ENCLOSURE

Long Term Seismic Program

Development of Scope of Work for Phase III

(Results of Phase II Scoping Study)

Pacific Gas and Electric Company
Diablo Canyon Power Plant
Docket Nos. 50-275 and 50-323

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CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION AND OBJECTIVES

This report presents the results of Phase II of the Diablo Canyon Long Term Seismic Program (LTSP) which consists of the development of the refined scope of work for Phase III of the LTSP. Phase I of the LTSP consisted of the preparation and submittal of the LTSP Program Plan, dated January 31, 1985.

The general objective of the Phase II study is to more clearly define the LTSP scope of work in terms of detailed and scheduled work plans to be carried out in each of the six major elements of the LTSP. This report presents the results of efforts conducted to refine the scope of work of the LTSP for each of the six program elements. These results consist of task plans and the program schedule. It is recognized that during the future course of the work, modifications of these work plans may be made due to the findings of the studies.

It is a constant goal of the LTSP program to provide a comprehensive response to the intent of license condition 2.C.(7) of the Diablo Canyon operating license DPR-80. A major consideration in conducting the Phase II studies has been the recognition of the importance of setting and meeting a tight schedule in order to accomplish the project within the allotted period. The LTSP schedule for Phase III activities is included as Figure 1-1.

Since the LTSP began, certain high priority technical activities have been conducted in each program element in addition to refining the scope of work. The progress and results of these activities are discussed in the LTSP quarterly progress reports and are not included in this report.

The need for developing a more detailed scope of technical activities varies greatly from element to element, as described in the following paragraphs that summarize the approaches used for each element. Two changes in nomenclature are introduced to clarify program element descriptions in this report and henceforth in the LTSP. The "Geology" and "Maximum Magnitude" elements of the

LTSP Program Plan are combined in a single category called "Geology/Seismology/Geophysics." Similarly, the numerical and empirical ground motion elements are integrated into one technical element called "Ground Motions."

The approaches to refining the scope of work for the six LTSP program elements are summarized as follows:

1. Geology/Seismology/Geophysics: A major component of the Phase II study has been the effort to further focus and specify the scope of the geology/seismology/geophysics activities. The approach has involved both analytical studies and judgments to identify and evaluate technical considerations that are significant with respect to the license condition. A comprehensive specification of tasks was developed to form an integrated and scheduled work plan that addresses the significant considerations. The primary emphasis in the geology/seismology/geophysics study has been to use multiple approaches so as to avoid missing potentially significant technical considerations.

2. Ground Motions: Within the LTSP, the need is clearly recognized for a comprehensive program of ground motion studies that is closely integrated with the geology/seismology/geophysics studies. This is necessary to provide the most appropriate input for the subsequent engineering analyses. The scope for the ground motions element was developed using input from two in-house workshops and additional discussions and assessments. Significant ground motion considerations were identified, and a set of tasks that integrated numerical and empirical techniques was developed.

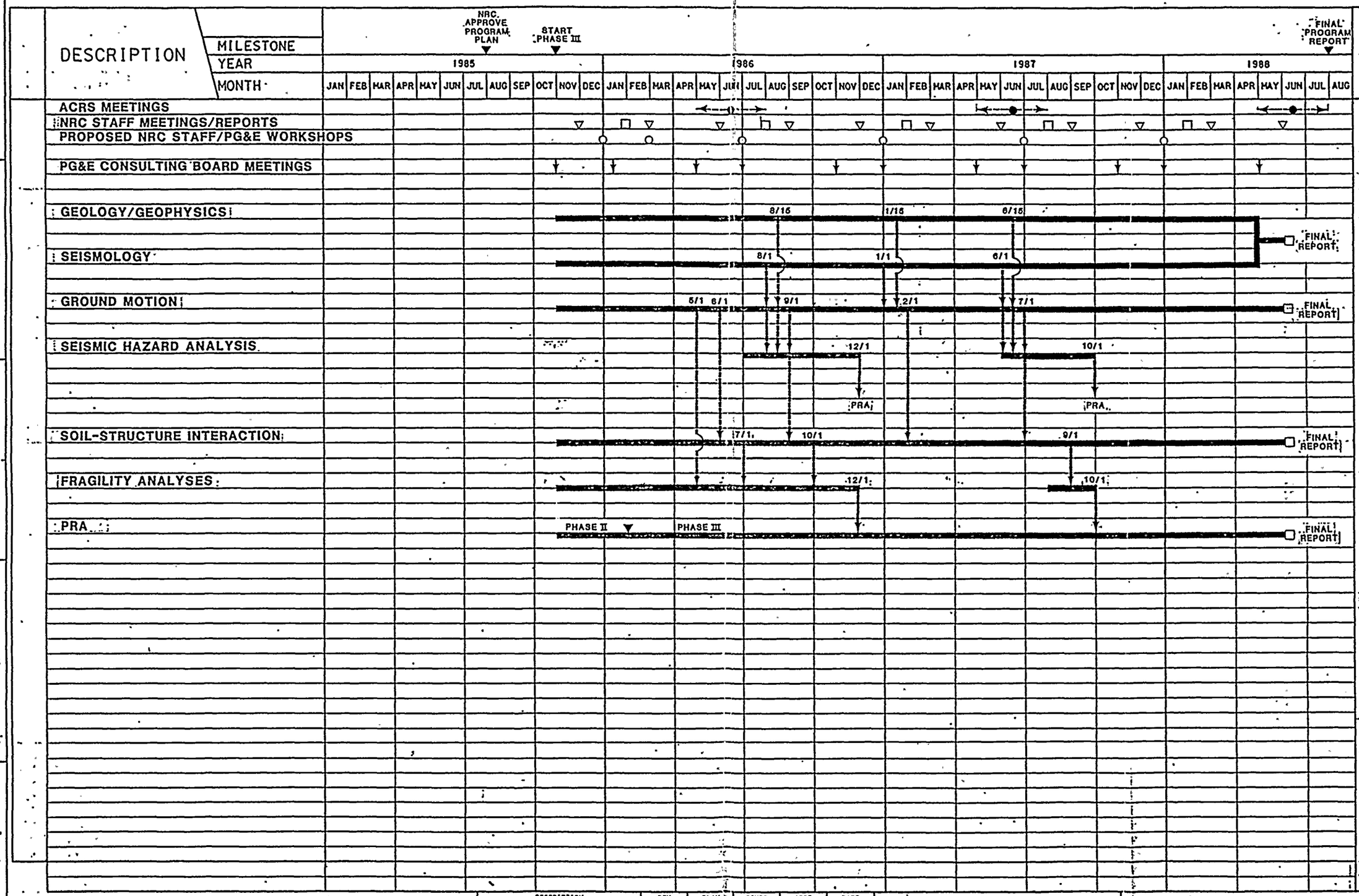
3. Seismic Hazards Analysis: No need for revisions of the scope of the seismic hazards analysis has been identified at this time.

4. Soil-Structure Interaction: The scope of the soil-structure interaction (SSI) studies has remained essentially unchanged from that described in

the LTSP Program Plan. A set of preparatory tasks were, however, initiated during Phase II, as discussed in Quarterly Progress Report No. 1. Using these intial activities, the tasks to be performed during Phase III are refined from the LTSP Program Plan and are described in detail herein.

5. Fragilities: A list of plant-specific structures and components were identified for inclusion in the Phase II probabilistic risk assessment (PRA) study, for which fragility data have been developed. These fragility data are input to the Phase II PRA, which identifies the structures and components that are the dominant contributors to the seismic risk. The Phase III fragility studies will reevaluate fragilities of these items in addition to performing other sensitivity studies to quantify some of the assumptions inherent in the overall evaluation.

6. Probabilistic Risk Assessment: The Phase II PRA study involves a preliminary assessment using an integrated risk model for systems and events. The analysis is used to plan the activities and priorities for the Phase III PRA. The activities and results of the Phase II PRA study are presented herein.



NOTES

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LEGEND:

- NRC STAFF REPORT
- NRC STAFF MEETING
- NRC/PG&E WORKSHOP
- ACRS MEETING
- CONSULTING BOARD MEETING
- TIME DATUM

PRELIMINARY

DESCRIPTION	REV	PLAN	SCHED	APPR	DATE

PROJECT: PACIFIC GAS & ELECTRIC CO. DIABLO CANYON LONG TERM SEISMIC PROGRAM

TITLE: LONG TERM SEISMIC PROGRAM SUMMARY SCHEDULE PHASE III

SCHEDULE | REV.

Figure 1-1

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2.0 GEOLOGY/SEISMOLOGY/GEOPHYSICS

2.1 OBJECTIVES AND APPROACH

It was recognized as part of the preparation of the LTSP Program Plan that the geology/seismology/geophysics element would need further definition of the scope of topics covered and would need development of a detailed and scheduled work plan to address the topics. Thus, during the initial phase of the project, a study has been conducted to identify the significant technical considerations of the scope of work that serve as the focus for the preparation of a task-by-task work plan and a schedule that addresses these considerations.

The fundamental objective of the Phase II study for geology/seismology/geophysics is to provide a work plan (1) that is focused on those technical considerations in the disciplines of geology, seismology, and geophysics that are most significant in fully describing the potential earthquake environment at the DCPP site; and (2) that does not omit potentially significant considerations.

In this context, a clear definition of "significant consideration" is needed. A "consideration" is a technical factor or set of technical factors related to the assessment of earthquakes as they may affect the Diablo Canyon Power Plant (DCPP). Such considerations, for example, may include length, orientation, and rate of slip of an identified seismic source, because these elements, in turn, constrain the location, size, and rate of occurrence of potential earthquakes. "Significant considerations" are those technical factors that make a major contribution to the engineering impact of potential earthquakes and thus are evaluated to be important to one or more elements of the license condition. For example, the slip rate on a fault close to the DCPP site is important to the frequency of occurrence of strong ground motions at the site and, therefore, would be significant to Element 4 of the license condition, which concerns probabilistic risk. Significant considerations are grouped together and treated as topics.

Identifying and evaluating technical considerations involved four steps:

- Identify specific seismic sources that are potentially significant to earthquake hazards assessments at the DCPP site

- Use a logic tree format to organize relevant data that specify a set of technical considerations for each source

- Apply analytical techniques and judgmental evaluations to the sources and associated logic trees to identify considerations that are significant to earthquake hazards assessments and to provide high confidence that significant considerations have not been omitted

- Group the resulting significant considerations into topics for study

To develop a work plan that addresses the identified topics, the collective judgments of PGandE staff, consultants, and reviewers were used to plan an organized and scheduled set of work tasks. These tasks and their associated schedule are intended to incorporate the following:

- Consideration of the technical topics of the scope of work

- Consideration of the technical resources required to address the topics

- Provision for efficient and effective sequencing of work tasks

- Monitoring technical progress to identify the need for changes in tasks as the LTSP progresses

The following subsections describe the activities that identified the significant technical considerations and the resulting topics and work plan.

2.2 IDENTIFICATION OF SIGNIFICANT TECHNICAL CONSIDERATIONS

The identification of significant technical considerations involved the identification of potential seismic sources, the use of logic trees to organize relevant data, and the application of analytical techniques and judgmental evaluations.

2.2.1 Potential Seismic Sources

Early in the Phase II study, the decision was made to organize the analysis around selected geologic structures or sets of structures that, for the purposes of the study, are to be treated as potentially significant seismic sources. This organization constitutes a refinement of the more purely geographic organization used in the January 31, 1985 Program Plan. These selected seismic sources are listed in Table 2-1 and are shown in Figure 2-1. In making this selection, other structures along coastal central California were considered but were not included in the analysis, primarily because of their great distance from the site. If, during the course of the LTSP, information suggests that additional structures should be included as seismic sources of potential significance to the DCPP site, they can be incorporated in the scope of work. It is expected that the completion of the scope of work will identify that some of these assumed significant sources are, in fact, not significant.

2.2.2 Logic Trees

Numerous parameters and characteristics collectively describe each seismic source listed in Table 2-1. In order to organize this information about each source, a logic tree format has been used. As commonly applied in earthquake hazard studies, logic trees have several advantages as a means to analytically organize the characteristics of a seismic source:

- Logic trees incorporate an explicit understanding of the interrelationships among the various characteristics in a logical, consistent way

- For quantitative parameters, ranges of values can be specified and given weights or probabilities

- For other kinds of physical characteristics, alternative interpretations can be identified and given weights or probabilities

- The logic tree format of data organization is especially amenable to sensitivity analyses and scenario testing, which are useful for assessing the significance of individual parameters or characteristics to earthquake hazard assessments at the DCPP site

For each of the potential seismic sources listed in Table 2-1, a number of characteristics are represented in the logic tree for the source. These characteristics are listed in Table 2-2 in sequence (from the top to the bottom of the list) of their logical relationship. A graphic presentation of the logic tree is provided in Plate 1. The logical relationships chosen for the technical considerations for each seismic source are represented by the sequence of nodes from left to right in the tree structure. Each characteristic in the tree is considered to be a technical consideration for the particular seismic source being evaluated. It should be noted that some of the characteristics are combined into groups and their significance is considered jointly. For example, several characteristics relate to the fault capability (such as evidence of recency of slip, causal association with earthquakes, and structural association with a capable fault) and can be treated jointly in assessing significance to earthquake hazards.

For the source characteristics of Table 2-2, information was gathered from the published literature and from several in-house workshops to assess the ranges in parameters or variations in characteristics for each seismic source. These values, as presented in Table 2-3, are the full range of values and bracket estimates generally accepted within the technical community and values or alternatives that may be very unlikely extremes. The branches of the logic tree structure shown in Plate 1 represent the alternatives or range of values associated with each node (technical consideration) of the tree. The data of Table 2-3 are used in the Phase II study in two ways: they serve as input to the analytical techniques discussed in Subsection 2.2.3, and they are used as input to the preliminary PRA discussed in Section 7 and in the quarterly progress reports.

2.2.3 Analytical Techniques

Four analytical techniques have been applied to the logic trees to identify seismic sources and the technical considerations associated with those sources that make a large contribution to the potential seismic hazard at the DCPP site. The application of these techniques is carried out using the Hosgri fault case (Table 2-3) as the reference. Because of the proximity of the Hosgri fault zone to the DCPP site and because in previous DCPP licensing the Hosgri fault has been assumed to be a significant seismic source, it is reasonable to use the Hosgri source and its characteristics as a comparative basis for the analysis of the other selected seismic sources. Thus, in the application of the analytical techniques discussed below, the results of the techniques are usually shown in relation to the Hosgri fault. It is important to recognize two implications of this method:

- The assumption is made that all of the fault characteristics listed in Table 2-2 are significant for the Hosgri fault

- Specific numerical results of individual hazards analyses are not necessary for the purposes of the study; relative results referenced to the Hosgri source are sufficient to assess possible significance

The four analytical techniques are derived from the application of a standard probabilistic hazard analysis computational technique. For each source, the logic tree is formatted for input to the hazard analysis program. Using the hazard analysis program, the probability of exceedence as a function of ground motion level is computed relative to the probability distribution for the Hosgri fault. These results and additional derived analyses comprise the following four techniques.

Relative Hazard Values. Hazard results in the form of peak acceleration distributions normalized to the Hosgri fault for ground motion at 0.75g level are computed and are presented in Table 2-4. At the 50th-percentile level, the relative probabilities of exceedence for the selected sources are much

less than for the Hosgri source, and range from factors of 1/2800 to about 3 billionths of the value for the Hosgri source. The factors of increase for the 84th percentile values reflect the uncertainty in the hazard results and indicate that the Hosgri source dominates the probabilistic hazard results even when the uncertainty range is considered. These results confirm that the Hosgri source is the most significant to the DCPP site. In Table 2-4 the sources are listed in descending order of contribution to probabilistic hazard. The conclusion is that several of the more distant faults are not significant to the probabilistic hazard.

