral shape. We feel that this is important because very simple correction factors for Q applied to recorded time histories suggest that the spectral shape is more significantly influenced by changes in Q than the peak g value. If this is indeed true, then we must scale the spectral shape with different amplification factors in the East than in the West for the same peak g value. It should be noted that we do not expect this study to provide us with estimates of the peak g value but only the relation between spectral shape, amplitude and peak g value for two tectonic regions with significant difference in Q . Lastly, we note that the application of the subtask to Phase I will be carried out in the Subtask II.5.

In addition to the above, a number of studies show that non-vertically incident waves can have a significant impact on the response of the structures. The difficulty with all such analyses is that there is no data describing the division of the arriving energy among wave type or angles of incidence. Some SSI models do not need detailed information on wave type but only approximate information on the Fourier decomposition of the ground motion, i.e., the ground motion is treated as plane waves and the method assumes that the ground motion can be given a Fourier representation. It is reasonably easy and inexpensive to develop the required information from the source studies. The translation of the information into the actual input for the SSI models used in Phase I with real time histories will be done in an approximate manner. The overall purpose is to assess the overall effect and determine if in Phase II we must do additional work.

C. Approach

(1) At least one of the most promising computer models will be used to investigate the effect of the various parameters. The parameters of most

interest are:

- (i) fault type (strike slip, normal, thrust, etc.)
- (ii) stress conditions (both dynamic and static)
- (iii) starting, stopping and breakout phases of the motion
- (iv) source dimensions (long faulting vs. a number of shorter breaks).
- (v) transmission path complexities and variations in Q to attempt to assess the differences in observed ground motion between the Eastern and Western U.S.

(2) Several of the most important cases found in the analysis (1) will be expanded to insure that sufficient site detail is included in the model so that the second objective can be achieved.

5.2.4 Subtask II.3 Attenuation

A. Objective

The objective of this task is to use recent results of earthquake source modeling, newly recorded ground motion, and improved knowledge of site recording conditions to obtain correlations between earthquake source parameters, distance from energy release and earthquake ground motion.

B. Background

Currently used correlations are based on magnitude as the sole earthquake parameter. It is now well known that the magnitude is not the correct parameter to use. Recent studies have suggested a number of other parameters which are important. In addition, several studies suggest that it may be possible to use far-field ground motion to make reasonable estimates of the near-field. This could be useful in the Eastern U.S. as only far-field data is available. Finally, data is now available from other tectonic settings such as Southern Europe which will allow the study of regional bias on typical correlations.

C. Approach

(1) Using recent studies and results from subtask II.2 determine new correlation models. These will then be applied to the data set gathered in subtask II.1 and other available data sets. Possible regional variations will be studied in detail. The spectra of the ground motion as well as peak parameters will be included in the study. In particular, we are interested in the very near-field and how to extrapolate the available data set into the near-field. The results of this study will be complimented by the results of Subtask II.3.

(2) For earthquakes which have sufficient near and far-field ground motion data determine if reasonable estimates of the near-field ground motion can be made from only the far-field peak ground motion and attenuation models. If the results are successful, then a program can be started to obtain the available far-field data for major earthquakes located in the Eastern U.S. This data, plus the results for (1) should suggest how to correct various correlations so that they are valid in the Eastern U.S.

5.2.5 Subtask II.4 Alternative Descriptions of Motion

A. Objective

The objective of this subtask is to apply various statistical modeling methods such as broad class ARIMA time-series models to determine if it is possible to develop models to generate time histories useful for the analysis of structures for the system model studies.

B. Background

The number of actual earthquake records available which are appropriate for a given site location/geologic column is limited, and in fact, for eastern sites effectively nonexistent. Clearly there is a need to supplement the actual data base with realistic time histories appropriate for a given site, earthquake source model and epicentral distance. The problem of developing time histories has received some study; however, it is from the point-of-view of use in design where "worse cases" or meeting a given broadband spectrum. Here we are interested from the point-of-view of analysis and best estimates of the real case. This is a very low level of effort task but a useful one.

C. Approach

(1) A literature search will be made to determine work done on time-series modeling of earthquake ground motion. In particular, we are interested in finding the extent to which Box-Jenkins and Kalman filtering techniques have been used.

(2) Use time series models to determine if appropriate and meaningful models can be developed. The model outputs will be compared with actual earthquake data. The structure of the residuals generated by comparing the model output with actual data will be analyzed.

(3) If the generic models developed in (2) appear reasonable, refinements will be made by considering subsets of the data. These subsets of data will be developed from the source/attenuation models developed in 5.2.3 and 5.2.4, so that the time history is related to the basic earthquake source parameters.

(4) In order to better understand the modification introduced by local site effects on the basic model, the various models will be applied to the data obtained at sites which have recorded a large number of earthquakes (e.g., El Centro and Ferndale). Here, we have to learn how important the nonlinear behavior of the soil is in altering the frequency content and duration of motion. This can be supplemented by analysis of the data from San Fernando where the same earthquake was recorded at a large number of sites. We hope that this analysis will provide insight into the special site conditions which greatly alter the basic model and give either very large or small ground motion.

5.2.6 Subtask II.5 Develop Seismic Input

A. Objective

The objectives of this subtask are to develop a probabilistic statement of the seismic hazard as required for the system studies and to insure necessary studies are carried out so that the appropriate data is available to develop the input.

B. Background

At various stages of the program an improved description of the seismic hazard at various sites will be needed. This will require us to continually improve the methodology used, incorporate the results from the various subtasks and develop improved correlations to input into the overall seismic hazard model. For Phase I, we plan to improve the seismic hazard model developed for DOR as part of the SSSP.

C. Approach

There are three main subtasks:

(1) For Phase I, the seismic hazard will be developed by incorporating improvements in the approach used in the SSSP. The basic approach can be classified as a Bayesian approach where informal judgment and basic theoretical results developed in the various subtasks are incorporated into the analysis to supplement the meager data base. One change that will be incorporated into the formal computer model will be a Monte Carlo scheme similar to the one discussed in Section 6 of UCRL-52236. The first effort will be to develop this Monte Carlo scheme.