Relative Deterministic Results. All of the elements of the logic trees except recurrence-related parameters are used to develop a distribution of "deterministic" site ground motions for each seismic source. The results are computed so as to be normalized with respect to the Hosgri source. In Table 2-5, the relative deterministic computations are shown for the four sources having the highest values; ratios are given for relative ground motion values at three points in the distributions. The Hosgri is the dominant source at all probability levels, since the ratios for the other sources are all less than 1.0. It is significant to note that for all the sources except the Little Pine-Foxen Canyon, the ratios have nearly the same values at 50, 84, and 95 percentile levels. Thus the uncertainty in deterministic ground motion values for the Hosgri source is similar to that for the three other sources except that the overall ground motion levels are lower than for the Hosgri.

The range of uncertainty in the deterministic values for the Little Pine-Foxen Canyon source is substantially greater, as shown by the variation in ratios at different points of the distribution. The ratios increase significantly at high percentile values (i.e., extremes of the distribution). Evaluation of the logic tree for this source shows that the cause of this increase in ratio is the very-low-probability scenario considered for the Little Pine-Foxen Canyon source whereby it may be hypothetically extended northwest from its known location (Figure 2-1). This scenario is also responsible for the large dispersion in the relative hazard results for the Little Pine-Foxen Canyon source (Table 2-4). Thus the fault length and seismic capability of the Little Pine-Foxen Canyon source, including its hypothetical extension, are

identified as significant considerations in the analysis. The deterministic analysis also identifies the capability and maximum magnitude of the San Miguelito and Edna faults as significant considerations.

Contribution to Uncertainty. The total uncertainty in hazard analysis (as represented by the distribution about the median hazard curve for each seismic source) may be analyzed in terms of the contribution that each technical consideration or set of considerations contributes to the total uncertainty. In this way, it is possible to identify those considerations that contribute most to the total uncertainty and whose resolution would lead to the greatest reduction of uncertainty. These considerations would thereby be identified for emphasis in the scope of work. Because of its dominance in terms of deterministic and probabilistic ground motions, the total uncertainty has been analyzed for the Hosgri fault. Considerations have been aggregated to focus the analysis on nine main topics, as shown in Table 2-6.

Contributions to uncertainty are assessed for both deterministic ground motions and for probabilistic ground motions. The incremental percentage contribution to uncertainty resulting from each consideration is given. The first seven considerations are related to seismic source characterization, and the eighth and ninth (ground motion model and amplification) are included to show the relative significance of source characterization considerations to ground motion considerations. The uncertainty analysis clearly shows that ground motion considerations are important. Source characteristics that are important to the uncertainty in either the deterministic or probabilistic assessments are the sense of slip, maximum magnitude, slip rate, and fault dip.

Relative Magnitude Contribution. Unlike deterministic ground motion estimates that only consider the ground motions resulting from the maximum earthquake magnitude occurring at the closest point on a seismic source, probabilistic estimates also include contributions from smaller magnitude events, which are usually assumed to occur more frequently. By examining the relative contributions of various magnitude increments to the total probabilistic seismic hazard, it is possible to assess whether considerations associated with the maximum magnitude are more important than those associated with the

distribution of smaller events (e.g. earthquake recurrence models). Because of the dominance of the Hosgri fault, this analysis was done for this fault and is shown in Table 2-7.

The results show that the largest contribution to the hazard results from magnitudes at or within one magnitude unit of the maximum event. This suggests that for the Hosgri fault the considerations related to the size of the maximum magnitude and the recurrence of events close in size to the maximum are probably more important than considerations related to the frequency of small to moderate magnitude earthquakes. Therefore, studies focused on reducing the uncertainty about maximum magnitude values are relatively significant.

2.2.4 Judgmental Approaches to Identifying Technical Considerations

In addition to the analytical techniques used to identify and evaluate technical considerations, professional judgment and experience and recommendations made by the NRC were also used.

During the history of the licensing of DCPP, some technical considerations have been of long-term or repeated significance in technical evaluations and decisions. The location and structural association of the 1927 Lompoc earthquake has been identified as such an issue.

During the development, presentation, and initial review of the LTSP, the NRC Staff identified technical considerations they saw as significant. These considerations, compiled from the NRC's questions on the LTSP Program Plan, are presented in Table 2-8.

Additional considerations were identified that are based on professional judgments made during the reviews and evaluations performed during this study. In particular, the members of the Long Term Seismic Program Consulting Board have critically reviewed the identification and evaluation of considerations. Additional considerations were also identified through an assessment of combinations of source and extreme-valued parameters that were judged unlikely, but would be potentially significant if they were likely.

2.3 IDENTIFIED TOPICS

From the evaluations described above, several technical considerations were found to be significant. These considerations have been grouped into seven topics. The topics provide the primary basis for developing the work plan. Each is discussed below, followed by a comparison of the various work items with the NRC-identified issues.

2.3.1 Hosgri Fault

A key technical topic is the characterization of the geometry and behavior of the Hosgri fault. The evaluations made as part of this study show that several aspects of the Hosgri fault are important. First, the sense of slip is of utmost importance, primarily because of its relevance to the tectonic model of the region. The Hosgri fault is a significant fault of the central California coastal region and exists within the transition zone between the Coast Ranges and the Transverse Ranges; therefore, its sense of slip is important to understanding the kinematic relationship among major structures in this region. The dip of the fault and the downdip extent of the fault within the brittle crust are important to an understanding of the appropriate tectonic model for faulting in this region as well as the proximity of the fault to the site. The total length of the Hosgri fault and its degree of segmentation are important for understanding the tectonic model and for assessing the maximum earthquake magnitude. The slip rate of the Hosgri fault is judged to be very important to an understanding of the kinematic role that the fault plays in the accommodation of interplate strain. In addition, the slip rate provides a strong constraint on the earthquake recurrence rate, which, in turn, is important to the probabilistic seismic hazard assessment.

2.3.2 Edna and San Miguelito Faults

Because uncertainty exists regarding the capability of the Edna and San Miguelito faults, their capability is a significant consideration. Although the Edna fault is not a major fault in the central coast region, its proximity

to the site and its northwesterly orientation suggest that its sense of slip is important to understanding the tectonic model appropriate to the site region. Despite the fact that the lengths of both of these faults are limited, their proximity to the site suggests that if they are found to be capable, the assessment of their maximum magnitudes should be a consideration. The slip rate on these faults is also judged to be potentially important to estimates of earthquake recurrence rates.

2.3.3 West Huasna, Rinconada, and Nacimiento Faults

The West Huasna, Nacimiento, and Rinconada faults are relatively major faults of the central California coastal region that are reasonably close to the site. A knowledge of their sense of slip could assist in understanding the tectonic model appropriate to the site region. Another consideration that was found to be of moderate significance for these faults is their slip rates. Their rates of slip are indications of their degree of importance in understanding the tectonics within the plate boundary region. Slip rate is also important to the earthquake recurrence rate on these faults, although their distance from the site greatly limits their contributions to the probabilistic seismic hazards at the site.

2.3.4 Little Pine-Foxen Canyon Fault, Onshore Santa Maria Basin

Included in this topic with the Little Pine-Foxen Canyon fault is an assessment of the internal structure and boundary relations of the Santa Maria Basin. The capability of this fault is uncertain and is therefore judged to be of potential importance. Because the Little Pine-Foxen Canyon fault may be a relatively major tectonic element in the site region, its geometry and sense of slip were found to be of some significance to the regional tectonic model. The total length of the Little Pine-Foxen Canyon fault is found to be potentially significant because its northerly extent (hypothesized Santa Maria River fault) and proximity to the site are uncertain (Figure 2-1).

2.3.5 1927 Earthquake

The location of the November 1927 earthquake and its tectonic association with offshore faults west of Point Arguello was an important consideration during the selection of the seismic design basis for DCPP. Updating the understanding of the event is significant from the standpoint of its size, location, focal mechanism, postulated association with the Hosgri fault zone, and relation to regional tectonics.

2.3.6 Unknown Nearby Faults and Folds

The existence of folds and presently unknown faults proximate to the site and their capability are judged to be potentially significant considerations. If such features were found to exist and to be capable, then estimates of their maximum magnitudes and earthquake recurrence rates would be important.

2.3.7 Tectonic Model

The appropriate tectonic model for the site region is judged to be very important to the license condition. The tectonic model includes consideration of proposed hypotheses such as listric thrust faulting and the existence and capability of a regional decollement. As part of the tectonic model, an evaluation is needed of the distribution of strain within the plate boundary region. The kinematics of regional structures should be integrated into the model and the implications to seismicity examined.

2.4 WORK PLAN

Once the significant topics were identified and evaluated, a series of work items and investigations were identified that would address each topic. These work items were then prioritized with respect to their relative usefulness and potential for addressing the significant topics. Based on this analysis, particular tasks and subtasks were developed that became an integral part of the work plan. Also included in the work plan are the expected products of each task and the interaction of tasks. The schedule for the geology/seismology/geophysics activities is given in Figure 1-1.

Individual tasks are described below in terms of the planned activities, expected products, and interaction of tasks.

2.4.1 Task 1 - Characterization of the Geometry and Behavior of the Hosgri Fault

This task addresses those aspects of the Hosgri fault that are related to its seismic potential, including its sense of slip, downdip width, total length, segmentation, and slip rate. As part of this task, available geologic, geophysical, and geodetic data will be reviewed for the region along the San Gregorio-Hosgri trend and within the Santa Maria Basin inner zone (Figure 2-1). Available and newly acquired seismic reflection data will be integrated with borehole and surficial geological data to develop a map of the San Gregorio-Hosgri trend and structural contour maps of several prominent horizons. These will provide an updated basis for assessment of the earthquake potential of the Hosgri fault.

Subtask 1.1 - Review of Geology and Geophysics. The geology and geophysics of the San Gregorio-Hosgri trend will be reviewed as part of this subtask, including available field mapping, seismic reflection profiles, well data, and potential field studies. The review will include an examination of the pattern of structures at the junction of the San Gregorio fault with the San Andreas fault, as well as an interpretation of the slip rate of the San Andreas fault north and south of this junction. The geology of the onshore regions adjacent to the San Gregorio-Hosgri trend (e.g., Santa Lucia and Santa

Cruz mountains) will be reviewed for evidence of Quaternary deformation and for listric thrust faulting. Finally, the structure at the south end of the Hosgri fault will be reviewed, especially with regard to the structural and tectonic relationship of this fault to the Western Transverse Ranges structural province. The results of this subtask will be used in Subtask 1.5.

Subtask 1.2 - Review of Geodetic Data. Vertical and horizontal geodetic modeling data and interpretations will be reviewed to evaluate evidence for the sense of slip and the rate of slip along the San Gregorio-Hosgri trend. The results of this assessment will be compared with geologic studies performed as part of Subtask 1.3.

Subtask 1.3 - Geologic Studies of Onshore Portions of Trend. Available evidence will be reviewed and neotectonic studies performed to assess the distribution, geometry, and rate of slip on the onshore portions of the San Gregorio-Hosgri trend. Particular emphasis will be placed on the San Simeon fault zone and on establishing its Quaternary behavior. Neotectonic studies may include interpretation of air photos (including low sun angle), local mapping, shallow seismic reflection, exploratory trenching, and age dating of dislocated horizons. These studies will integrate the results of the neotectonic/Quatenary studies (Task 2) to arrive at the style, distribution, age, and rates of displacement of onshore segments of the San Gregorio-Hosgri trend. The results of the subtask will provide a major basis for Subtask 1.5.

Subtask 1.4 - Analysis of Geophysical Data. For this subtask, seismic reflection data will be reviewed, selected, acquired, and analyzed for the region along the Hosgri fault trend and eastward to the near-shore region. Deep multichannel seismic data (e.g., Ogle-GSI, Western, Digicon, Seisdata) will cover the Hosgri trend as well as portions of the onshore Santa Maria Basin. The deep data will be interpreted along with data from the intermediate depth (e.g., CGI, Nekton) and shallow, high-resolution data (e.g., USGS, MMS, PGandE data). Reprocessing of the multichannel reflection

data will be performed as necessary to further define the geometry, age, and structural nature of the Hosgri trend. Potential field data (e.g., aeromagnetic and gravity) will be analyzed, and the results will be integrated with interpretations of the San Gregorio-Hosgri trend and the Santa Maria Basin inner zone. The results of this subtask will be directly utilized in Subtask 1.5.

Subtask 1.5 - Development of Fault Map and Areawide Structural Contour/Isopach Maps. On the basis of data gathered and interpreted in Subtasks 1.1 through 1.4, a map of the overall San Gregorio-Hosgri trend will be developed with dips determined wherever possible. By tying well logs and seismic reflection data into cross-sections and fence diagrams, structural contour maps of several prominent horizons within the Santa Maria Basin inner zone will be developed. The fault map and structural contour maps will include interpretations of the geometry and continuity of faults on the San Gregorio-Hosgri trend, including evaluation of the structural relationship between the Hosgri and San Simeon faults and between the southern termination of the Hosgri fault and the faults of the Western Transverse Ranges. Also included in this subtask will be interpretations of the age and slip rate along the length of the trend, integrating the onshore and offshore interpretations.

2.4.2 Task 2 - Neotectonic and Quaternary Geology Studies

The objective of this task is to provide data and interpretations of the location and age of deposits and surfaces that can aid in understanding the nature and timing of neotectonic deformation throughout the central California coastal region. Neotectonic is here understood to refer to the time span since the existing pattern of relative motion along the Pacific-North America Plate boundary was established, somewhere between 5 and 1 mya.

Subtask 2.1 - Mapping of Geomorphic Surfaces. Quaternary geomorphic surfaces and associated deposits will be identified and mapped within the Santa Maria

Basin inner zone, with particular emphasis on locations important to the understanding of both fault behavior and of regional tectonic deformation within fault-bounded blocks. Onshore field mapping may be supplemented by aerial photo analysis, shallow seismic refraction, shallow drilling, and exploratory trenching, as required. Offshore studies will include mapping of both sea floor and shallow subsea floor horizons. Onshore and offshore deposits and surfaces will be correlated to the extent possible. These studies will be conducted in coordination with other field tasks (Tasks 1, 4, 5, and 6) to assist in interpretations of ages and field relationships. This subtask also provides significant input to interpretations of neotectonic deformation (Subtask 2.3).

Subtask 2.2 - Analyze Seismogenic Potential of Active Folds. As an integral part of the geologic analysis of the San Luis-Pismo fold trend outlined in Task 4, case studies of earthquakes associated with active surface folds (e.g., Coalinga earthquake) will be reviewed and analyzed for characteristics such as geometry of seismogenic source, form and amount of coseismic surface deformation, earthquake magnitude, sense of slip, amount of slip, hypocentral depth, and geologic/geodetic constraints on the rate of deformation. These characteristics will be used to interpret the likelihood of seismogenic surface folding in the local area.

Subtask 2.3 - Interpretation of Neotectonic Deformation. In conjunction with other tasks, the age, style, and amount of neotectonic deformation at selected localities will be interpreted. Study objectives include deformation of the marine terraces along the San Simeon fault zone and possibly along other onshore portions of the San Gregorio-Hosgri trend. Fluvial terraces along the northeastern boundary of the Santa Maria Valley will be analyzed for evidence of faulting and regional tilting or folding. Local studies along individual faults, including those specified in Tasks 1, 4, 5, and 6, as well as any newly recognized zones of significant deformation, will focus on determining the style and rate of Quaternary fault slip. Available geodetic data will be incorporated in estimates of Holocene deformation rates.

As needed for tectonic interpretations, geomorphic surfaces and late Neogene deposits will be dated using absolute and relative age-dating techniques, such as tephrachronology, amino acid racemization, radiocarbon and uranium-thorium analysis, and soil profile development.

2.4.3 Task 3 - Seismology Studies

Subtask 3.1 - Seismicity Analyses. The objective of this subtask is to compile and analyze seismicity data within the central coastal region of California. The resulting data sets and analyses are used to assess such topics as the association between seismicity and geologically or geophysically identified faults, the depth of the seismogenic zone, and the orientation of the local or regional stress regime. The coastal region of central California consists of the region north of the Transverse Ranges, south of Monterey Bay, and west of the San Andreas fault. As is appropriate for comparative purposes, earthquake activity adjacent to this region may be considered as well.