As results become available from other subtasks, such as II.1-4, these will be incorporated into the basic schemes used. Improvements in the Bayesian method for incorporating judgment, etc., into the model will be made. The experience gained from our SSSP will be most helpful here.

(2) The choice of appropriate site location is straightforward. The results of the SSSP and the generic requirements of the overall system model will guide the choice of generic sites to be considered. A few added studies using the models developed for the SSSP will allow us to define the locations and number of sites that should be analyzed so that the final results can be easily extrapolated to most eastern site locations.

The basic data required for eastern sites will be available from the SSSP. Most of the effort will be spent in incorporating the improvements developed in the various subtasks into the model. For example, it is possible that one of the results of II.2 will be that the known difference in Q between the East and the West means that relative to the peak acceleration higher spectral amplification factors are required in the East. This would require the development of approximate methods to include this effect in the Phase I analysis.

Efforts in subtasks II.1 and II.3 will provide insight and a basis to judge the results of the source model studies. Clearly considerable judgment will be required as it is unlikely that the results of the computer modeling studies can be directly used.

(3) This subtask is to carry out the detailed analysis for the various sites chosen in (2) above, the computer model developed in (1), and the data and correlations developed in (2).

5.3.0 Task III Soil Structure Interaction

This task deals with the methodology to be used in SSMRP for soil structure interaction. The ultimate goal of this task is to develop transfer functions to be used in the system model to represent the soil structure interaction effect. A transfer function relates the input of soil structure interaction calculation to the output. For example, for a given site with a selected approach the transfer function is a mechanism to predict the output at the bottom of structure foundation (in terms of time history or frequency) when a free-field earthquake motion becomes available (in terms of ground acceleration time history velocity or other parameters). This transfer function is obviously a function of a number of variables, such as time, frequency, soil properties, soil damping, computer code, idealization and modeling techniques. Therefore, to be able most efficiently handle the problem, the fewer the variables within the transfer function the better. By performing sensitivity studies separately, certain variables can be identified to have very little effect on the soil structure interaction results. Hence, a best estimate model can be developed with a number of pre-determined judgments. The following subtasks are required to meet this requirement.

5.3.1 Subtask III.1 Soil Structure Interaction Review

A. Objective

The objective of this subtask is to review methods for performing soil structure interaction calculations in order to obtain the latest information on available methods and methods under development. This will be used to select the procedure to be used for the SSMRP.

B. Background

Soil structure interaction has been a highly controversial area of seismic design for some time. As a result, many new methods have been developed and more are under development.

C. Problem Definition

Our objective in performing soil structure interaction is to do so using methods which are as realistic as possible, as opposed to using methods which produce conservative results for design purposes. Further, these methods should be able to be economically used to develop transfer functions between the free-field earthquake environment and inputs for detailed major structure seismic analysis. These transfer functions should have a random component characterizing the random uncertainties and a systematic uncertainty component characterizing the confidence in the soil structure interaction method. A review of available and future soil structure interaction methods in the light of the requirements of the SSMRP is not available and is required in order to select the most appropriate methods for SSMRP use.

D. Approach

Our approach to this subtask is the following:

1. This subtask is planned to be sublet to a number of experts in soil structure interaction calculational methodology.

2. Each subcontractor will provide a written report. The report will cover areas such as:
 - a. Description of all available methods used in the current design for soil structure interaction. Discuss the advantage and disadvantage of each method described.
 - b. Discussion of available computer codes and description of advantage and disadvantage of each code.
 - c. Recommendation of the most appropriate soil structure interaction methods for SSMRP use and provide the bases.
 - d. Discussion of possible further improvement on the recommended method.
 - e. Discussion of sources of random soil structure interaction results. Examples are modeling methods or soil properties, but time histories are not considered a random source for this subtask as they are more naturally a source of randomness for seismic input.
 - f. Quantitative estimates of randomness.
 - g. Discussion of sources of systematic uncertainty in soil structure interaction results.
 - h. Quantitative estimates of systematic uncertainties.
 - i. Suggested methods for including the effects of nonlinear soil properties.
- E. Remarks

The end product of this subtask will be reports reviewing the present state-of-the-art of performing soil structure interaction

calculations, recommended improvements, and estimates of accuracy.

5.3.2 Subtask III.2 Analytical Development (I)

A. Objective

The objective of this subtask is to develop additional analytical capabilities of methods used to perform soil structure interaction calculations.

B. Background

Soil structure interaction has been a highly controversial area of seismic design for some time. As a result, many new methods and techniques have been developed and more are under development.

C. Problem Definition

Our preliminary review of available soil structure interaction methods indicates that none of them are completely adequate for the first phase of the SSMRP soil structure interaction effort. Therefore, some analytical development effort is anticipated to be required.

D. Approach

Our approach to this subtask is the following:

1. Review the results of Subtask III.1.
2. Select appropriate improvements to be made.
3. Perform required development.

E. Remarks

The end product of this subtask will be a report describing the development effort, testing and comparative analyses, and the improved analytical tool itself.

5.3.3 Subtask III.3 Transfer Functions

A. Objective

The objective of this subtask is to develop transfer functions between the free-field earthquake environment and the required inputs for detailed structural response.

B. Background

One of the required elements in the system analysis method to be used on the SSMRP is the transfer function between the free-field earthquake and the local component loads. The transfer function to be developed in this subtask is just one portion (the first one) of the free-field to component transfer function.

C. Problem Definition

The soil structure interaction methodology to be used at this early stage of the SSMRP must be the best estimate of a realistic methodology consistent with simplicity, economy, and schedule. This methodology must be translated into a transfer function between the free-field earthquake environment and the required inputs for detailed structural seismic analysis. Further, this transfer function must include a random component characterizing the random uncertainty and a systematic uncertainty component characterizing the confidence in the soil structure interaction methodology.

D. Approach

Our approach to this subtask is the following:

1. Develop appropriate mathematical models of the site and site structures.
2. Exercise the models developed in 1) for typical free-field earthquake excitations. Use methods determined from Subtasks III.1 and III.2.

3. Use the results of 2) to develop nominal transfer functions.
4. Perform sensitivity studies to obtain random and systematic variations.
5. Perform soil structure interaction calculations using SRP methods and compare results with SSMRP method.

E. Remarks

The end product of this subtask will be reports documenting:

1. Transfer functions which include random and systematic variations.
2. A sensitivity study on soil structure interaction calculations.
3. A comparison of SRP and SSMRP soil structure interaction results.

5.3.4 Subtask III.4 Nonlinear Soil Structure Interaction

A. Objective

The objective of this subtask is to evaluate the effects of nonlinear soil properties on soil structure interaction results.

B. Background

There is wide agreement that a realistic soil structure interaction method must include the effects of nonlinear soil properties. The present plans for the SSMRP analytical efforts do not include extensive use of a soil structure interaction method which accounts for nonlinear soil properties. However, this is a likely area for future improvements toward a more realistic characterization of soil structure interaction.

C. Problem Definition

The most common way that nonlinear soil properties are included in soil structure interaction at this time uses the so-called equivalent linear method. This method does not truly account for nonlinear soil properties as it really only provides an adjustment to linear soil properties which are then used in a linear analysis. It will be useful to compare the results of "equivalent linear" methods with truly nonlinear ones to determine if the effect of nonlinear soil properties is significant or not. These results will be used in three ways: 1) to evaluate and perhaps modify the systematic variations on the transfer functions developed in Subtask III.3, 2) to determine if a larger nonlinear effort is required in future work, and 3) to evaluate present SRP soil structure interaction methods.

D. Approach

Our approach to this subtask is the following:

1. Develop appropriate mathematical models of the site and site structures.

2. Select realistic earthquake time histories for input at the base of finite element models.
3. Exercise both the "equivalent linear" and nonlinear methods using the common inputs selected in 2).
4. Compare results and evaluate "equivalent linear" method.

E. Remarks

The end product of this subtask will be reports documenting the significance of the inaccuracies introduced by the use of linear rather than nonlinear methods in the SRP approach.

5.4.0 Task IV Structural Building Response

This task deals with the methodology to be used in SSMRP for structural building response. The final goal of this task is to develop transfer functions to be used in the system model to properly represent the structural building response. When an output from soil structure interaction becomes available (it may be in terms of time history or frequency at the foundation base) it will be used as input into structural building model to evaluate structural building response. This response can be in terms of stress, strain, displacement, velocity as well as acceleration. A transfer function in structural building response is a mechanism to relate these outputs with the input time history or spectrum at the foundation base. It is clear that this transfer function can be a function of structural material property, structural dynamic behavior, damping property, configuration, computer code, idealization and modeling techniques as well as solution methods. These variables can be random or systematic and also can be generic or plant unique. To reduce the number of variables or to pre-define the range of variation, sensitivity studies will be used to provide good engineering judgment. The following subtasks are designed to achieve this purpose and develop a best estimate model for structural building response.

5.4.1 Subtask IV.1 Structural Building Response Review

A. Objective

The objective of this subtask is to review methods for performing structural response calculations in order to determine the most appropriate way to perform such calculations concomitant with the needs of the SSMRP.

B. Background

Methods and procedures for performing structural response calculations for nuclear power plant seismic design have developed in certain ways in order to provide conservative design values rather than realistic results.

C. Problem Definition

The needs of the SSMRP in the area of structural response are methods which provide realistic rather than conservative estimates of the structural response. For example, some nuclear power plant structures are highly asymmetric and it is not clear that anything but a three-dimensional model of such a structure will produce a realistic estimate of the structural response. Such three-dimensional analyses will be quite expensive computationally and their cost may not justify the added accuracy. Again, basemat flexibility is sometimes cited as a source of uncertainty in response calculations. Areas such as these need evaluation in order to determine if they significantly affect realism, and thus if they need to be included in the SSMRP.

D. Approach

Our approach to this subtask is the following:

1. This subtask is planned to be sublet to a number of experts in structural response calculational methods.
2. Each subcontractor will provide a written report. This report will cover areas such as:

- a. Description of all available methods used in the current design for structural building response. Discuss the advantage and disadvantage of each method described.
- b. Discussion of available computer codes and description of advantage and disadvantage of each code.
- c. Recommendation of the most appropriate structural response methods for SSMRP use (not design or licensing use).
- d. Recommendations for improvements.
- e. Discussion of sources of random structural behavior.
- f. Quantitative estimates of randomness.
- g. Discussion of sources of systematic uncertainty.
- h. Quantitative estimates of systematic uncertainties.
- i. Model validity/cracking.

5.4.2 Subtask IV.2 Analytical Development (I)

A. Objective

The objective of this subtask is to develop some additional capabilities of existing structural response analytical methods.

B. Background

The theory of structural response is developed to a high stage but in many cases very little of this capability is exercised in the seismic analysis and design of nuclear power plants.

C. Problem Definition

The major reason simplified rather than complex structural models are used is economic. The development of new generation of computers, advances in developing efficient numerical techniques, and modularization of computer programs may mean that a special purpose computer program could be developed which could economically evaluate the response of much more complex structural models than is presently used. These models should provide a much more realistic estimate of the structural response than present ones.

D. Approach

Our approach to this subtask is the following:

1. Identify modeling improvements to be made. Use results from Subtask IV.1.
2. Perform required development and test.

5.4.3 Subtask IV.3 Structural Damping

A. Objective

The objective of this subtask is to develop realistic damping values for use in large structure analysis.

B. Background

The structural analyses to be performed in the early phase of the SSMRP are planned to be linear. In such a case damping values are required. Further, realistic rather than design values are required in order to obtain the best estimate of response.

C. Problem Definition

Recent research in structural system identification has demonstrated that while the best achievable lower bound on the coefficient of variation (COV) for structural frequencies is about 0.005, it is about 0.30, or 60 times larger for structural damping. Since these values are lower bounds, we should expect real tests on structures to yield larger values for the COV, perhaps 0.5 to 1.0 for damping, or more, depending on the noise in the test data. Another example shows that from the same test and data the damping values can be expected to vary 30% or so depending on the numerical procedures used to estimate the damping. Damping values can also be expected to vary with the excitation time histories (stress time histories) and excitation level (stress level). These results mean that for a given structure a significant number of tests may be required at each excitation level in order to obtain reliable realistic damping values. These results may also call for a re-examination of the test data from which damping values have been obtained in the past.