Seismicity catalogs for the coastal region of California will be compiled and integrated. Data sources include USGS; California Institute of Technology (CalTech); University of California, Berkeley (UCB); and California Division of Mines and Geology (CDMG). Location accuracy and seismic station density as a function of time and space will be assessed. A computerized catalog of regional seismic stations will be prepared including operating history, instrument type, location, etc.

As part of this subtask, original phase data will be acquired for approximately 1,000 selected events of interest in the vicinity of faults and fault zones of coastal California that are studied in the other tasks. Relocations will be made using individual event and master or joint location techniques. Key arrival times will be reread as needed. Velocity models and location programs appropriate to the region of interest will be used, based on the experience of the USGS and others. Data bases and analyses will be set up to easily update the relocation analyses using results of Subtask 3.2.

Available single-event focal mechanisms will be compiled for earthquakes in coastal California. For events occurring along the southern Coast Ranges for which mechanisms have not been determined, the feasibility of constraining mechanisms will be evaluated, either individually or as composite mechanisms, and additional mechanisms will be prepared (approximately 50). For larger earthquakes in the region (magnitude greater than 4), the data will be examined for events amenable to waveform modeling, and such modeling will be performed for selected events (approximately 10) using regional phase data (e.g. Pnl). Crustal velocity models developed in Subtask 3.2 will be used.

For use in earthquake recurrence estimates, the magnitude information associated with the earthquake catalogs will be reviewed. Uniform magnitude scales will be established as a function of time, and magnitude detection limits will be evaluated. Relationships among magnitude scales will be assessed for the region to allow physically meaningful extrapolation of frequency-magnitude data sets. Mathematical models (e.g., log-linear, "characteristic") to describe the observed frequency-magnitude data sets will be used, incorporating temporal variations in catalog completeness and assessments of uncertainties. Both regional and fault-specific models will be considered.

Subtask 3.2 - Refine Crustal Velocity Model. Knowledge of the regional crustal velocity structure is necessary for accurate earthquake locations and focal mechanisms, as well as for understanding regional tectonics. The objective of this task is to compile the available data on crustal structure and, once the Central Coast Seismic Network is operational, to calibrate the network.

As part of this subtask, model data including refraction, reflection, potential field inversions, surface wave inversions, deep drilling, etc., will be reviewed and the results synthesized. Ranges of parameters and sources of uncertainties will be identified. Basement rock type will be considered in comparing data from different areas along coastal California.

Following installation of the Central Coast Seismic Network, a calibration study will be conducted using onshore and offshore sources (either high explosives or large air guns). This study will be based on:

- Offshore bottom conditions (selecting offshore locales of limited sedimentary deposits for shooting, so as to maximize generation and propagation of S-waves)

- Areas of microearthquake activity

- Expected or possible lateral variations in velocity structure based on available geological and geophysical evidence

Onshore calibration is assumed to involve approximately 10 sites along the area of coverage of the Central Coast Seismic Network. Analysis of the results will focus on improving structure models and microearthquake location accuracy, and on the potential for improving offshore earthquake location accuracy by means of ocean bottom stations. The results of this subtask provide input to the deep crustal studies (Task 7).

Subtask 3.3 - 1927 Earthquake Analysis. The 1927 earthquake has been an important element in the design earthquake assessment for DCPP. The objective of this subtask is to assemble and synthesize the available information about this event and to perform modeling studies to update the earthquake source characterization.

Published and unpublished evidence regarding the location, size, focal mechanism, and effects of the 1927 earthquake will be reviewed and compiled. Recent evaluations of tsunami sources by the USGS, geodetic modeling for coseismic slip, and available marine geology evidence for coseismic surface rupture or local sea floor uplift will be included. The likely impact of performing more studies in these areas will be assessed.

Regional and teleseismic seismograms for the 1927 earthquake will be compiled. Teleseismic modeling studies of body waves will be performed to constrain the earthquake mechanism, focal depth, and uncertainties of the results. As appropriate, the 1927 earthquake data and models will be compared with those of the October 22 and November 5, 1969 Santa Lucia Banks earthquakes.

2.4.4 Task 4 - Studies of Edna and San Miguelito Faults and San Luis-Pismo Fold Trend

The objectives of this task are:

- To review and characterize the Edna and San Miguelito faults, focusing on evidence concerning their capability, sense of slip, segmentation, and slip rate
- To develop an understanding of the structural evolution of the San Luis-Pismo fold trend
- To evaluate the local site area for evidence of late Quaternary tectonic deformation

Subtask 4.1 - Review and Analysis of Available Geologic Data. Available geologic mapping, oil wells, and geophysical data in the local area will be reviewed with emphasis on faults and the relationship among the Franciscan, Obispo, Monterey, Pismo, and Paso Robles formations and the unconformities that separate them. The geologic history of the San Luis-Pismo fold trend will be reviewed. Balanced cross-sections will be prepared to the extent possible, or other structural analysis appropriate to illuminating the style and rate of deformation will be performed. These studies will provide a framework for conducting the geologic field studies (Subtask 4.2).

Subtask 4.2 - Geologic Field Studies. Geologic field mapping will be conducted to confirm structural/stratigraphic relations, focusing on unconformities and evidence of tectonic transport based on microstructural analysis. Remote sensing data will be reviewed for evidence of Quaternary deformation and local shallow subsurface studies (e.g., drilling, trenching) will be conducted as required. Sea-cliff exposures in the local area will be examined for evidence of tectonic transport and deformation associated with either tectonic activity or volcanic intrusion. The results of the shallow offshore review (Subtask 4.3) will be integrated with this task in making interpretations.

Subtask 4.3 - Offshore Geophysics Review. Available high-resolution reflection profiles in the near-shore area will be reviewed for evidence of direct fault disturbance of the sea floor, shallow Quaternary deposits, or deformation of submerged benches and shoreline angles. The results of the review will be integrated with the onshore geologic studies.

2.4.5 Task 5 - Studies of Little Pine-Foxen Canyon Fault Trend and Onshore Santa Maria Basin

The objectives of this task are:

- To review and characterize the Little Pine-Foxen Canyon fault trend with particular emphasis on capability, total length, sense of slip, and downdip width of the faults that define this trend

- To review and characterize the major structural features and trends of the Santa Maria Valley-Santa Ynez Valley region, in order to establish the structural relation of this region to the structure and neotectonics of the Western Transverse Ranges to the south.

Subtask 5.1 - Review of Available Geologic Data. Available geologic mapping and surface interpretations from well data and geophysics will be reviewed for the region generally and especially in the vicinity of the Little Pine-Foxen

Canyon fault trend. As part of this review, particular locations for additional geologic studies to be made as part of Subtask 5.2 will be identified.

Subtask 5.2 - Geologic Field Studies. At particular locations along the Little Pine and Foxen Canyon faults and along trends of other known and suspected structural features, geologic field mapping will be conducted to confirm observable structural/stratigraphic relations. Particular emphasis will be placed on evidence for the hypothesized Santa Maria River fault. As required, field mapping will be supplemented with review of remote sensing data and local shallow subsurface studies (e.g., drilling, trenching). The locations and scope of the field efforts for this subtask will be based, in part, on the geologic data review (Subtask 5.1), on consideration of the structural contour and isopach maps developed for the Santa Maria Basin as part of Subtask 1.5, and on the results of the neotectonic/Quaternary studies of Task 2.

2.4.6 Task 6 - Studies of West Huasna, Rinconada, and Nacimiento Faults

The objective of this task is to review and characterize the West Huasna, Rinconada, and Nacimiento faults, with particular emphasis on their sense of slip and late-Quaternary slip rate.

Subtask 6.1 - Review of Available Geologic Data. Available geologic studies of the West Huasna, Rinconada, and Nacimiento faults will be reviewed to focus on the history of slip and sense of slip on these faults. As part of this review, particular key locations for additional geologic studies will be identified for consideration in undertaking Subtask 6.2.

Subtask 6.2 - Geologic Field Studies. To supplement the available data base related to the West Hausna, Rinconada, and Nacimiento faults, geologic mapping will be conducted at key locations along the faults and their major branches (e.g., Suey fault, East Huasna fault). To supplement the mapping efforts,

remote sensing data may be reviewed, and local shallow subsurface studies (e.g., trenching) will be performed if required. The results of these studies may include maps, trench logs, well logs, and text.

Subtask 6.3 - Analyze Seismic Reflection and Refraction Data. To place possible constraints on the geometry and sense of slip of the West Huasna, Rinconada, and Nacimiento faults, deep seismic reflection and refraction lines (e.g., Seisdata, Western, USGS) will be analyzed. The geophysical interpretations will be made in conjunction with other tasks (1, 4, 7) to ensure that they are compatible. In addition, the location and orientation of faults in the seismic data will be compared with the geologic interpretations made in Subtask 6.2. As a part of this subtask, interpretations will be made that directly address the sense of slip and late-Quaternary slip rate of these faults. The results of this subtask will include interpreted seismic profiles and written discussion.

2.4.7 Task 7 - Deep Crustal Studies

The objectives of this task are:

- To review current interpretations and models of intermediate and deep crustal structure in geotectonic settings comparable to that of the southern Coast Ranges

- To review available deep crustal data for the Santa Maria Basin region, including deep seismic reflection, refraction, gravity, magnetic, seismicity, and geologic data

- To acquire and analyze appropriate data in order to evaluate the existence, form, history, and capability of a postulated regional decollement in coastal south-central California

Subtask 7.1 - Review Deep Crustal Models for Continental Transform Boundaries. Current interpretations and models of intermediate and deep crustal structure, crustal studies, interpretations, and models for geologic environments similar to that of coastal central California (translational-convergent plate boundary regions) will be reviewed to provide a framework for interpretation in the Santa Maria Basin region as part of Subtasks 7.2 and 7.3.

Subtask 7.2 - Review Deep Crustal Data for Santa Maria Basin Region. Available deep crustal data (depths of 5 to 15 km) applicable to the Santa Maria Basin region will be reviewed. Such data include deep seismic reflection, refraction, gravity, magnetic, and geologic data. Seismologic results from Subtask 3.2 will be incorporated. Some of these data are available from the USGS, other research and academic organizations, geophysical contractors/data vendors, and oil companies. Data review as part of this subtask provides a basis for the analysis conducted in Subtask 7.3.

Subtask 7.3 - Synthesize Deep Crustal Model for Santa Maria Basin Region. This task will acquire, reprocess as necessary, and analyze appropriate data reviewed for Subtask 7.2. The analysis will seek to establish:

- The general form of deep crustal structure
- The relationship of faults and folds expressed near or at the surface to elements of deep crustal structure

Particular emphasis will be directed toward determination of whether a regional decollement feature (or local decollements related to individual listric faults) exists within the crust. If evidence for such a feature (or features) is found, an attempt will be made to evaluate the form, history, and role in the contemporary tectonic environment of each decollement. Results of this analysis may include interpreted seismic profiles, maps, and textual discussion. The analysis of the possible existence of a regional decollement will be conducted in conjunction with seismicity studies (Task 3).

2.4.8 Task 8 - Development of Regional Tectonic Model

The objective of this task is to develop a tectonic model of the region pertinent to the site. The tectonic model will be based on a synthesis of available and new interpretations of the regional geology, geophysics, and seismology. The model, which may actually comprise several tectonic hypotheses, will serve as a means of predicting kinematic relationships including the location, timing, and amount of crustal deformation. Various proposed hypotheses will be evaluated as part of this task, including strike-slip tectonics, listric thrust faulting, and the possible existence of a regional decollement.

Subtask 8.1 - Synthesis of Data Pertaining to Tectonic Model. Available data and data developed for other tasks will be synthesized for use in developing a tectonic model as part of Subtask 8.2. This includes evaluations of the Hosgri fault and Santa Maria Basin inner zone (Task 1), and studies of particular faults (Tasks 2, 4, 5, 6, 7). In addition, geodetic evidence, as well as Quaternary data for sense and rate of slip occurring on faults, rate and orientation of fold growth, and other deformation within fault-bounded structural blocks, will be compiled along various transects of central California.

Subtask 8.2 - Development of Model and Its Implications. Based on the synthesis accomplished as part of Subtask 8.1, a regional tectonic model will be developed, and the implications of the model to seismic sources will be evaluated. The tectonic model will take into account the structural patterns and kinematic relationships among folds, faults, and other deformations over various time periods. Primary focus will be on neotectonic processes and deformation and will include assessments of rigid versus nonrigid block motion. Scales will range from the plate boundary scale to the local structural domain in the site vicinity. Based on the compilations of deformation rate data, interpretations will be made of the distribution of strain across the plate boundary in the central California region, including

the relationship between the kinematics of faults and folds in the Santa Maria Basin to crustal shortening and left-slip faulting in the Transverse Ranges. This subtask will include evaluation of graphic and computer-simulation models for representing and evaluating kinematic models.

In developing the regional tectonic model, the various proposed hypotheses (e.g., large scale right-slip listric thrust faulting) will be considered for compatibility with the available data. Where considerable uncertainty exists and it is not possible to select one model over another, multiple models will be included and evaluated for agreement with the available data. The implications of the resulting regional tectonic model will be assessed with respect to fault geometries, styles of deformation, rates of activity, and potential seismicity. These implications will provide a comparative basis for the source characteristics assessed in Task 9.

2.4.9 Task 9 - Seismic Source Characterization

The objective of this task is to characterize the potential seismic sources in the site region for purposes of deterministic and probabilistic ground motion assessment. A key element of this task is the evaluation of uncertainty in source characteristics through the use of logic trees.

Subtask 9.1 - Specification of Seismic Sources. Each potential source will be defined by parameters that specify its capability, geometry, and late Quaternary behavior. The parameters will include: recency of slip, rate of slip, structural association with capable faults, association with seismicity, sense of slip, dip, downdip width, total length, rupture length, segmentation, maximum displacement per event, and distribution of slip along active traces per event. The specification of these parameters will come from the data and analyses developed in fault-specific tasks (Tasks 1, 3, 4, 5, and 6). Parameters and associated weights will be documented by updating the logic tree analysis that was initiated for the LTSP Phase II scoping study. If any non-fault-specific seismic sources (e.g., random source zones) are deemed to be required for the seismic hazard analysis, they will be identified as part of this subtask.

Subtask 9.2 - Maximum Earthquake Magnitude Assessment. On the basis of the parameters selected in Subtask 9.1 and on empirical relations between earthquake magnitude and fault characteristics, maximum earthquake magnitudes will be assessed. Multiple approaches will be utilized and the several published empirical relationships will be examined to determine the applicability of the data contained therein to the faults in the site region. It is expected that the relationships to be examined will include those relating magnitude to total length, rupture length, rupture area, displacement per event, slip rate, seismic moment, and maximum historical event. From this analysis, each technique will be weighted as to its applicability to this magnitude assessment.

Subtask 9.3 - Earthquake Recurrence Assessment. For purposes of the probabilistic seismic hazard assessment, earthquake recurrence for all seismic sources will be estimated. The primary basis for these estimations will be late-Quaternary fault slip rate data defined in other tasks. The possibility of seismic slip associated with active folding will also be considered. Available recurrence models for utilizing slip rates will be examined and appropriate models selected. Recurrence based on historical seismicity (Task 3) will be compared with the seismic moment rates derived from slip rate data. If appropriate, non-Poisson spatial-temporal earthquake models will be used (e.g., renewal model) if the data required to parameterize the models are available.

2.4.10 Comparison of Work Plan with NRC Issues

As discussed in Section 2.1, the NRC Staff identified a number of issues in its review of the LTSP Program Plan. The various tasks of the work plan outlined here directly address each of the issues raised. The correlation of the issues with the tasks is shown in Table 2-8.