D. Approach

Our approach to this subtask is the following:

1. Develop a mathematical model of major structures housing

significant safety related equipment, for example, a concrete building.

2. Perform structural response analyses on this structure using nonlinear methods and material properties.
3. Use structural system identification methods on the analytical response to estimate structure damping.

5.4.4 Subtask IV.4 Transfer Functions

A. Objective

The objective of this subtask is to develop transfer functions between the soil structure interaction results and building response.

B. Background

One of the required elements in the system analysis model to be used on the SSMRP is the transfer function between the free-field earthquake and local component loads. The structural response transfer function is just one part of the free-field to component transfer function. For some subsystems, for example, piping, the combined soil structure interaction and structural response transfer function will be used to develop inputs for structural response analyses of subsystems. In other cases, for example, major structure stresses, the combined soil structure interaction and structural response transfer function will be used to evaluate the strength of the structure itself.

C. Problem Definition

The structural response methodology to be used at this early stage of the SSMRP must be a best estimate of a realistic structural response methodology. This methodology must be translated into a transfer function between the results of soil structure interaction and structural response. A number of such transfer functions are required as well as different types. On the one hand, kinematic transfer functions are required to develop inputs for the various subsystem structural analyses. On the other, transfer functions will also be required for stresses in the major structure itself. Further, these transfer functions must include a random component characterizing random uncertainties and a systematic component characterizing the confidence in the structural response methodology.

D. Approach

Our approach to this subtask is the following:

1. Identify structures, systems, and equipment for which results are required.
2. Develop nominal structural models and variations therefrom. Variations include structural idealization, refinement, mass distribution, structural properties, damping, etc.
3. Perform structural analyses and develop transfer functions where the random and systematic uncertainties are characterized.

5.4.5 Subtask IV.5 Nonlinear Structural Response

A. Objective

The objective of this subtask is to evaluate the effects of nonlinear structural response on the structural response results.

B. Background

There is wide agreement that a realistic structural response method must include the effects of nonlinear response. The present plans for the SSMRP analytical efforts do not include extensive use of a structural response method which accounts for nonlinear structural properties. However, this is a likely area for future improvements toward a more realistic characterization of structural response.

C. Problem Definition

Nonlinear analyses will be quite expensive compared to linear ones, and thus the effort required to develop statistical transfer functions may be prohibitive. However, it will be useful to compare the results of linear methods with nonlinear ones to determine the potential significance of nonlinear methods. These results will be used in three ways: 1) to evaluate and perhaps modify the systematic variations on the transfer functions developed in Subtask IV.4, 2) to determine if a larger nonlinear effort is required in future work, and 3) to evaluate present SRP structural response methods.

D. Approach

Our approach to this subtask is the following:

1. Develop appropriate mathematical models of the structure.
2. Select realistic earthquake time histories for input to the structure.
3. Exercise both the linear (SRP) and nonlinear methods.
4. Compare results.

This subtask will be performed in coordination with the effort in Subtask IV.3 (damping).

5.5.0 Task V Subsystem Structural Response

This task deals with the methodology to be used in SSMRP for subsystem structural response. The final goal of this task is to develop transfer functions to be used in the system model. These transfer functions will relate the subsystem responses such as piping stress, displacement or strain to the input environment which is the floor response spectrum or time history. It will include the mechanical or electrical equipment response to floor response input. It is clear that the input to the subsystem response is floor response time history or response spectrum. But the output can be in terms of stress, strain, displacement, velocity or acceleration in time domain or frequency domain. The variables in a transfer function can be of material property, configuration, dynamic behavior, damping affect, computer code, idealization and modeling techniques. Due to the complexity of nuclear power plant subsystem, it is necessary that each subsystem and component to be qualified or analyzed by a separate analysis. The method used to perform such an evaluation should be determined by a series of sensitivity studies. The variables left in the transfer function for each subsystem do not have to be the same. The following subtasks are developed for the purpose of this task.

5.5.1 Subtask VI Subsystem Response Review

A. Objective

The objective of this subtask is to review methods for performing subsystem (piping system, mechanical and electrical equipments) calculations in order to obtain the latest information on available methods and methods under development. This will be used to select the method to be used for the SSMRP.

B. Background

Methods and procedures for performing subsystem response calculations for nuclear power plant seismic design have developed in certain ways in order to provide conservative design values rather than realistic results.

C. Problem Definition

The needs of the SSMRP in the area of subsystem response are methods which provide realistic rather than conservative estimates of the subsystem response. For example, in the piping system analysis, the input used at the various elevations of piping supports is the most conservative one. It is the spectrum enveloped from all of the floor response spectra at those elevations plus peak widening.

Also, the methods used to qualify the mechanical and electrical equipments are sources of uncertainty in subsystem calculations. Areas such as these need evaluation in order to determine if they significantly affect realism, and thus, if they need to be included in the SSMRP.

D. Approach

Our approach to this subtask is the following:

1. This subtask is planned to be sublet to a number of experts in subsystem response calculational methods.

2. Each subcontractor will provide a written report. This report will cover areas such as:
 - a. Separate description of available methods used to evaluate piping system, mechanical equipment and electric equipment. Discussion of the advantage and disadvantage of each method described.
 - b. Recommendation of the most appropriate subsystem response methods (separate between piping system, mechanical and electrical equipments) for SSMRP use.
 - c. Discussion of the applicable computer code or test program which can be used in SSMRP.
 - d. Recommendations for improvements in methods and computer codes for each subsystem.
 - e. Discussion of sources of random subsystem behavior.
 - f. Quantitative estimates of randomness.
 - g. Discussion of sources of systematic uncertainty.
 - h. Quantitative estimates of systematic uncertainties.

5.5.2 Subtask V.2 Analytical Development

A. Objective

The objective of this subtask is to develop some additional capabilities of existing subsystem response methods.

B. Background

Current design methods used in piping system analysis is very conservative. Equipment qualification has been the weakest area in nuclear power plant design. Due to the complexity, no available method can adequately predict the equipment behavior and its failure mode.

C. Problem Definition

Our preliminary review of available piping system evaluation methods indicates that a more realistic method needs to be developed. An analytical model which can better predict the equipment behavior and failure mode is recommended. Some analytical development effort is anticipated to be required.

D. Approach

1. Review the results of subtask V.1.
2. Select appropriate improvements to be made.
3. Perform required developments.

b.5.3 Subtask V.3 Subsystem Transfer Functions

A. Objective

The objective of this subtask is to develop transfer functions between the major structure response and subsystem response.

B. Background

One of the required elements in the system analysis model to be used on the SSMRP is the transfer function between the free-field earthquake and local component loads. The subsystem transfer function is the last link in this transfer function chain for most subsystems.

C. Problem Definition

The subsystem response methodology to be used on the SSMR must be a best estimate of a realistic structural response methodology. A number of transfer functions are required for the different subsystems as well as different locations on the same subsystem. Further, these transfer functions must include a random component characterizing random uncertainties and a systematic component characterizing the confidence in the subsystem structural response methodology.

D. Approach

Our approach to this subtask is the following:

1. Identify subsystems for which transfer functions are required.
2. Develop mathematical models for nominal cases and variations.
3. Perform structural analyses and develop transfer functions where the random and systematic uncertainties are characterized.

5.5.4 Subtask V.4 Nonlinear Subsystem Response

A. Objective

The objective of this subtask is to evaluate the effects of nonlinear structural response on the subsystem response results.

B. Background

There is wide agreement that a realistic failure evaluation must include the effects of nonlinear response. The present plans for the SSMRP analytical efforts do not include using a structural response method which accounts for nonlinear structural properties. However, this is a likely area for future improvements toward a more realistic characterization of structural response.

C. Problem Definition

Subsystem structural response is the last step prior to a failure analysis of the subsystem. If the subsystem response can be estimated more accurately, it will increase the confidence in the failure estimation significantly. Selected subsystems will be analyzed using nonlinear methods and the results used in three ways: 1) to evaluate and perhaps modify the systematic variations on the transfer functions developed in Subtask V.1, 2) to determine if a larger nonlinear effort is required in future work, and 3) to evaluate present SRP subsystem response methods.

D. Approach

Our approach to this subtask is the following:

1. Develop appropriate mathematical models of selected subsystems.
2. Select inputs for the analyses.
3. Exercise both linear (time history and SRP) and nonlinear methods.
4. Compare results.

5.6.0 Task VI Fragility Definition

The objective of this task is to develop component and structural fragility curves to estimate the failure of the component or structure. A fragility curve describes the probability of component or structure failure under a certain input environment. However, most of the components are qualified based on non-destructive dynamic tests. Therefore, it becomes difficult to define proper fragility curve for each component. With the limited test data available, it is necessary to collect information from outside the nuclear industry. The information or data which we are able to collect may not be enough to fully describe or define fragility curves for each component. If sufficient data is not obtained, engineering judgment will be used to develop such curves. For the qualification of a system or a structure, seismic loading is not the only loading required. In most cases the combined effect of seismic and non-seismic loads are necessary to qualify a system. Proper loading combination criteria is therefore required. The method to be used to combine the response from seismic and non-seismic loads are needed. This task contains the following subtasks.

5.6.1 Subtask VI.1 Component Identification

A. Objective

The objective of this subtask is to establish a list of mechanical and electrical components to be included in the Phase I activity of SSMRP. Useful information regarding the as-built condition for each component needs to be established.

B. Background

The as-built condition of a component may be quite different from its design. To be able to develop proper component fragility curve to be used in the system model, the information for component qualification, installation, connectivity, and manufacture specification as well as deficiency record need to be collected.

C. Problem Definition

Equipment or component fragility curve is anticipated to be a major difficulty on the SSMRP, primarily because the lack of qualification information and component complexity behavior. The information regarding each component's qualification method, installation procedure, connectivity and as-built condition and manufacture specification will improve our estimate of component capability.

D. Approach

Our approach to this subtask is the following:

1. To incorporate with system analysis task to establish a list of components to be included in the system model.
2. Collect necessary information for each component, such as manufacture specification, design specification, installation, connectivity and qualification.
3. Provide a summary for each component to see whether the collected information is adequate to produce component

fragility curve.

4. Provide recommendation for additional information or test data required to define component fragility curves.

5.6.2 Subtask VI.2 Test Data Collection

A. Objective

The objective of this subtask is to collect test data which can be used to establish component fragility curve for the component in SSMRP model.

B. Background

Non-destructive dynamic test which was generally used in the component qualification during the design is not adequate to predict the component fragility up to failure.

C. Problem Definition

After understanding the characteristics of components which are included in SSMRP model a data collection effort is required to collect and review the test data for those and similar components from nuclear power industry or from related industries.

D. Approach

Our approach to this subtask is the following:

1. Categorize mechanical and electrical components into a few categories according to functional requirement, component characteristics, component installation.
2. Collect test data from every possible source for each category.

5.6.3 Subtask VI.3 Component Fragilities

A. Objective

The objective of this subtask is to establish failure loads, for components which are normally qualified by non-destructive testing.

B. Background

One of the required elements in the system analysis model to be used in the SSMRP is the transfer function between the free-field earthquake and the local component loads. As described above, this transfer function is obtained by combining a number of related transfer functions, that is, transfer functions for soil structure interaction, large structural response, and sub-system structural response. For each Monte Carlo simulation, this overall transfer function will be used to develop a component load, and the component load is then used to estimate a probability of failure using the fragility curve developed in this subtask. This probability of failure is then combined with others obtained likewise to obtain an overall probability of failure for the system.

C. Problem Definition

The development of component fragilities is anticipated to be a major difficulty on the SSMRP. To see this consider the ideal case. Here, a number of like components would be tested to failure for a given load. We could then use these results to develop a curve relating probability of failure versus load. However, in nuclear power plant testing this is not the approach taken. Here, qualification testing is usually performed. That is, the component is qualified for a given load and the load at which it would fail is rarely determined.