Table 2-1

LIST OF POTENTIAL SEISMIC SOURCES
INCLUDED IN THE SCOPING STUDY

Hosgri Fault

Little Pine/Foxen Canyon Fault Trend

West Huasna Fault

San Miguelito Fault

San Andreas Fault

Santa Lucia Bank Fault

Offshore Lompoc Fault

Edna Fault

Rinconada Fault

Nacimiento Fault

Table 2-2

LOGIC TREE CHARACTERISTICS

The following fault characteristics are included in the logic trees:

- Sense of slip (fault type)
- Evidence of recency of slip
- Causal association with earthquakes $M > 5$
- Causal association with earthquakes $M < 5$
- Structural association with capable fault
- Fault dip
- Downdip fault width (within the brittle crust)
- Segmentation
- Total fault length
- Rupture length
- Displacement per event
- Maximum historical earthquake
- Fault slip rate
- Earthquake magnitude distribution model
- Earthquake temporal model

Table 2-3

RANGES OF VALUES USED IN LOGIC TREES

Fault	Sense of Slip	Prob. of Capability*	Fault Dip	Downdip Width	Total Length	Rupture Length	Max. Dis. Per Event	Max. Histor-ical EQ	Slip Rate
Hosgri	RLSS-Thrust	0.99	15°-90°	9-58 km	150-400 km	10-200 km	0.5-2m	5.5-7.3	0.4-23 mm/yr.
Edna	RLSS-Thrust	0.93	15°-90°	9-58 km	40-60 km	15 km	no data	5.5	0.001-0.1
San Miguelito	RLSS-Thrust	0.48	30°-90°	9-30 km	10-20 km	10 km	no data	5.5	0.001-0.01
West Huasna	RLSS-Thrust	0.90	15°-90°	9-58 km	40-200 km	20 km	no data	5.5	0.1-1.0
Little Pine-Foxen Canyon	RLSS-Thrust	0.78	15°-90°	9-58 km	60-140 km	12-70 km	no data	5.5	0.1-0.1
Rinconada	RLSS-Thrust	0.96	15°-90°	9-58 km	130-250 km	26-125 km	no data	5.1	0.1-12
Nacimiento	RLSS-Thrust	0.98	15°-90°	9-58 km	150-250 km	10-60 km	no data	6.2-6.7	0.05-1.0
Offshore Lompoc	RLSS-Thrust	0.91	15°-90°	9-58 km	25 km	13-25 km	no data	7.3	0.2-2.0
Santa Lucia Bank	RLSS-Thrust	0.98	15°-90°	9-58 km	100-200 km	20-100 km	no data	5.5-7.3	0.05-1.0
San Andreas	RLSS	1.0	60°-90°	9-17.3 km	1400 km	**	**	7.5-8.3	9-45

* Probability of capability derived from consideration of recency of slip, association with seismicity, and relation to other capable faults.

** Maximum magnitude defined from maximum historical magnitude.

Note: Other source characteristics included on logic tree are fault segmentation, recurrence model, and temporal occurrence model.

Table 2-4

RELATIVE PEAK ACCELERATION HAZARD RESULTS AT 0.75g

Source	Relative Probability of Exceedance 50th Percentile	Factor Increase for 84th Percentile
1. Hosgri	1	10
7. Little Pine/Foxen Canyon	$<10^{-4}$	>100
2. Edna	2×10^{-3}	9
3. San Miguelito	9×10^{-4}	6
8. San Andreas	$<10^{-4}$	5
5. Nacimiento	7×10^{-4}	15
4. West Huasna	9×10^{-4}	14
6. Rinconada	2×10^{-4}	9
9. Santa Lucia Bank	$<10^{-4}$	10
10. Offshore Lompoc	$<10^{-4}$	20

Table 2-5

RELATIVE DETERMINISTIC GROUND MOTION RESULTS AT 0.75g

Source	Percentile Value		
	50%	84%	95%
Hosgri	1	1	1
San Miguelito	.71	.76	.78
Edna	.72	.71	.78
LP-FC	.09	.47	.61
West Huasna	.32	.35	.38

Table 2-6

CONTRIBUTIONS TO UNCERTAINTY IN HAZARD

HOSGRI FAULT

Issue	% Contribution to Deterministic Results	% Contribution to Probabilistic Results
1. Sense of slip (fault type)	1.6	24.0
2. Fault dip (angle measured from horizontal)	10.4	9.4
3. Down-dip extent of fault within seismogenic crust	0.2	0.6
4. Total fault length	0.1	0.0
5. Maximum magnitude	23.1	6.0
6. Earthquake size distribution model (exponential or characteristic)	0.0	0.3
7. Seismic slip rate	0.0	14.7
8. Ground motion attenuation model (see note 1 below)	40.0	31.8
9. Ground motion amplification factors based on fault type and dip (see note 2 below)	24.5	13.1
	100%	100%

Note 1: The following three models were selected as representative of methods for estimating peak acceleration at DCPP and were assigned equal weight:

- Joyner and Boore (1981)
- Campbell (1981)
- Sadigh (1983)

Note 2: Amplification of ground motion resulting from certain styles of faulting and focusing. The following factors were used to represent ground motion amplification:

Vertical strike-slip faults	1.0
Inclined strike-slip faults with site above fault projection	1.2 1.4
Thrust, listric thrust, reverse, and oblique faults with site on upthrown block	1.1 1.95 3.0

Table 2-7

PERCENT CONTRIBUTIONS TO 0.75g HAZARD BY MAGNITUDE RANGE

HOSGRI FAULT

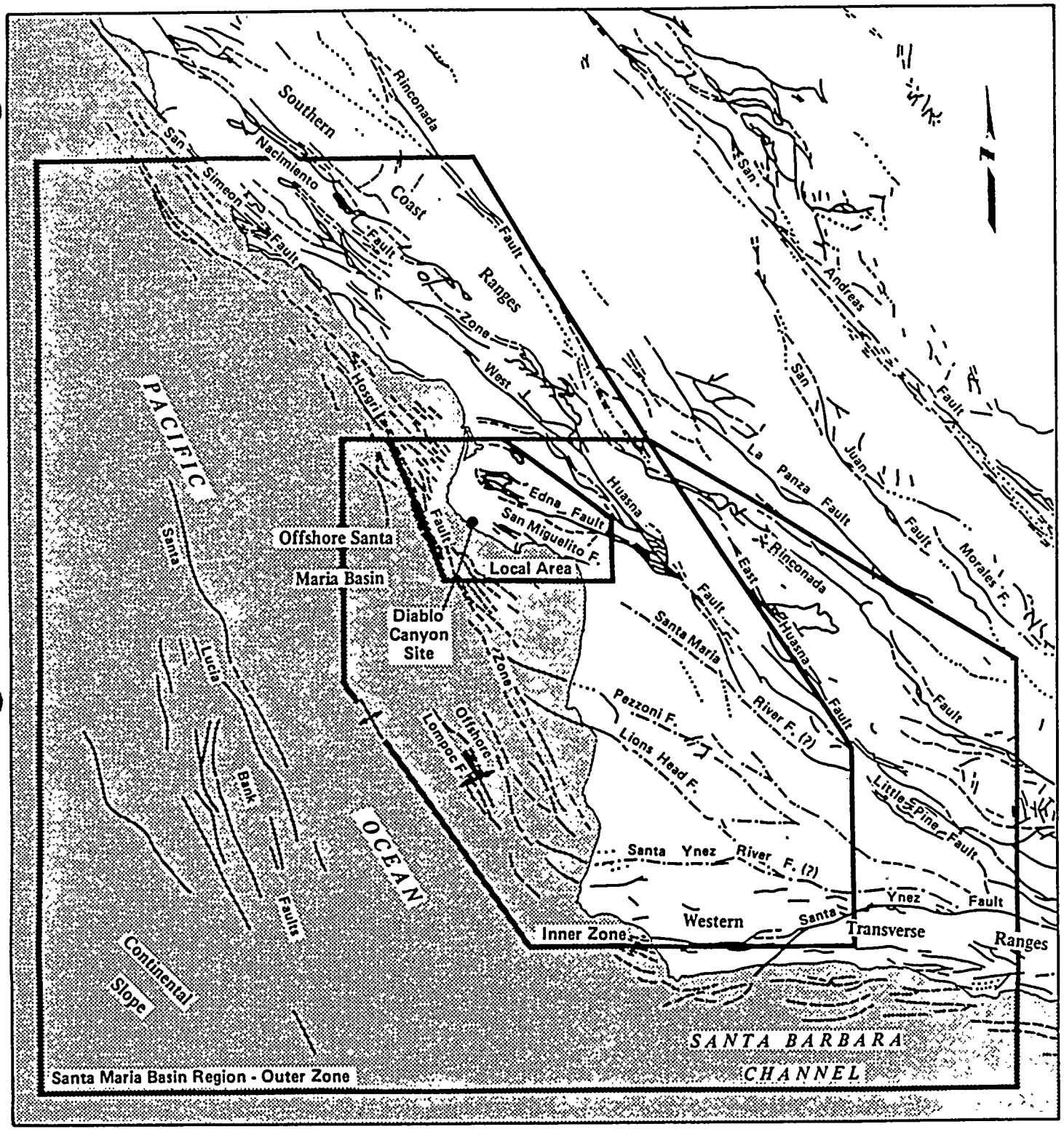
	$5.0 < M \leq 5.5$	$5.5 < M \leq 6.0$	$6.0 < M \leq 6.5$	$6.5 < M \leq 7.0$	$7.0 < M \leq 7.5$
Max. mag.=6.00	3.5	96.5			
Max. mag.=6.25	1.3	23.4	75.3		
Max. mag.=6.50	0.6	6.7	92.7		
Max. mag.=6.75	0.3	4.1	36.4	59.2	
Max. mag.=7.00	0.2	2.3	16.7	80.8	
Max. mag.=7.25	0.1	1.5	10.6	42.2	45.5
Max. mag.=7.50	0.1	1.2	8.7	27.0	63.0

Table 2-8

TECHNICAL CONSIDERATIONS IDENTIFIED IN NRC COMMENTS

TO LTSP PROGRAM PLAN

Geology/Tectonics	Geology/Seismology/Geophysics Task Where Addressed
Sense of slip, amount and age of slip on Hosgri fault	1
Linkage of Hosgri, San Simeon, San Gregorio fault zones	1
Relationship of Hosgri fault zone to Transverse Range structures	1, 8
Alternative tectonic models	8
Presence and earthquake potential of nearby faults and folds (flexural slip folding)	2, 4
Presence and earthquake potential of horizontal detachment	7, 8
Amount and style of slip to west of San Andreas fault	8
Cumulative slip and slip rate on San Gregorio, Palo Colorado, Sur, San Simeon, and Hosgri faults	1, 8
Slip rate on San Andreas fault north and south of junction with San Gregorio	1, 8
Maximum Magnitude	
Use and documentation of multiple empirical approaches	9
Criteria for segmentation	9
Fractional fault lengths	9
Slip rate versus magnitude approaches	9
Use of seismological methods	3, 9

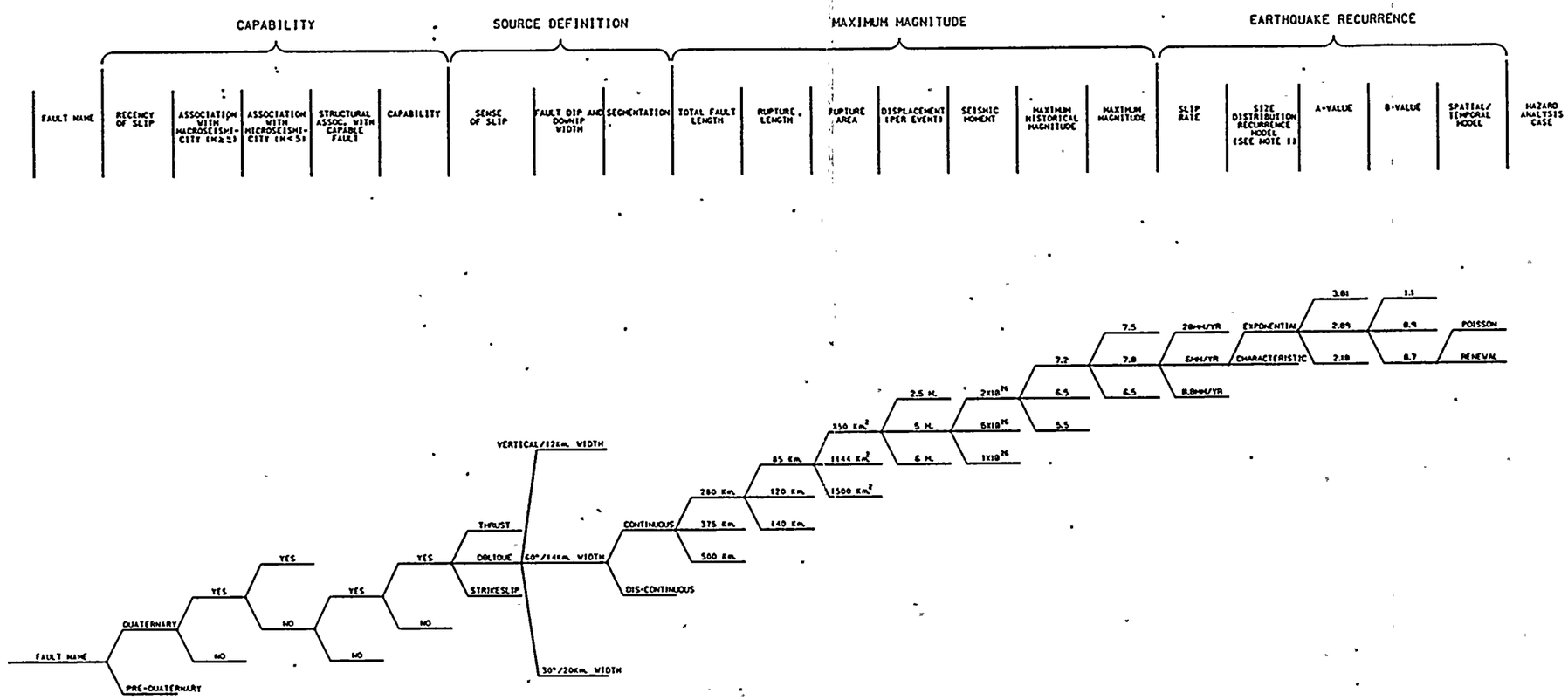


——— Mapped fault, dotted where concealed.

—·—·— Trend of proposed subsurface fault. (Hall, 1977; Sylvester & Darrow, 1978).

SANTA MARIA BASIN REGION

Figure 2-1



EXAMPLE LOGIC TREE

TI APERTURE CARD

Also Available On Aperture Card

PLATE 1

PACIFIC GAS AND ELECTRIC COMPANY
SAN FRANCISCO, CALIFORNIA

8602140130-02

3.0 GROUND MOTIONS

3.1 SCOPING STUDY

An important part of the Long Term Seismic Program is to update the assessment of the nature of ground motions associated with possible seismic sources that are characterized as a result of the previously described geology/seismology/geophysics studies. A detailed refinement of the scope of work in the ground motions area has been conducted during the scoping study and has resulted in a set of tasks that integrate empirical and numerical analyses. To develop these tasks, the primary approaches used to identify significant ground motion considerations were in-house ground motion workshops, analysis of uncertainty, consultations with ground motion specialists, and discussions among the members of the LTSP team.

3.1.1 Ground Motions Workshops

PGandE held two in-house workshops to identify significant ground motions considerations and to develop a set of tasks to respond to these considerations. The participants fully bracketed the fields of earthquake engineering and engineering seismology, with considerable research and applications experience in both empirical and numerical ground motion techniques. At the start of the first workshop, the participants were made aware of the results of the analyses used to identify contributions to uncertainty in ground motions. The significant topics identified during geology/seismology/geophysics scoping were also reviewed as part of the framework for identifying significant ground motion topics.

During both the workshops, advances in ground motions during the past decade were reviewed. These include substantial additions to the strong-motion data base, as recently as the Chilean and Mexican earthquakes of 1985. Also, increasingly accurate physical models have been developed to understand the observations of the dynamic fault-rupture process and to relate these observations and derived models to geological and geophysical features of

earthquakes. Improved data bases and analyses have increased knowledge about the propagation of seismic energy through local site materials.