D. Approach

Our approach to this subtasks is the following:

1. Review results from subtask VI.2
2. Estimate fragility curves with confidence limits.
3. If the curves in 3) are estimated to be too conservative (for example, "cookie cutter" curves) because of the absence of appropriate data, develop plans for the analytical estimation of fragilities.

5.6.4 Subtask VI.4 Loading Combination

A. Objective

The objective of this subtask is to establish the load combinations used to qualify the component. Perform evaluation for the component under other loads (other than seismic) according to loading combination requirement.

B. Background

Each component during various stage or time will be subjected to various loads and loading combinations. To qualify a component it is necessary that every load combination condition is satisfied. The stress, strain, etc., associated with non-seismic loads need to be evaluated.

C. Problem Definition

To establish the loading combinations to be used in SSMRP. To perform appropriate analysis to obtain the component response to other non-seismic loads.

D. Approach

Our approach to this subtask is the following:

1. Establish load combination criteria.
2. Perform component response analysis for each non-seismic load.
3. Develop the methods to combine the non-seismic and seismic response.

5.6.5 Subtask VI.5 Structural Fragilities

A. Objective

The objective of this subtask is to establish failure loads, stresses, strains, etc., for structural elements which are normally qualified by analysis and design.

B. Background

See Subtask VI.1.

C. Problem Definition

Estimates of stresses/strains at which failure will occur are required at various locations in major structures, subsystems, piping, etc. Furthermore, the seismic loads must be combined with any other loads resulting from normal operations such as temperature loads, dead loads, etc. One major problem is to estimate failure in terms of stresses/strains predicted by linear methods.

D. Approach

Our approach to this subtask is the following:

1. Select locations where failure evaluation is required.
2. Determine stresses/strains due to normal or expected operating loads.
3. Determine the manner in which seismic and non-seismic loads will combine.
4. Develop failure curves from material properties.

5.6.6 Subtask VI.6 Design Loading Combination

A. Objective

The objective of this subtask is to investigate methods and develop criteria for appropriate combinations of dynamic loads and/or responses in systems and components under plant operating transients, postulated accidents and seismic events for nuclear power plant design. The analysis will be founded on a probabilistic basis with a specified level of confidence.

B. Background

As specified in the General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena" of Appendix A to 10 CFR part 50, "General Design Criteria for Nuclear Power Plants," nuclear power plant structures, systems, and components which are important to the plant safety shall be designed for appropriate combinations of the effects of natural and accident phenomena. This requires the design of systems and components to consider the combination of loadings associated with normal operation, postulated accident and specified seismic events. Basically, which dynamic loads need to be combined and how to combine them are determined by various criteria; such as the component or system's function, the nature of the load and event occurrence in relation to the function of the system. If a component or a system is required to be designed for a group of dynamic loads, the requirement is such that this component or system shall be designed to withstand the joint effects of the combined loads. The joint effects implies the various dynamic loads should be combined in such a way that the response of the joint effect is maximum unless a justification can be provided to prove the actual joint effect differs from the

maximum. In general, all dynamic transient loading functions should be combined at the loading input level and an analysis is performed by using the combined time history loading. Obviously, it is difficult to predict the proper time phases between each dynamic loads for which the combined load will produce the maximum response. The most commonly used approach in the nuclear industry is to perform dynamic transient analysis for each individual event. The responses of the separate analyses are then superimposed to obtain the final result. Various methods can be used to superimpose the responses. The absolute sum method which adds the absolute maxima of all dynamic responses is generally recommended because it produces the most conservative result. However, such a procedure may involve undue conservatism in the estimate of the overall design loading.

C. Problem Definition

This subtask will achieve the following two goals.

1. To investigate event occurrence phenomena for light water reactors and determine the criteria for combining dynamic loads (events) in the system design.
2. To investigate methods and develop criteria for appropriate combinations of dynamic responses in systems and components under plant operating transients, postulated accidents and seismic events.

The detailed work scope will be defined after coordination with NRR Load Combination Task Force.

D. Approach

1. Load (event) Combination
 - a. List events of plant operating, postulated accident, and natural calamity that are used as the basis of plant system and component design.

- b. Investigate event occurrence rate and develop joint event occurrence probabilities for typical systems and components.
- c. Based on design requirement and joint event occurrence probabilities establish load (event) combination criteria.

2. Response Combination

- a. Dynamic characteristics of each load (identified from load combination criteria as established in 1) above) will be evaluated. The response characteristics for each component subjected to a particular dynamic loading case will be investigated. The governing parameters will be identified by reviewing the component dynamic characteristics and the nature of the load.
- b. Review the governing parameters for each loading case and develop a methodology to determine the relationship between the combined dynamic responses and the governing parameters.
- c. Based on conditions defined in "b" above, system and component dynamic responses can be categorized into two major groups: (1) responses where absolute sum shall be used if combining with other responses, and (2) responses where the use of absolute sum may not be necessary.
- d. Survey existing methods and develop appropriate methods based on probabilistic approach for combining responses if absolute sum is not necessary.
- e. Perform sensitivity studies to define error bound.

5.7.0 System Analysis

The systems analysis task is composed of two parts. The first involves the specification and development of an overall computational procedure encompassing the seismic design mathematical and event/fault tree models developed by this program. This procedure will have as its output the probability of radioactive releases caused by seismically induced events in nuclear power plants. The second part of the systems analysis task will deal with the construction and evaluation of the event/fault tree model of a nuclear power plant subject to a seismic event.

5.7.1 Subtask VII.1 Experimental Validation of Failure

A. Objective

The objective of this subtask is to develop a plan for experimental validation of the capability of a methodology (the one to be used on the SSMRP) to predict structural failure. The approach will not include actual testing as the intent is to use existing data.

B. Background

The major objective of the SSMRP is to provide a best estimate of the true risk from an earthquake in terms of the probability of release. In order to do this we must first obtain a best estimate of the probability of structural failure.

C. Problem Definition

Experimental verification of the methods used in the SSMRP will be quite useful in enhancing the credibility of these results. At present, this verification is largely absent.