3.1.2 Contributions to Uncertainty

The analysis of relative seismic hazard, as discussed in Section 2.2.2, required the use of ground motion characteristics in the computational procedures. The ground motion models used for this analysis contain two elements: attenuation relationships and amplification factors. Three attenuation relationships were used in the hazard analysis with one-third weights assigned to each. The variations in ground motions predicted by each of these relationships depend on the distance range and magnitude range of interest. A set of amplification factors were judgmentally determined to reflect influences of certain styles of faulting and of near-source effects on ground motions. Amplification affects ground motions primarily at near-source distances.

The results of the uncertainty analysis for the Hosgri fault indicate that much of the total uncertainty in the hazard is associated with ground motion attenuation relationships. Similar importance of ground motion issues is noted in the uncertainties associated with other seismic sources at close distances from the plant site.

3.1.3 Significant Considerations for Ground Motions

As a result of the above activities, five significant considerations are identified regarding the assessment of ground motions at DCPP for the LTSP:

1. Empirical Ground Motion Models: Numerous recent studies of empirical ground motion relationships provide a reasonable basis for beginning the characterization of ground motions for DCPP. Available relationships for acceleration, velocity, and displacement and associated spectra can be reviewed, and the most appropriate relationships can be selected for use with the initial seismic source characterizations.

2. Incorporation of Recent Data: Existing relationships selected as noted above should be tested or augmented using appropriate recently recorded earthquake data. Such data include the Morgan Hill, Chilean, and Mexican earthquake records within the past several years.

3. Evaluation of Dispersion, Truncation, and Saturation Effects: Dispersion about the mean, truncation at high ground motion levels, and saturation effects for large magnitudes are identified as sensitive considerations. Assessments and refinements of these topics for DCPP are significant in improving ground motion characterizations.

4. Wave Propagation and Site Effects: The LTSP ground motion analyses will provide input ground motions - evaluated for coherency, wave type, and angle of incidence - for soil-structure interaction analyses. Site-specific features of wave propagation need to be included in the treatment of worldwide data sets.

5. Numerical Methods: Computational methods provide the ability to extend the available data bases and relationships to better constrain them in cases of limited data, such as for close distances, large magnitudes, and alternative fault types.

3.2 WORK PLAN

In consideration of the above topics concerning seismic ground motion, specific tasks have been identified to address the topics. Input for these tasks will make use of the results from the geology/seismology/geophysics program. The tasks have been structured with the objective of producing specific products needed during the conduct of the SSI, fragility, and seismic hazards investigations (Figure 3-1). These products include acceleration time histories, probabilistic attenuation relationships for horizontal and vertical peak ground accelerations and velocities, and response spectra for use in deterministic and probabilistic evaluations of seismic risk. The schedule for the ground motion studies, including dates for primary interaction with the other parts of the LTSP, is given in Figure 1-1. The identified tasks on seismic ground motion are described in the following subsections.

3.2.1 Task 1 - Selection of Attenuation Relationships for Peak Ground Acceleration and Velocity

The objective of this task is to select a set of attenuation relationships which will give peak ground acceleration and velocity as a function of magnitude and distance for use in deterministic and probabilistic assessments of the free-field ground motion at the plant site.

Subtask 1.1 - Select Appropriate Attenuation Relationships for Horizontal and Vertical Peak Ground Accelerations and Velocities for Rock Site. Available attenuation relationships will be critically reviewed for:

- Their applicability to the project in terms of source characteristics, travel path conditions, and site properties

- Their appropriateness for providing estimates on the median values as well as the dispersion about the median of the peak ground acceleration and velocity in the magnitude and distance range of interest to the LTSP

Attenuation relationships for both horizontal and vertical peak accelerations and velocities will be selected. The results of this subtask will be a set of candidate attenuation relationships for potential use in evaluating ground motions for the LTSP.

Subtask 1.2 - Refine Attenuation Relationships with Recent Earthquake Data and Evaluate Statistical Dispersion and Upper Bound Constraints. The candidate attenuation relationships identifed in Subtask 1.1 will be further tested for their ability to predict peak accelerations and velocities recorded at rock sites during recent earthquakes. Emphasis will be placed on examination of the existing records obtained in the near-field of California earthquakes, including those obtained at the DCPP site. On the basis of these comparisons, a set of most appropriate attenuation relationships will be selected for future use. Both the available data and the results from numerical modeling (Task 5) will be used to refine the selected attenuation relationships. Statistical dispersion and the upper bound constraints associated with the peak ground accelerations and velocities will also be assessed during the selection and refinement process. It is anticipated that several representative attenuation relationships will be defined to provide estimates of horizontal and vertical peak ground accelerations and velocities for the LTSP.

3.2.2 Task 2 - Assessment of Response Spectra

The objective of this task is to specify a set of response spectra that are representative of the earthquake magnitude, source-to-site distance, and wave environment of the potential seismic sources for use in deterministic and probabilistic assessments of the free-field ground motion at the DCPP site.

Subtask 2.1 - Select Appropriate Horizontal and Vertical Response Spectra for Rock Site. The available response spectra will be critically reviewed for:

- Their applicability to the project in terms of source characteristics, travel path conditions, and site properties

- Their appropriateness for providing estimates on the median values as well as dispersion about the median of the response spectral ordinate in the frequency range of 1 to 30 Hz, and in the magnitude and distance range of interest to the LTSP

Response spectra for both horizontal and vertical ground motions will be selected. The results of this subtask will be a set of candidate response spectra for potential use in evaluating ground motions for the LTSP.

Subtask 2.2 - Refine Response Spectra with Recent Earthquake Data and Evaluate Statistical Dispersion and Upper Bound Constraints. The candidate response spectra identified in Subtask 2.1 will be further compared with the response spectra recorded at rock sites during recent earthquakes. Emphasis will be placed on examination of the existing records obtained in the near-field of California earthquakes, including those obtained at the DCPP site. On the basis of these comparisons, a set of most appropriate response spectra will be selected for future use. Both the available data and the results from numerical modeling (Task 5) will be used to refine the selected response spectra. Statistical dispersion as well as the upper bound constraints of the response spectral ordinate will also be assessed during the selection and refinement process. The selected response spectra will be extended to cover damping ratios in the range of 2% to 10%. It is anticipated that several response spectra that are representative of the earthquake magnitude, source-to-site distance, and wave environment of the potential seismic sources will be defined to provide estimates of the horizontal and vertical response spectral ordinates for the LTSP.

3.2.3 Task 3 - Development of Acceleration Time Histories

The objective of this task is to develop a set of realistic acceleration time histories that are representative of the earthquake magnitude, source-to-site distance, and wave environment of the potential seismic sources for use as input to the soil-structure interaction and fragility analyses for the LTSP.

Subtask 3.1 - Select Representative Horizontal and Vertical Acceleration Time Histories for Rock Site from Existing Accelerograms. The available actual accelerograms of horizontal and vertical components will be critically reviewed for their applicability to the project in terms of earthquake source characteristics, travel path conditions, and site properties. A set of representative horizontal and vertical acceleration time histories will be selected as a result. These selected time histories will be checked for their compatibility with the selected attenuation relationships (Task 1) and the selected response spectra (Task 2). Necessary scaling will be made. Furthermore, the results from numerical modeling (Task 5) will also be used to evaluate these selected acceleration time histories.

Subtask 3.2 - Generate Realistic Artificial Acceleration Time Histories for Rock Site. The number of representative time histories that can be selected from actual records may not be large enough because existing accelerograms from rock sites are relatively scarce. In order to supplement these, artificial time histories will be generated to match the selected horizontal and vertical response spectra. The artificial time histories will consist of three components of ground motion. The peak ground acceleration as well as the strong motion duration of these artificial time histories should also be consistent with the magnitude of the earthquake and source-to-site distance represented by the selected response spectra. Again, these artificial time histories will be evaluated by the results of numerical modeling (Task 5).

Subtask 3.3 - Assess Amplification Factor for Spectral Acceleration and Evaluate Duration of Strong Motion. The selected real and artificial time histories and their response spectra will be used to determine the amplification factor for spectral acceleration with reference to the peak ground acceleration. These acceleration time histories will also be evaluated for strong motion duration.

3.2.4 Task 4 - Assessment of Site-Specific Ground Motion Characteristics

The objective of this task is to improve our assessment of those ground motion characteristics that are specific to the DCPP site. This is important in minimizing the uncertainty while providing predictions of free-field ground motions appropriate to the plant site. Furthermore, determination of wave types, their incidence angles, and the degree of spatial coherency will be attempted by using the records obtained at the plant site. These site-specific ground motion characteristics are important for the soil-structure interaction analyses.

Subtask 4.1 - Assess Ground Motion Variability at the Site. Existing digital acceleration records obtained by the free-field instruments at the DCPP site and additional records from calibration shots will be analyzed to assess the focusing and defocusing effects due to topographic relief and structural heterogeneities in the vicinity of the site. Results from numerical modeling will be applied to understand part of these effects. It is hoped that this subtask will allow us to make better assessment of the variability in ground motion estimation.

Subtask 4.2 - Assess Wave Types and Spatial Coherency at the Plant Site. Available strong motion data from the array of three free-field accelerographs at the DCPP site will be analyzed to the extent possible to identify the incoming wave types and their apparent velocity and incidence angle. The spatial coherency of the ground motion associated with these wave types as a function of frequency will also be assessed. The feasibility of collecting additional data from calibration shots recorded by a temporary dense array, with spacings on the order of the foundation dimensions of the plant structures, is being evaluated. In addition, a review will be made of available research results on wave coherency based on other array recordings from both earthquakes and underground nuclear explosions.

Subtask 4.3 - Install Additional Ground Motion Instruments at the DCPP Site. The existing records obtained by the strong-motion instruments at the DCPP site for four earthquakes since 1980 provide valuable raw data for assessing the site-specific ground motion characteristics as outlined above. These include three small local earthquakes as well as the Coalinga earthquake of 1983 (Table 3-1). In order to strengthen the strong ground motion observations, additional free-field accelerographs will be installed at the plant site as part of the LTSP. New data will be evaluated during the course of the LTSP when they become available.

3.2.5 Task 5 - Application of Numerical Modeling of Ground Motions

Although the LTSP will rely primarily on empirical ground motion characterizations developed from prior accepted statistical analyses of strong motion records and updates of those analyses using currently available data and analytical techniques, it is highly desirable to augment the empirical analyses with the application of selected and well focused numerical modeling methodologies. The objectives of this numerical modeling task are: (1) to provide quasi-independent evaluation of the attenuation relationships, response spectral shapes, and time histories selected by the empirical approaches; (2) to evaluate the effects on ground motion of alternative fault types, fault geometry, and rupture process for near-site sources; and (3) to assess the effects of local site conditions on ground motion.

Subtask 5.1 - Evaluate the Selected Attenuation Relationships, Response Spectra, and Time Histories. Applicability of the attenuation relationships, response spectra, and time histories selected empirically for the DCPP site may be checked by real records from the site. Unfortunately, records currently available at the site are too limited to serve this purpose adequately. Alternatively, as more information about possible sources, crustal structure, and local site geology for the DCPP site becomes available, currently available numerical modeling methods that have been used satisfactorily in explaining strong motion records of some California earthquakes may be used to evaluate the general applicability of these empirical results for the DCPP site.

Subtask 5.2 - Assess Effects of Alternative Fault Types, Fault Geometry, and Rupture Process for Near-Site Sources. Although it is anticipated that the LTSP geology/seismology/geophysics program will substantially improve the definition of possible source geometries on the Hosgri and other nearby faults, some uncertainty is likely to remain. Also, the process of fault rupture is known to have a significant effect on ground motion characteristics. Numerical modeling may be used to evaluate the significance of alternative fault types, fault geometry, and rupture process of the postulated nearby seismic sources on ground motion characteristics at the DCPP site.

Subtask 5.3 - Assess Local Site Effects. High-frequency ground motion depends strongly on local site structure. The DCPP site appears to be characterized by considerable lateral heterogeneity in the near-surface rock formation and moderate topographical relief in its vicinity. The effects of such site conditions on ground motion can be assessed to some extent by numerical modeling. In order to improve the modeling results, currently available information about site structure will be augmented by well designed field studies and experiments aimed at refining key aspects of the site structure. The existing earthquake records at the DCPP site will be used for this modeling subtask to the extent possible.

Figure 3-1

GROUND MOTION PROGRAM
TASK STRUCTURE

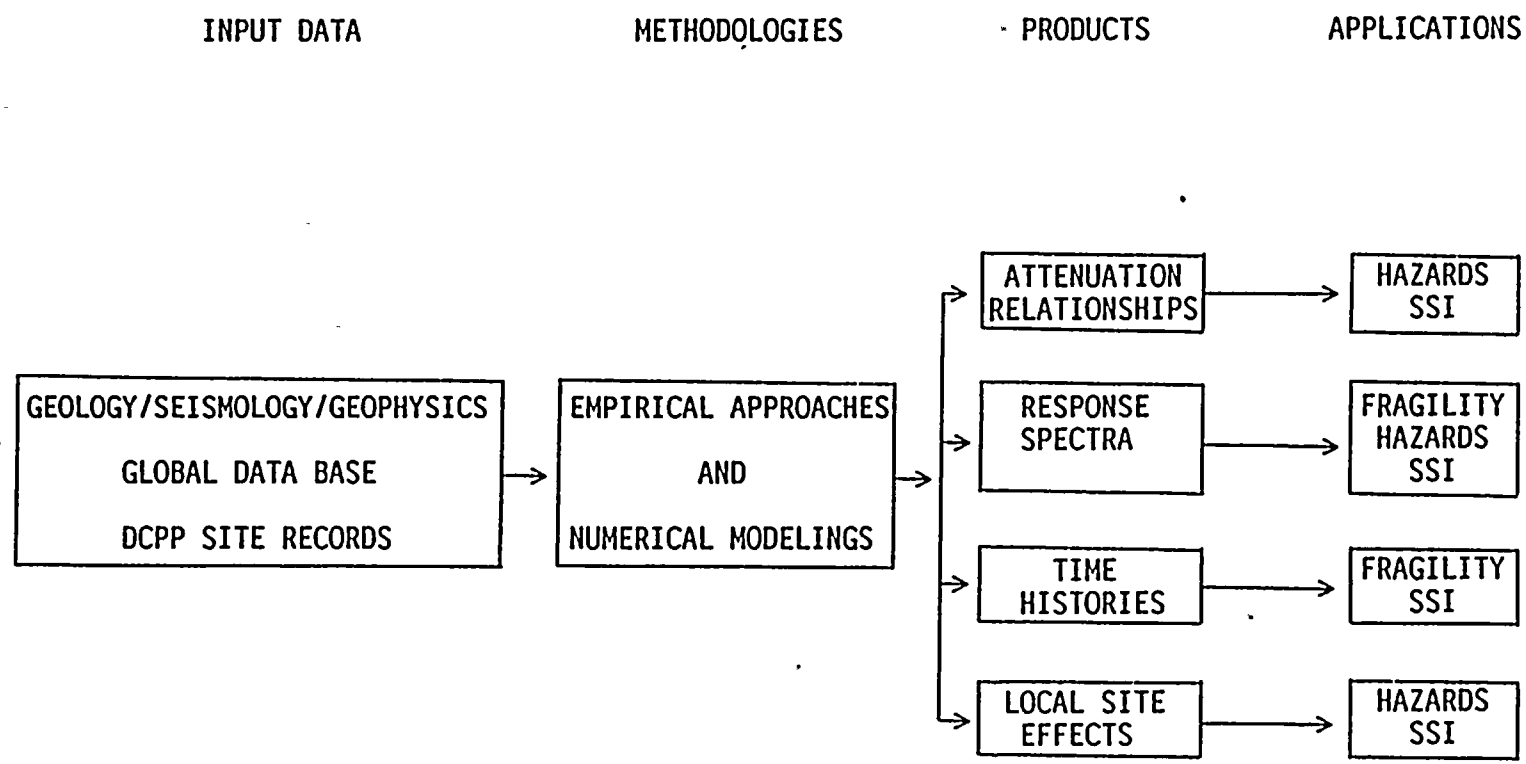


Table 3-1

GROUND MOTION RECORDS OBTAINED AT DCPP SITE

				Peak Ground Acceleration (g) Free-Field Site No.		
DATE	M_L	Δ (km)	DEPTH (km)	5-3	5-4	6-1
5/29/80	4.9	30	6.0	--	--	0.0097
				--	--	0.0118
				--	--	0.0120
5/2/83	6.7	110	8.4	0.0112	--	0.0096
				0.0095	--	0.0139
				0.0134	--	0.0111
6/20/84	4.7	30	9.4	--	0.0035	--
				--	0.0106	--
				--	0.0109	--
11/12/84	2.4	5	4.9	0.0050	0.0186	0.0099
				0.0058	0.0088	0.0267
				0.0078	0.0161	0.0118

4.0 SEISMIC HAZARDS ANALYSIS

4.1 INTRODUCTION

The seismic hazards analysis for the LTSP involves the development of probabilistic site ground motion estimates. The principal inputs for the hazard assessments are based on the geology/seismology/geophysics and ground motions activities. The results of the hazards analysis serve as inputs to the PRA, which are described in Section 7. The work plan for the seismic hazards analysis is described in this section.

4.2 WORK PLAN

The seismic hazards analysis is divided into two principal tasks that have been scheduled to meet the required dates for input to the PRA activities (Figure 1-1). Both of these tasks are described below.

4.2.1 Task 1 - Evaluate Ground Motion Descriptions

Several different methods of characterizing seismic ground motions will be examined for their applicability to the LTSP, and the advantages of each will be assessed. The methods to be examined include:

- Peak acceleration - This is the usual simple descriptor used for PRAs
- Peak acceleration plus duration - The addition of duration to the ground motion description will allow more accurate estimation of structures and equipment fragilities as a function of earthquake size
- Spectral acceleration - The characterization of ground motions in terms of one or more spectral accelerations may provide a basis for more accurate estimates of fragilities by providing information on the frequency content of ground motions

It is expected that any representations more sophisticated than that for peak ground acceleration would provide benefits by making more realistic estimates of strong ground shaking. This task will involve discussions with fragility and PRA team members to assess the usefulness of such representations for the PRA effort and the ability to carry out such analyses within the schedule.

It is expected that a "scenario" representation of the seismic hazard at DCPP will provide a major benefit in the implementation of more sophisticated representations of ground motions. Many of the problems associated with describing probabilities of exceedence in multidimensional representation can be avoided while obtaining the benefits of multidimensional characterization of ground motions.

The above alternatives will be evaluated by assessing the utility of each for estimating seismic fragilities. An appropriate representation for the Phase III hazard curves will then be selected, based on the results of the Phase II analyses and the need for more refined ground motion representation in the Phase III fragility analyses.

4.2.2 Task 2 - Seismic Hazards Analysis

In this task the ground motion description selected in Task 1 will be used to produce hazard curves for DCPP. The development of the hazards curves will use geologic and seismologic input developed in other parts of the LTSP, and will draw probabilistic conclusions regarding effects of earthquake occurrences on the DCPP facility. Revisions to the input will be incorporated into the seismic hazard analysis, in order to update it using the results of other LTSP efforts. As other parts of the LTSP became finalized, especially earth science interpretations, these will be used to develop final seismic hazard curves, which will be appropriately documented. As part of this task, sensitivity analyses will be conducted to determine the relative contributions of various geology/seismology/geophysics and ground motions considerations to the total seismic hazard. In addition, parametric studies will be made to evaluate the hazard resulting from various scenarios in the logic tree analysis.

5.0 SOIL-STRUCTURE INTERACTION

5.1 INTRODUCTION

The soil-structure interaction (SSI) element of the LTSP provides the link between the geosciences elements (geology, seismology, ground motion, and hazard analysis) and the structural elements (plant fragility analysis) of the overall program. Source information is received from ground motion and geotechnical studies, including the geophysical properties of the plant foundation rock and free-field ground motion information, and is appropriately processed through SSI analyses to develop results for structural and equipment evaluation.

A set of preparatory tasks were initiated during Phase II involving activities discussed in LTSP Quarterly Progress Report No. 1. Phase III items of work are a continuation, rather than the result, of Phase II activities.

5.2 WORK PLAN

The SSI work plan comprises eight tasks as described below.

5.2.1 Task 1 - Assemblage and Review of Site Rock Data

This task is to assemble the existing site rock data, evaluate the adequacy and variability of these data, and assess the potential sensitivity of SSI responses due to variabilities of rock properties. The results of this task will be used to determine the appropriate values and the associated uncertainties for the site rock properties to be used for constructing SSI models and to determine the need for acquiring additional data on the site rock properties. The specific work to be performed in this task includes:

- Assembling available rock boring data and data from geophysical surveys and geotechnical investigations of the site rock
- Reviewing these data and determine the rock profile and properties (wave velocities, Poisson's ratios, material moduli of elasticity, and densities) and their ranges of variation
- Performing simplified SSI analyses to assess the potential sensitivity of SSI responses due to variations in the rock profile and properties
- Evaluating the sensitivity of responses due to variations of foundation rock properties as functions of response amplitudes at the level of high-intensity, design-level earthquakes

5.2.2 Task 2 - Free-Field Input Motions

The objective of this task is to review the results of the earthquake ground motion studies for the plant site and to develop appropriate free-field seismic input motions for SSI analyses. To achieve this objective, the following subtasks will be performed.

Subtask 2.1 - Evaluation of Literature on Spatial Coherency of Free-Field Ground Motions. This subtask is to perform an evaluation of literature on analyses of dense array ground motion records, evaluate the "coherence/noncoherence" characteristics of free-field seismic ground motions, and study the means for characterizing the noncoherence component of seismic incidence wave motion for input to SSI analyses. The specific work to be performed in this subtask includes:

- Gathering literature on ground motion studies of dense array records (e.g., SMART-1 array in Taiwan and El Centro differential array)

- Studying the collected literature for evidence of coherence/noncoherence in ground motions, and clarify its characteristics

- Evaluating the effect of noncoherence and infer its significance on SSI responses

- Investigating a means of incorporating the noncoherence component of ground motion into the current SSI analysis methodologies using either the CLASSI or the SASSI computer program and define the interface requirement with ground motion study

Subtask 2.2 - Review of Results of Earthquake Ground Motion Studies. This subtask is to review the results of the earthquake ground motion studies and determine the adequacy of this information for input to the SSI analyses. The ground motion information to be reviewed includes:

- Site-specific free-field ground response spectra and definition of the motion location

- An ensemble of real and/or synthetic ground motion time histories associated with the site-specific spectra

- Free-field ground motion seismic wave incidence characteristics (wave type and composition, incidence angles, and spatial coherency) and their relationship with seismic source locations

It is anticipated that during the course of the LTSP, the site-specific ground motion will be generated in at least two phases, namely, a preliminary phase and the final phase. Consistent with these phases, the review in this subtask will have corresponding phases..

Subtask 2.3 - Development of Free-Field Input Motion Data for SSI Analyses. From the results of the review of Substask 2.2, this subtask is to develop the required free-field input motion data for SSI analyses using the CLASSI and SASSI programs. The work to be performed in this subtask is as follows:

- Convert the synthetic earthquake ground motion time history information that is generated by the ground motion studies into ground motion input formats suitable for CLASSI and SASSI analyses

- Identify an appropriate subset of real earthquake ground motion time histories from the ground motion studies associated with the site-specific ground response spectra, which have a controlling effect on the ground response spectra. The time histories in this subset will be used for SSI analyses considering nonlinear responses, if necessary

- Decompose free-field input motion time histories according to the wave incidence characteristics identified in the ground motion studies, such as the wave types and their frequency contents, the associated angles of incidence, and the spatial coherency

Like the ground motion studies, the free-field input motion data in this subtask will also be developed in two phases.

5.2.3 Task 3 - Implementation of CLASSI and SASSI Computer Programs

The objective of this task is to implement and perform testing, verification, and documentation of the computer programs CLASSI and SASSI. The CLASSI computer program will be used for 3-D SSI analyses following the half-space approach, whereas the SASSI computer program will be used for 3-D finite element SSI analyses. This task is divided into the following subtasks.

Subtask 3.1 - Implementation and Testing of CLASSI and SASSI Computer Programs. This subtask is to investigate the availability of the most recent versions of the CLASSI and SASSI computer programs, determine the levels of technical support, procure and implement a suitable version of each of these programs for LTSP SSI use, and test the implemented versions to ensure that they have the capabilities needed by LTSP SSI. This preparatory work is required before any actual SSI analyses can be made. The specific work to be performed in this subtask includes:

- Holding discussions with the respective program developers of CLASSI and SASSI and determine the present status and availability of these programs

- Arranging to procure and implement a suitable version of each of these programs which has the analysis capabilities required by the LTSP-SSI study, and arrange for technical support for both programs

- Analyzing test problems using the implemented versions of CLASSI and SASSI to ascertain the capabilities required for the LTSP SSI study

Subtask 3.2 - Verification and Documentation of CLASSI and SASSI Computer Programs. This substask is to perform formal verifications of the CLASSI and SASSI computer programs to ensure that the capabilities required by the LTSP SSI applications function properly, and then to document the results of these verifications in formal verification reports. The specific work to be performed for this subtask includes:

- Researching literature to collect published SSI benchmark solutions which can be used for verifying the CLASSI and SASSI computer programs. The benchmark solutions used for CLASSI and SASSI verifications may be different, since they do not have identical capabilities

- Analyzing the problems of the benchmark solutions using CLASSI and/or SASSI and compare these results with the benchmark solutions

- Discussing with the CLASSI and SASSI program developers any potential problems or program bugs that may become apparent during verification of these programs and debug, if required

- Documenting the results of verification analyses in formal verification reports for both the CLASSI and SASSI programs

5.2.4 Task 4 - Development of SSI Analytical Models

Based on the as-built structural configuration of DCPP and the foundation rock profile and properties as determined in Task 1, the objective of this task is to develop suitable 3-D analytical SSI models for the power block structures and the site rock foundation using the CLASSI and SASSI analysis methodologies. The model development in this task is further divided into the following subtasks.

Subtask 4.1 - Review of Dynamic Models of Power Block Structures. This subtask is to review the existing dynamic models for the power block structures (i.e., the containments of both units, the auxiliary building, and the turbine building) to determine how much revision or refinement of these models is required to be compatible with the CLASSI and SASSI analysis methodologies and to conceptually develop the appropriate dynamic models, if necessary. This review will scope the work required for the development of structural dynamic models. The specific work to be performed in this subtask includes:

- Evaluating the bases of the assumptions made for both the horizontal and the vertical models of each building. This requires a review of calculations used in model development

- Determining how much revision or refinement is necessary for the models to be compatible with CLASSI and SASSI

- Evaluating the most effective means to combine the horizontal and the vertical models into the 3-D dynamic models that are needed for 3-D SSI analyses

- Developing appropriate conceptual dynamic models, determining the effort required to complete the dynamic model development, and preparing work plans for completion. This work is based on the three reviews noted above

Subtask 4.2 - Development of 3-D Structural Dynamic Models. Based on the results of Subtask 4.1, this subtask is to perform the actual development of appropriate 3-D structural dynamic models for each of the four power block structures. The actual analytical models for the structures may be different for the CLASSI and SASSI analysis methodologies. The 3-D structural models will, in general, be in the form of generalized 3-D lumped-mass-beam-stick models. As-built structural and equipment masses will be lumped at floor locations. The generalized stiffnesses of beam elements in the stick models will be developed considering realistic stiffness distribution of major structural elements. The effect of floor flexibility will be considered in developing the stick models. Three-dimensional finite element structural models will be utilized as necessary for a more realistic presentation of the structural stiffness distribution, from which the generalized stiffnesses of the 3-D stick models can be constructed. An adequate number of lumped masses and dynamic degrees-of-freedom will be used so that model properties of the fixed-base structural modes within the frequency range of interest will be adequately represented.

Subtask 4.3 - Development of 3-D Foundation Models. Three-dimensional foundation models for the power block structures will be developed using both the CLASSI and SASSI analysis approaches. These foundation models will be coupled with the 3-D structural dynamic models for the power block structures to form the 3-D SSI analytical models. This subtask is further subdivided below.

CLASSI Foundation Model. For the CLASSI foundation model, the structural base for individual structures will be assumed to be rigid and resting on the surface of the foundation half-space. Six dynamic degrees-of-freedom, i.e., three translations and three rotations, will be used for each structurally independent basemat. The foundation impedance matrix which represents the inertial interaction effect of the foundation, and the seismic wave scattering matrix which represents the kinematic interaction effect of the rigid foundation basemats, will be developed considering the presence of all four power block structures. Thus, the resulting matrices represent not only the SSI effect of individual structures, but also the effect due to the through-rock, structure-to-structure interaction effect. The CLASSI foundation model can consider the horizontal layering of site rock profile.

SASSI Foundation Model. For the SASSI foundation model, the structural base for individual structures is modeled by finite elements. Thus, the effect of basemat flexibilities and structural embedment can be included in the SASSI foundation model. A finite portion of the foundation rock surrounding the structural bases will also be modeled with finite elements. The finite element mesh for the rock foundation will be selected to accommodate the significant frequency range of interest. The SASSI foundation model can consider the horizontal layering of site foundation rock.

5.2.5 Task 5 - Correlation with Recorded Data

The objective of this task is to perform data analyses of selected earthquake accelerograms recorded at the Diablo Canyon site and in the plant structures. The processed data will be used as appropriate to study the following:

- The SSI effect for the power block structures

- The low amplitude dynamic characteristics of the plant structure-foundation system

This task is divided into the following two subtasks.

Subtask 5.1 - Analyses of Recorded Data. The recent earthquakes for which recorded data are available at the plant site are:

- Point Sal earthquake of May 28, 1980 (M_L = 4.6)

- Coalinga earthquake of May 2, 1983 (M_L = 6.5)

- Santa Maria offshore earthquake of June 20, 1984 (M_L = 4.3)

The recorded data for these earthquakes will be analyzed in this subtask using current accelerogram processing techniques. Transfer functions from the free-field recording stations to the instrumented locations in the power block structures, and between paired recording stations in the power block structures, will be extracted from the recorded data. Due to the low intensity levels (maximum accelerations recorded were about 0.01g), the useful frequency range of recorded data may be limited; however, these ranges will be evaluated and determined after these data are processed. The useful and reliable information from the processed data will then be used for correlation with the results from analytical SSI models.

Subtask 5.2 - Correlation Between Analytical Models and Recorded Data. The transfer functions developed with the CLASSI and SASSI analytical SSI models will be correlated with those extracted from the processed recorded data. The processed data in the useful frequency range will be utilized, to the extent practical, for correlating the low amplitude dynamic response characteristics of the analytical SSI models. Adjustments to the analytical SSI models will be made when the correlations indicate such adjustments are warranted.

5.2.6 Task 6 - Parametric Studies

The parametric studies will be undertaken after the analytical SSI models have been constructed and appropriately adjusted with the recorded data. The purpose of this task is to perform parametric studies on SSI response to assess the sensitivity of the responses to parametric variations, and to evaluate the effect of specific assumptions made in each analysis case on the SSI responses. The results of this parametric study will be the quantitative characterizations of the variations in SSI responses due to parametric variations. The results will also be used to establish a representative SSI model for generation of SSI responses to be used by the other segments of LTSP. This task is divided into the following subtasks.

Subtask 6.1 - Reconciliation of CLASSI and SASSI Solutions. The SSI analysis results using the CLASSI and SASSI models for the DCPP power block structures under the same assumptions of model parameters and input motions will be compared with each other. The difference in responses, if any, will be assessed and reconciled to ensure that, for the same SSI problem, the two analysis methodologies will give similar responses. Any significant differences will be explained through assessment of inherent assumptions used in the formulations of the two methodologies.

Subtask 6.2 - Basemat Flexibilities. The CLASSI SSI model is based on the assumption of rigid basemat. The effect of basemat flexibilities on the SSI response will be assessed in this subtask using the SASSI SSI model, which can include the actual basemat flexibilities in the finite element model. The results of this assessment will be used to quantify the response variations, if any, due to the assumption of rigid basemat.