D. Approach

Our approach to this subtask is the following:

1. Review existing structural failure data for applicability. Two possible sources of a large number of similar structures subjected to similar inputs are some of the structures in the 1971 San Fernando earthquake, and structures tested at the Air Force Weapons Laboratory.
2. Review adequacy of detailed (rather than overall structural) failure data, for example, tests on concrete specimens.
3. Develop a few typical failure modes/paths/chains.
4. Develop plans, procedures, costs, and schedules.

5.7.2 Subtask VII.2 System Analysis Methods

A. Objective

The objective of this subtask is to identify, describe, and qualitatively evaluate various system analysis methods which might be applicable to this program and to describe any improvements required.

B. Background

An increasing amount of work is being done in the area of seismic risk. Several such studies, for example Amendment 52 to Diablo Canyon and the Acres seismic risk assessment for Canadian facilities, have been carried out on nuclear power plants. These or other techniques may be applicable to SSMRP.

C. Problem Definition

A review of available methodologies in the field of operations research, systems analysis, probabilistic assessment, and seismic risk, especially as they relate to the SSMRP does not exist.

D. Approach

Our approach to this subtask is the following:

1. Identify and categorize various methodologies and provide references.
2. Describe each methodology.
3. Tabulate the advantages and disadvantages of each methodology in general and as they might apply to the SSMRP.
4. Identify improvements required for the SSMRP.

5.7.3 Subtask VII.3 Specification of Computational Approach

A. Objective

The objective of this subtask is to specify an overall computational procedure to be used to evaluate the mathematical models developed by the SSMRP.

B. Background

A probabilistic based failure assessment technique has been developed (FAST) and applied to the strategic weapons survivability problem. Inputs to this technique are the random and systematic variations of various environmental conditions to which the hardened weapon might be exposed, as well as component fragilities and transfer functions. Output from FAST is a damage function relating failure probability to a variable such as miss distance, from which the weapon's chance of survivability can be estimated. There are certain similarities between the way one could assess a weapon's chance for survival in a hostile environment and the way one could assess a nuclear power plant's survival following a seismic event. A modification of FAST or some similar code might be useable as the overall computational procedure for the SSMRP.

C. Problem Definition

Specification of a computational procedure to incorporate all the mathematical models developed by the SSMRP must be accomplished at an early date to guide their development and I/O procedures.

D. Approach

Our approach to this subtask is the following:

1. Specify the computational approach to be used in the SSMP including a flowchart and how the individual mathematical models will be incorporated.
2. Assess the time and cost involved in developing and applying the code specified to an entire nuclear power plant not including event/fault tree construction but including the incorporation of them into the code.

b.7.4 Subtask VII.4 Probabilistic Computation Techniques

A. Objective

The objectives of this subtask are to identify and evaluate various methods of combining the results of individual analysis methods which make up the seismic methodology chain and to determine the requirements for incorporating candidate methods into the computational procedure to be developed for the SSMRP.

B. Background

The computational procedure to be used on SSMRP requires the linking of complex methodologies such as seismic input, site response, soil structure interaction, structural response, combination of seismic and non-seismic stress or strain, and evaluation of failure.

C. Problem Definition

No comprehensive method exists which can evaluate the variability existing design methods have on the overall seismic design process. To measure this variability, a non-deterministic method of representing and combining existing and any proposed methods is required. This may require the use of techniques such as Monte Carlo simulation interpolation functions, response surfaces, stratification, control variates, and importance sampling. Some of these ideas are outlined in UCRL-52236.

D. Approach

Our approach to this subtask is the following:

1. Define a seismic methodology.
2. Define the input and output of each link in this chain.
3. Evaluate alternate inputs and outputs and methods for combining them.
4. Define system analysis interface requirements.

5.7.5 Subtask VII.5 Event/Fault Tree Development

A. Objective

The objective of this subtask is to develop an event/fault tree model of the nuclear power plant selected in Task 1 for incorporation into the computational procedure called for in Subtask VII.6

B. Background

The event/fault tree methodology used in the Reactor Safety Study has been applied to a seismic risk assessment of the Diablo Canyon Nuclear Power Plant (Amendment 52 of the FSAR). Inputs to this assessment were component fragility curves and earthquake probability distributions. The output was the overall risk to the public from the Diablo Canyon plant due to seismic events as measured by population exposure. These event/fault tree techniques are to be used to model the reactor system of a selected nuclear power plant and will be incorporated into the overall computational procedure. The event/fault tree must also be capable of being exercised by itself, using associated component fragility curves as input and generating the probability of release with associated confidence intervals as output.

C. Problem Definition

An event/fault tree model of an existing nuclear power plant needs to be constructed for incorporation into the overall SSMRP computational procedure which uses radioactive release to verify new or existing seismic design methodologies.

D. Approach

Our approach to this subtask is the following:

1. Establish the scope of an event/fault tree model of a selected nuclear power plant including information requirements, systems

and sequences to be analyzed, bounds of the analysis, etc.,
For Phase I only sequences leading to core melt will be
considered. Define how this model will be incorporated into
the overall computational procedure and how it can be
exercised alone.

2. Construct the event/fault tree model to the level agreed to and
for the systems and sequences specified.
3. Demonstrate the validity of the model using arbitrary component
fragility inputs.

5.7.6 Subtask VII.6 Develop Computational Procedure

A. Objective

Develop an integrated, comprehensive computational procedure to be used as the probabilistic based system model of the Seismic Safety Margin Research Program (SSMRP).

B. Background

In order to demonstrate the conservatism of the seismic design of nuclear power plants the real or perceived risks due to seismically induced accidents are to be determined from combinations of mathematical models. These models will be used to measure the change in the estimated risk which results from changes in seismic design assumptions and also the uncertainty in risk due to random occurrences, e.g., seismic event probabilities, material property variability, etc. From these risk estimates the variability and conservatisms of current and new seismic design methodologies can be established. For our purposes, risk will be measured by the probability of radioactive release per reactor year.

A computational procedure must be developed to evaluate the combination of outputs from these models. The purpose of this task is to specify this computational procedure and then develop it into a useable tool for the SSMRP.