Subtask 6.3 - Structural Embedment. The power block structures have varying degrees of structural embedment. The CLASSI SSI model is based on the assumption of surface-supported structures and, therefore, the structural embedment effect is ignored. On the other hand, the SASSI SSI model, which uses a finite element model for the foundation, can incorporate the structural

embedment effect. The effect of structural embedment on SSI responses will be assessed in this subtask by quantifying and comparing the CLASSI solution without embedment effects with the SASSI solution including structural embedment.

Subtask 6.4 - Variations of Soil/Structure Properties. The effect of variations in foundation and structural property parameters, such as the foundation rock shear wave velocity and the structural stiffness properties, will be assessed in this subtask. The results will be used to quantify the variations of SSI responses due to soil/structure property variations.

Subtask 6.5 - Variations of Input Motion Parameters. The effect of variations in the free-field input motion parameters such as the input time history, wave incidence characteristics (wave type, composition, and path effects), and the spatial coherency will be assessed in this subtask. The results of this parametric study will be used to quantify the effect of these parameters on the SSI responses.

Subtask 6.6 - Soil/Structure Nonlinearities. The effect on the SSI responses of potential structural base uplifting and structural nonlinearities due to potential inelastic responses will be assessed in this subtask. The effect of base uplifting, if it occurs, will be analyzed using simplified nonlinear time history analysis techniques. The effect of inelastic structural responses, when significant, will be analyzed using equivalent linear models for the structures. The results of this study will be used to quantify the SSI response variations due to these potential nonlinearities.

5.2.7 Task 7 - SSI Responses

Based on the results of studies in Tasks 5 and 6, a representative SSI model, with model parameters adjusted from correlation with applicable low-amplitude responses from recorded data, will be used to generate the SSI responses of the plant. The SSI responses will be generated in phases as the free-field ground motion information is received from the ground motion studies.

The preliminary SSI responses will be generated when the preliminary input motion is available. These preliminary responses will be later improved as the ground motion input information is finalized in stages. The ranges of SSI response variations deduced from the parametric studies in Task 6 will be used as the basis for developing the final SSI response of the plant structures.

5.2.8 Task 8 - Documentation and Preparation of Reports

This purpose of this task is to document the results of all previous tasks into calculation files for document retention purposes, and to prepare technical reports summarizing the analysis assumptions, procedures, and significant results obtained in the SSI work.

6.0 FRAGILITIES

6.1 INTRODUCTION

The seismic fragility analysis of plant structures, equipment, and components of the LTSP involves determination of median ground spectral acceleration capacities and their associated variabilities. The results of the fragility analysis serve as input to the PRA.

Appendix A shows the list of equipment, components, and structures that were developed on a preliminary basis for which the seismic fragility data were required for Phase II PRA studies. This list was compiled by the principal PRA investigator (PL&G) on the basis of their earlier experience with similar other Westinghouse plants and study of Diablo design documents, as well as physical review of the plant systems.

The fragility data evaluated for the above items were used for Phase II PRA scoping studies. These studies identified the dominant risk contributors to the overall seismic risk. The Phase III effort will concentrate on improving the fragilities of those items in addition to performing other sensitivity studies. These tasks are described under the work plan below.

6.2 WORK PLAN

The fragilities work plan comprises the following tasks.

6.2.1 Task 1 - Reevaluation of Dominant Contributors to Seismic Risk

The preliminary fragility data for the selected structures and components, developed for the purpose of Phase II scoping studies, are based on extrapolation analysis of the currently available plant-specific qualification calculations and test results. Often, existing qualification calculations describe the stress summaries which include normal operating loads, nozzle loads, etc. without any detailed breakdown of these loads. In such instances, conservative assumptions are made for the contribution of seismic to overall stresses.

In this task, effort will be devoted to identify any such conservatism by reanalysis, if necessary, with new in-structure response spectra for those components identified in Phase II as dominant contributors to the seismic risk of the plant. In general, it is anticipated that most of the effort will be concentrated in refining the fragilities in the range of accelerations that contribute the most seismic risk to the plant.

Subtask 1.1 - Incorporate Results of Other Elements of the LTSP. This subtask will incorporate the results of the currently ongoing evaluations in the geotechnical and soil-structure interaction areas. These areas are expected to affect not only the dominant contributors but virtually all the structure and the equipment fragilities. Also, it is expected that modifications of the site-specific ground response spectra are likely to occur. Narrower amplified peaks in the spectra may result, and it may be desirable to develop separate spectra for different magnitude ranges of earthquakes. Emphasis will be placed on the magnitude ranges that develop accelerations that contribute the most seismic risk. It may also be possible to identify directional excitation characteristics of the earthquake, rather than assume an equal probability of maximum excitation from any direction. Other possible refinements include more detailed consideration of the earthquake duration and number of strong

motion cycles, and a possible change in the ratio of vertical to horizontal excitation.

The only soil-structure interaction (SSI) effects incorporated in the Phase II fragilities investigations resulted from the preliminary consideration of statistical incoherence in the input waves. However, the more refined SSI analyses currently underway are expected to consider, in addition to the incoherency aspect of the ground motion, the diffusion phenomenon due to the wave scattering effect. This may produce somewhat different results, and the Phase III fragilities will incorporate these new results.

Subtask 1.2 - Improve Phase II Fragilities. After the results of the geotechnical and SSI investigations have been incorporated to upgrade the Phase II fragilities, it is likely that further additional refinement will be warranted for those items identified as dominant contributors to the plant seismic risk. Although preliminary estimates for the Phase II fragilities have been completed and integrated with the seismic hazard using the plant systems models, detailed investigation of the ultimate seismic capacities of the dominant contributors may be required, including nonlinear analysis in some cases. Also, for equipment qualified by test, it is often difficult to justify failure levels greatly in excess of the test levels. In order to demonstrate significantly higher seismic capacity with moderate variability, it may be necessary to consider additional equipment testing in Phase III for selected components.

6.2.2 Task 2 - Median In-Structure (Floor) Response Spectra

In order to identify any significant conservatism in the current in-structure response spectra as well as to better quantify expected variabilities, new median spectra will be developed for the floors of the buildings where some of the dominant contributors are located. These in-structure spectra will be developed using a number of realistic time histories. These time histories will be obtained from the ground motion element of the LTSP and will be representative of time histories which could be expected at the site for earthquakes with spectral accelerations and frequency ranges at which the Phase II studies show most of the seismic risk.

The in-structure response spectra will be generated by obtaining the building response to the above earthquake records scaled to the same average spectral acceleration in the amplified acceleration range as the site-specific predicted ground motion exhibits. Thus, some variability is expected in the rigid as well as the amplified acceleration range. Appropriate variations in building response parameters will also be included in this effort. Such parameters as damping and structural frequencies will be accounted for. It is expected that linear models of the building structures will be adequate for this task.

6.2.3 Task 3 - Study of Lower Tails of Fragility Curves

Based primarily on engineering judgment developed from previous typical structures and equipment evaluations, it is felt that the lower tails of the fragility curves, as obtained from a log-normal distribution from the calculated median fragility level, should be truncated at an appropriate value. Since the seismic risk for Diablo Canyon appears to be very heavily influenced by these cutoffs, development of a realistic basis for the cutoffs is required for Diablo-specific structures and equipment.

The approach to the cutoffs will be to obtain seismic responses for both a building structure and selected items of equipment when subjected to a series of earthquake inputs. The same time histories described in Task 2 above will be used in conjunction with simplified structure and equipment models to develop actual structure and equipment seismic response. Parameters such as structure and equipment frequencies, damping, and any inelastic effects, as appropriate, will be varied in order to establish upper bound responses. In order to provide statistically valid results, several time history runs will be made which will necessitate simplified models. Again, it is expected that the effort will concentrate on the dominant contributors to risk discussed in Task 1 above. Once the response bounds have been established, they can be combined with the actual expected lower bound strengths of the components to provide a valid basis for the cutoffs.

6.2.4 Task 4 - Improved Balance-of-Plant Piping Fragilities

As discussed in Subsection 7.5.2 of this report, the Phase II PRA studies are based on the assumption that failure of a single pipe support will always result in a pipe break of sufficient size to prevent the system from functioning. This is obviously a conservative assumption, and establishment of a more realistic failure mode is required.

Phase III investigations will include a more detailed study of a number of important piping systems to determine the number of supports per line, and to determine if failure of a single support is expected to lead to fracture of the pipe, together with the expected leak path area and location if failure should occur. Additionally, studies will be conducted to evaluate the degree of dependence between the fragilities for individual pipe segments.

6.2.5 Task 5 - Items Not Considered in Phase II Studies

Several potential failure modes initially judged to be noncritical in Phase II based on very limited evaluations will be examined in this task. In addition, if Phase II PRA sensitivity studies show dependency between similar or identical equipment performing the same function and this becomes an important issue in evaluating seismic risk, it may become necessary to conduct a Diablo-specific study using a code similar to SMACS (developed for the SSMRP program) or its equivalent. Finally, the potential uplift of the containment base slab and the associated effects on equipment and piping responses will be studied to benchmark the initial fragility evaluations.

7.0 PROBABILISTIC RISK ASSESSMENT

PHASE II

7.1 SUMMARY

Phase II of the Diablo Canyon Probabilistic Risk Assessment (DCPRA) has been completed. The purpose of Phase II was to validate the scope and required resources for accomplishing Phase III. The results presented for Phase II are preliminary and subject to change. Appropriate caution should be used in applying them to any purpose other than the scoping of Phase III. The Phase II results are consistent with DCPP design and site characteristics as well as current PRA experience.

Phase II was based on a subset of the initiating events encountered in full-scope PRAs. The selected initiating events are believed to include all important contributors to risk. Event tree models were developed to display the sequences following each of the initiators. System logic models were developed for each top event in the event trees. The event tree and system models were first used to examine sequences developed from internal initiating events and then were modified for use in analyzing seismic initiating events coupled with random, nonseismic equipment failures. The result was a determination of the relative importance of sequences and contributing systems to plant damage. Although Phase II was a scoping study, the results appear reasonable and provide useful insights for planning the Phase III effort. Nevertheless, the original plan for Phase III required very little modification.

The objective, approach, scope, and results are discussed in more detail below.

7.2 OBJECTIVE

The purpose of the DCPRA is to satisfy the requirements of the license condition by quantitatively estimating the Level 1 risk from operating the Diablo Canyon Power Plant. This will be done by quantifying the total and seismic risk. The quantification will develop probability curves on the frequency of occurrence of different plant damage states. The risk information is to be presented in such a way as to enable backtracking from plant damage to contributing sequences, systems, components, causes, and basic event data.

Phase II was the preliminary scoping assessment in which the nucleus of a PRA model was constructed. This provided an early identification of important initiating events and scenarios, plant systems and equipment, and plant damage states. The Phase II objective was to use this preliminary assessment to verify the planned scope and necessary resources for accomplishing Phase III and through this effort highlight some of the important Phase II findings to be addressed more fully in Phase III.

7.3 SCOPE

The DCPRA will be a full-scope Level 1 PRA. The term full-scope is taken to mean: (1) the risk due to all causes, including internal and external events; (2) quantification of the frequencies of occurrence of plant damage, including all the contributing elements, such as specific plant damage states, accident sequences, systems and component failures, specific causes, and basic event and cause data; and (3) a quantification of uncertainty.

Early in Phase II the scope encompassed plant familiarization, identification of initiating events, some preliminary systems analysis sufficient to understand the plant functions, and support and frontline systems model development. Subsequently, the scope included preliminary seismic analysis using fragility and seismic hazard information and an analysis of internal and seismic initiating event sequences. The work was structured to determine the relative sensitivity of plant components to internal and seismic initiating events sufficient to confirm the Phase III scope of work.

7.4 APPROACH

The Phase II modeling effort began with the selection of a representative, yet reduced, set of initiating events. The selected initiators included those generally found to be important contributors to risk at other similar plants and also those that reflect the unique design features at Diablo Canyon. The initiators selected for evaluation in Phase II were:

- General transients (e.g., turbine trip, reactor trip, loss of feedwater)
- Loss of offsite power
- Loss of component cooling water/auxiliary saltwater (ASW)
- Small LOCA
- Loss of 480V switchgear ventilation
- Earthquakes at 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0g spectral acceleration

Event sequence models were developed for each of the initiators selected; all are subsets of the one for general transients.

A linked event tree approach to development of the plant model was chosen for Phase II. This approach has also been called the "event tree with boundary conditions approach" because each top event in the event tree is dependent only on the status of preceding top events in the tree. Four stages to the Diablo Canyon plant model were constructed and linked together for quantification. The four segments correspond to:

- Electric power systems

- Other plant support systems (actuation signals and cooling water systems)

- Early response frontline systems (e.g., AFW, pressure relief, high pressure injection)

- Late response frontline systems (e.g., RHR, containment isolation, fan coolers)

Figure 7-1 pictorially represents the event tree model linking. In the figure, the electric power tree and the other plant support system tree are combined into one module, the support system model. The definitions of all the top events and the structures of each of the four event tree model segments were developed after a thorough review of plant drawings, design information, and procedures and after discussions with plant engineering and operational staffs.

System logic models were then developed to quantify the split fractions for each top event in the four event tree segments, subject to the appropriate boundary conditions. These logic models varied in the degree of detail explicitly modeled for Phase II. For the turbine trip event, the likelihood of failure to trip was assumed to be the same as that computed previously for a similar plant. For key systems, such as auxiliary feedwater and high pressure injection, the logic modules developed were quite detailed, explicitly accounting for test and maintenance, alignments of the system, and a detailed treatment of common cause failures. The failure data used to quantify these detailed logic models were generic failure data.

The impacts of seismic events were modeled by using the same system and models described in the preceding paragraphs. Seismic failure modes were identified for important equipment and were directly incorporated into the system modules when appropriate. The system models were then requantified for each seismic initiator to account for the increasing likelihood of equipment failure at greater accelerations. Two changes to the plant modeling process were

required to accommodate the seismic failure models. First, at high accelerations, the rare event approximations of the plant model are no longer applicable. Thus, system equations had to be revised. Second, the hypothesized seismic failure of reactor coolant pump supports introduced a plant-level initiating event - a large LOCA. Thus, the general transient plant model was modified to account for the new dependencies introduced by seismic-caused equipment failures. Seismic-caused component failures were coupled with random, nonseismic failures to determine the integrated effect on the plant.

7.5 PHASE II FINDINGS AND IMPACTS ON PHASE III SCOPE

The findings and results from the Phase II PRA serve as important input to the Phase III effort. The pertinent findings from Phase II and their impacts on Phase III activities are discussed below.

7.5.1 Nonseismic Results

In the course of developing the Phase II plant model for Diablo Canyon, a few design features were found to be of particular importance. Diablo Canyon is a standard four-loop Westinghouse plant. All safety equipment is supplied cooling from the component cooling water (CCW) system. For example, both the centrifugal charging pumps and the safety injection pumps are served by CCW and are believed to require CCW cooling for continued operation. Failure of the CCW system itself was governed by a common cause failure of the three CCW pumps to run. Since only two CCW pumps are normally operating (the third is in standby) and only one of the three is needed for success, this Phase II model treatment may have been unnecessarily conservative.

The two-pump-train auxiliary saltwater system is the ultimate heat sink for the CCW system. Thus, loss of auxiliary saltwater would also cause failure of the CCW system. Loss of the ASW system is dominated by independent failures of the two Unit 1 pumps, combined with a failure of the operating crew to cross-connect to the Unit 2 ASW system. This assumes that only one of the four ASW pumps is needed to realistically fulfill the requirements of both units.

Loss of CCW can lead to core damage because both RCP thermal barrier cooling and seal injection that is provided by the charging pumps require CCW cooling. Consequently, failure of the three-pump-train CCW system might result in damage to the RCP seals and eventual core damage because of the inability to provide high pressure makeup.

There are three vital divisions of electric power; the emergency diesel generators are air-cooled and, therefore, independent of service water. The

125V DC vital batteries have a very high capacity and are expected to last for longer than 10 hours in the event of a loss of all AC power. In addition, the plant is designed to stay on line and not trip following a loss of offsite power.

The vital 4.16 kV buses at Diablo Canyon must fast-transfer from the auxiliary transformer to the startup transformer, given any turbine generator trip. Also, the Diablo Canyon units share one of the five diesel generators at the site. This swing diesel is automatically aligned to the unit that experiences an engineered safeguards actuation signal. If neither unit gets an actuation signal, but offsite power is lost to both units, the swing diesel then aligns to the first unit whose voltage decays the-fastest.

The most important loss of offsite power initiated sequence is similar to that identified in other PRAs, a subsequent failure of all onsite power and no recovery of either onsite or offsite power before RCP seal leakage leads to core damage. AFW is still available. The timing and rate of RCP seal leakage during a station blackout governs the time available for successful recovery actions.

As a whole, the plant seems to be well ventilated and contains large rooms. The 4.16kV switchgear rooms do not require forced flow during anytime of the year, and indications are that none of the major cooling pumps requires room cooling for even long-term operation. It appears that if the 480 V switchgear ventilation system were lost, the battery charger and inverter rooms and the 480 V switchgear rooms would heat up appreciably. This would be of concern if equipment failure limits were to be exceeded.

Sequences involving loss of the ventilation system that supplies the 480V switchgear and inverter rooms may lead to core damage if recovery actions for which there should be adequate time are unsuccessful. To recover this scenario, the operators could establish alternate ventilation using portable fans or they could shed some of the larger heat loads. Realistic heatup calculations with appropriate heat loads would likely indicate that

significant time would be available or that the room temperatures would peak before reaching equipment failure limits. Further investigation may also show that by simply opening the doors of the rooms served, natural circulation between floors may provide sufficient ventilation.

Phase II nonseismic investigations indicate the importance of at least the following two activities to be emphasized in Phase III.

Refinement of Systems Analyses. The Phase II systems analyses were preliminary, and consideration was not given to all system alignments. These system analyses will be enhanced to account for such considerations. Also, plant-specific models will be developed for some of the systems not covered in the Phase II scope.

Additional data to support the modeling of common cause failures in selected systems will be needed in Phase III. In particular, the dependencies between pump trains operating in mixed (run/standby) modes are especially of interest for the CCW system. Similarly, the interunit dependencies among the five diesels and, also, among the four ASW pumps will be investigated.

Analyses to Verify Success Criteria. Engineering analysis will verify and, in some cases, establish the appropriate system success criteria. Among the success criteria of most interest are: the number of ASW or CCW pumps needed for system success under different boundary conditions, the frequency of challenges to the primary system PORVs following a plant trip with AFW successful, 480V and inverter rooms heatup times, and verification of the adequacy of certain function restoration procedures, specifically for Diablo Canyon. In addition, engineering analyses will be accomplished to definitively identify the time that the batteries will provide power during a station blackout. A related activity will be to follow the industry research efforts into the RCP seal LOCA issue.

7.5.2 Seismic Results

The seismic hazard curve was divided into 0.5g spectral acceleration intervals

for computational purposes. In the range of 0.5g and higher accelerations, seismic-caused loss of offsite power is expected. Above 1.5g the fragility curve tails for a number of components, representing a very low chance of equipment failure, begin to become important relative to the nonseismic-caused component failures. Chief among these components are those that may lead to a loss of all onsite AC power. This would include the diesel generators themselves, and at greater accelerations, the turbine building block wall through which all the vital electric power cables pass. Since the turbine-driven AFW pump would still be operable, the concern again is that with a failure of all AC power, an eventual seal LOCA would occur because CCW had failed.

At spectral accelerations in the range of 2.5g and higher, seismic-caused loss of all AC power greatly dominates. In addition, however, in the range of 2.5g, the low tails of the balance-of-plant piping fragility curves are of interest, particularly for CCW piping. Since the fragility curves are derived in terms of individual pipe segments, it is important whether the fragility curves for these segments are treated independently or dependently. For a closed loop cooling system such as CCW, the pipe segments are essentially in series. For such situations, it would then be very conservative to multiply the fragility curve failure probabilities by the number of susceptible pipe segments.

Another conservatism in the Phase II assessment of seismic-caused piping failures is the assumption that failure of a single pipe support will always result in a pipe break of sufficient size that substantial ASW flow would be diverted or, if it occurred in the CCW system, that the break would be sufficient in size that normal system makeup could not keep up with it, and the operators would not have sufficient time to isolate the break area before the system drains enough to prevent the system from functioning.

Phase II seismic investigations indicate the importance of at least the following two activities to be emphasized in Phase III.

<u>Improved Fragility Definitions and Dependency Treatment</u>. It is important to ensure that there is compatibility between the way the fragility curves are

defined when they are generated and the way they are used in the plant model system equations. This is particularly true for the specific failure modes being represented. For example, the piping fragilities are currently derived on the basis of failure of the most highly stressed support in a piping segment. These curves are then incorporated into the plant model as if they represented the frequency of a complete pipe rupture. In Phase II this mismatch was assumed as a conservative approximation of the realistic situation. In Phase III, a special effort will be taken to ensure that this interface is carefully defined and the degree of conservatism controlled. Special representations of the fragility curves may be required to suitably account for the realistic failure modes of piping versus the definition currently in use for deriving the fragility curves.

Dependencies will be given greater attention in Phase III. There are partial or total dependencies between similar or identical equipment performing the same function. Also, piping introduces other special considerations of dependence. The degree of dependence between the fragility curves for individual pipe segments will be more accurately specified to give more meaningful results.

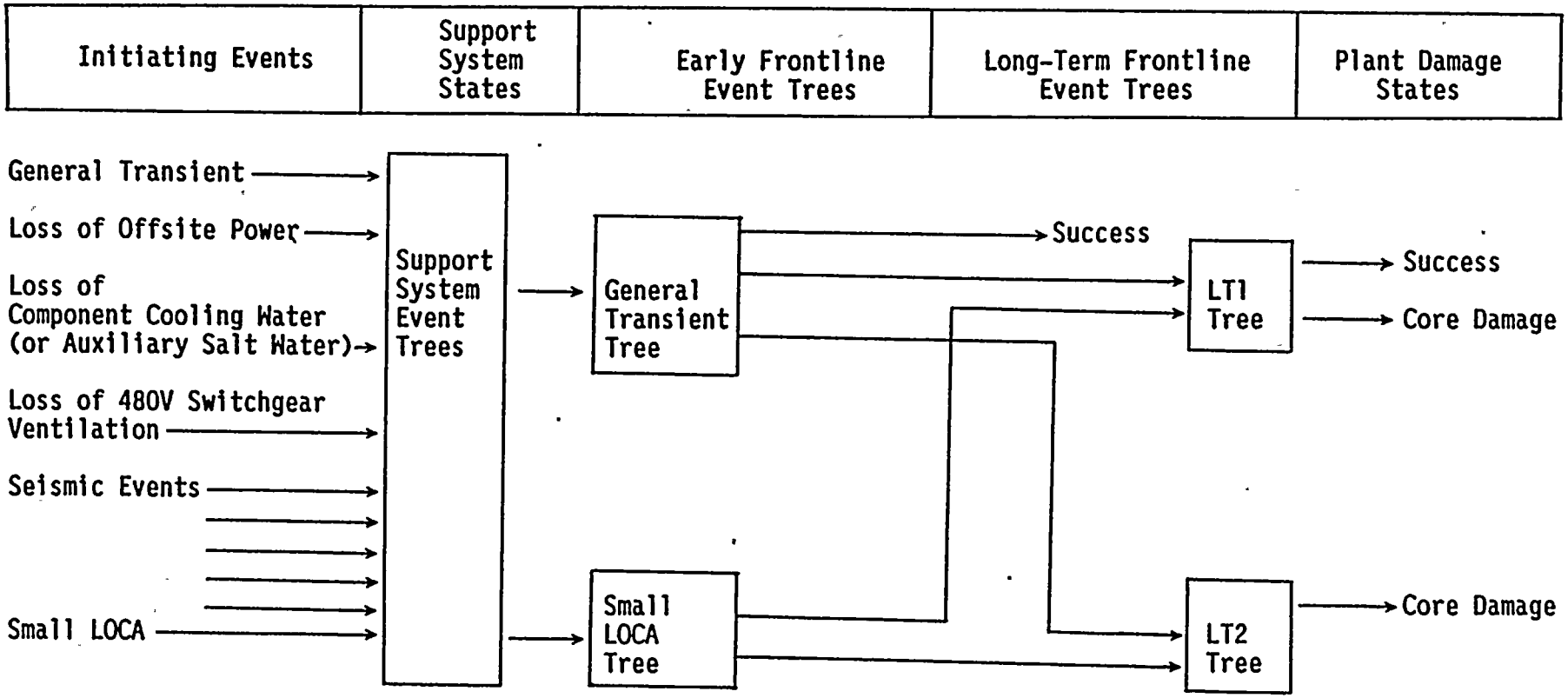
Fragility curves utilized in the Phase II analysis had long tails derived from logarithmic standard distributions. These tails are unrealistic for defining the chances of component failures at low accelerations, which have high frequencies. As a result, some components whose fragility curves have tails at these accelerations appear to have a chance of failing when, in fact, it is believed the component cannot fail at such low accelerations. In Phase III, a method for logically truncating fragility curve tails at low accelerations will be utilized.

Relay Chatter. In Phase II, the impact of relay and contact chattering was modeled in a very simplified way by assuming it was either always recoverable or never recoverable. The degree of recoverability is likely to be a strong function of the control circuits in which the relays are used. An analysis will be made of control circuits at Diablo Canyon to determine the effects on

system failure of relay chattering. Such a review will enable the PRA team to correctly model the effects of relay chatter in those plant systems deemed to be important. Currently, it is expected that at least several relays would have to chatter and not be easily recoverable for such a failure mode to be an important risk contributor.

Figure 7-1

FRONTLINE EVENT TREE MODEL LINKING



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Appendix

EQUIPMENT, STRUCTURES, AND COMPONENTS FOR FRAGILITY DEVELOPMENT

[illegible]

[illegible]

[illegible]

1. Reactor vessel
2. Reactor internals
3. Steam generators
4. Pressurizer
5. Pressurizer power operated relief valves
6. Pressurizer relief tank
7. Piping (NSSS)
8. Control rod drive mechanisms
9. Reactor coolant pumps

[illegible]

1. RHR pumps
2. RHR heat exchangers
3. Motor-operated valves (generic)
4. RHR piping (generic)

[illegible]

1. Accumulators
2. Safety injection pumps
3. Reactor containment sump
4. Boron injection tank
5. Boron injection piping
6. Motor operated valves (generic)
7. Piping (generic)

[illegible]

1. CCW pumps
2. CCW heat exchangers
3. Motor-operated valves (generic)
4. Piping (generic)

[illegible]

1. CS pumps
2. CS heat exchanger
3. Spray additive tank
4. Refueling water storage tank
5. Motor-operated valves (generic)
6. Spray header (generic)
7. Piping (generic)

Table A-1

EQUIPMENT LIST FOR FRAGILITY DEVELOPMENT

Reactor Coolant System

1. Reactor vessel
2. Reactor internals
3. Steam generators
4. Pressurizer
5. Pressurizer safety & relief valves
6. Pressurizer relief tank
7. Piping (NSSS)
8. Control rod guide tubes
9. Reactor coolant pumps

Residual Heat Removal System

1. RHR pumps
2. RHR heat exchangers
3. Motor-operated valves (generic)
4. RHR piping (generic)

Safety Injection System

1. Accumulators
2. Safety injection pumps
3. Boron injection recirculation pumps
4. Boron injection tank
5. Boron injection surge tank
6. Motor-operated valves (generic)
7. Piping (generic)

Primary Component Cooling Water

1. CCW pumps
2. CCW heat exchangers
3. Motor-operated valves (generic)
4. Piping (generic)

Containment Spray System

1. CS pumps
2. CS heat exchangers
3. Spray additive tank
4. Refueling water storage tank
5. Motor-operated valves (generic)
6. Spray headers (generic)
7. Piping (generic)

[illegible]

[illegible]

[illegible]

1. [illegible] (generic)
2. Piping (generic)

Main Steam System

1. Main steam isolation valves
2. Main steam safety valves (generic)
3. Power-operated relief valves (generic)
4. Air-operated valves (generic)
5. Piping (generic)

Feedwater System

1. Containment isolation valves
2. Piping (generic)

Diesel Generators

1. Fuel oil day tank
2. Air starting receivers
3. Air start receivers
4. Diesel generators
5. DG heat exchangers

Control Building [illegible] HVAC System

1. Supply fans
2. Return fans
3. Battery room exhaust fans
4. Cable tray supply fans
5. Dampers
6. Air-conditioning units

Emergency Feedwater System

1. Emergency feedwater pumps
   a. Motor driven
   b. Turbine driven

2. Air-Operated valves (generic)
3. Motor-operated valves (generic)
4. Piping (generic)

Table A-1 (Cont'd)

EQUIPMENT LIST FOR FRAGILITY DEVELOPMENT

Steam Generator Blowdown

1. Isolation valves (generic)
2. Piping (generic)

Main Steam System

1. Main steam isolation valves
2. Main steam safety valves (generic)
3. Power-operated relief valves (generic)
4. Air-operated valves (generic)
5. Piping (generic)

Feedwater System

1. Containment isolation valves (generic)
2. Piping (generic)

Diesel Generators

1. Fuel oil day tanks
2. Air start compressor
3. Air start receivers
4. Diesel generators
5. DG heat exchangers

Control Building Ventilation System

1. Supply fans
2. Return fans
3. Battery room exhaust fans
4. Cable spreading supply fans
5. Dampers
6. Air-Conditioning Units

Emergency Feedwater System

1. Emergency feedwater pumps
   a. Motor driven
   b. Turbine driven
2. Air-Operated valves (generic)
3. Motor-operated valves (generic)
4. Piping (generic)

[illegible]

[illegible]

[illegible]

[illegible]

1. [illegible]

[illegible]

1. [illegible] processing units
2. Exhaust fan
3. Supply fan

[illegible]

1. [illegible]

[illegible]

1. Switches
2. Cable [illegible]

[illegible]

1. Switches as [illegible]
2. [illegible]
3. Fuses [illegible]

[illegible]

1. 120 V [illegible] circuit breaker [illegible]

[illegible]

1. Transformer [illegible] centers
2. Fuses (or [illegible] cabinets)
3. Motor [illegible] centers

Table A-1 (Cont'd)

EQUIPMENT LIST FOR FRAGILITY DEVELOPMENT

Diesel Generator Building Ventilation

1. Supply fans

Primary Auxiliary Building Ventilation

1. Cont. enclosure cooling units
2. Exhaust fans
3. Supply fans

Service Water Pumphouse Ventilation

1. Exhaust fans

Electric Power 4160 (Vital)

1. Switchgear
2. Cable trays

Electric Power 125 V DC

1. Batteries and racks
2. Chargers
3. Buses (breakers)

Electric Power 120 V AC

1. 120 V AC instrument AC breaker panels

Electric Power 480 V AC (Vital)

1. Transformers (load centers)
2. Buses (breaker cabinets)
3. Motor control centers

Table A-1 (Cont'd)

EQUIPMENT LIST FOR FRAGILITY DEVELOPMENT

Generic Fragilities

Class 1, 2, and 3 BOP piping and supports
Relief and check valves
Air-operated valves
Motor-operated valves
Cable trays and supports
Ducting and supports (ventilation)
Dampers
Instrument sensors

Table A-2

STRUCTURES LIST FOR FRAGILITY DEVELOPMENT

Containment building
Containment internal structure
Turbine building
Pumphouse
Refueling water storage tank (RWST)

Table A-3

ADDED COMPONENTS FOR FRAGILITIES DEVELOPMENT

Offsite power
Fan coolers
Condensate water storage tank (CWST)
Buried fuel oil storage tank
Buried fuel oil transfer line
Buried auxiliary saltwater pipe