To put matters in perspective, a simple block diagram is shown in the figure below. Block 1 represents the seismic input which is the probability of an earthquake of a given magnitude per year versus some earthquake source parameter, e.g., peak ground acceleration. The second block takes, as given, the earthquake source parameter and produces a component load or stress as a function of this parameter. This block includes most of the links of the seismic design methodology chain such as soil-structure interaction analysis, structural response analysis, seismic stress or strain analysis, etc. [1]. The third block

takes the loads or stresses developed and compares these to component failure curves to determine component failure probabilities. The fourth block is the systems network model which may be an event/fault tree network of the full reactor system. The output of this block would be the probability of release of a given type (magnitude) as a function of the peak ground acceleration. Finally, the release probabilities are convolved with the earthquake frequency data and plotted as probability of release of a given magnitude per reactor year versus magnitude.

For each seismic design method, the above systems model is exercised. The degree to which the probability of release curve on the far right changes will be a measure of the variability of current seismic design methodology. If the risk assessment model is of a full reactor system, then the absolute release numbers can be compared to the release probability per year from non-seismic accident causes and other public risk to give a measure of conservatism.

The output of each box is a distribution of values rather

than a single continuous function. Thus, the release curve on the right will also be a distribution of values, with a mean and variance. This distribution is caused in part by the random nature of many of the input variables such as earthquake probability, soil variation, material properties, etc. Monte Carlo simulation or statistical techniques will be required to evaluate the model.

As a possible computational procedure, there is a probabilistic based failure assessment technique called FAST [2]. FAST was developed to study the strategic weapons survivability problem. Inputs to it are the random and systematic variations of various environmental conditions to which a hardened weapons system might be exposed, as well as component fragilities (failure curves) and transfer functions. Output from FAST is a damage function relating failure probability to a variable such as miss distance, from which the weapon's change of survivability can be estimated. There are certain similarities between the way one could assess a weapon's change for survival in a hostile environment and the way one could assess a nuclear power plant's survival following a seismic event. If a version of FAST is to be used, it must be capable of operating on fault tree models (or in conjunction with fault tree codes) of complex reactor systems such as generated for the seismic risk assessment of the Diablo Canyon Power Plant [3].

C. Problem Definition

No adequate computational method exists which can compute the probability of release from a nuclear reactor due to seismic events; such release probability to be used as a tool to measure the conservatism and variability in seismic design methodology. The computational method must provide a way of representing and combining the results from existing and proposed models used in seismic design, e.g., soil-structure interaction and event/fault tree models to give component and system failure probabilities and

the resulting release probability and a statistical measure of their precision, e.g., confidence intervals.

D. Approach

To meet the objective of this task, the following information is required in addition to a description and working version of the computational method suggested.

1. Assess the feasibility, time, and cost involved in applying the defined computational method to an entire nuclear power plant. A demonstration on an existing nuclear plant (or other) subsystem would be desirable if a candidate computational method is already operating.
2. Define the inputs required and outputs to be produced by the computational method. Define any interface requirements between the various parts of the computational method.
3. Describe what standard operating procedures will be used for software development and implementation so that component parts of the computational method and input data can be structured in a compatible manner.
4. Describe the analytical basis for the computational methods in detail.
5. Develop the computational method and demonstrate its capability using as input the event/fault tree models, seismic design models, component fragility curves, etc., developed in other-tasks on a selected nuclear power plant.

E. References

1. Bernreuter, D., et al., "An Evaluation and Assessment of Nuclear Power Plant Seismic Methodology," Lawrence Livermore Laboratory Report UCRL-52236, (March 1977).
2. Rowen, W. H., "Recent Advances in Failure Analysis by Statistical Techniques (FAST)." The Shock and Vibration Bulletin, 47, Part 2, Naval Research Lab., (Sept. 1977), pp. 19-32.
3. "Seismic Evaluation for Postulated 7.5 m Hosgri Earthquake, Units 1 and 2, Diablo Canyon Site, Vol. V: Analysis of the Risk to the Public from Possible Damage to the Diablo Canyon Nuclear Power Station from Seismic Events." Pacific Gas and Electric Co., (Aug. 1977), USNRC Docket Nos. 50-275 and 50-323.

5.8.0 Task VIII Phase II Task Definition

Four major efforts are considered for the Phase II (Future Improvement) activity.

1. Estimate the conservatisms in the Standard Review Plan (SRP) seismic design methodology.
2. Phase I model improvement.
3. Extend the developed methodology to other plants such as BWR and Western plants.
4. Develop an improved seismic design methodology based on probability.

Each of these areas are described in the following paragraphs. Note that these items are comprehensive in that they generally describe all major areas in the future development. As work on the program progresses, better task definition for Phase II will be defined and by the end of Phase I finalized.

5.8.1 Estimate the Conservatism in the Standard Review Plan (SRP)
Seismic Design Methodology

This will be done by comparing the results of the SRP methodology and the methodology resulting from the research and development in Phase I program at the system level. This comparison can be used to develop the structure capacity margin with a relatively small additional effort. It is clear that this comparison to the SRP methodology will be repeated each time when the developed model is improved in the Phase II effort.

5.8.2 Phase I Model Improvement

Models developed in the Phase I effort use certain simplified assumptions. When these assumptions are removed the models will be improved and the confidence level will be increased. A few possible improvements are tentatively identified:

- Nonlinear methods for soil structure interaction and structural response.
- 3-D analysis for nonsymmetrical structure.
- Large scale component fragility test program.
- Improvement on structural fragility predication through structural dynamic test and/or other methods.
- Overall computation code improvement.
- More detail and indepth event/fault tree analysis to cover more complex situations such as major damage other than core melt, considering human factors, design errors, and system interdependencies.

5.8.3 Extend the Developed Methodology to Other Plants Such as BWR and Western Plants.

For the Phase I program, a PWR nuclear power plant located at the eastern region of U.S. was selected to perform the study. It is intended that a BWR plant or a plant located at western region will be the plant to be selected for the next evaluation.

5.8.4 Develop an Improved Seismic Design Methodology Based on Probability

The final goal of the Seismic Safety Margin Research Program is to develop a new and improved seismic design methodology based on probability of release. This new methodology will provide a realistic assessment to the seismic hazard of a nuclear power plant. The developed design methodology should have the characteristics that it has an adequate and realistic but not overly conservative design basis.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

NOTICE

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately-owned rights."