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SUBJECT: Summary of 910916-17 ACRS Extreme External Phenomena Subcommittee meeting in San Luis Obispo,CA re review & discussion of Diablo Canyon long-term seismic reevaluation program.

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ACRS-2770

10/7/91

ACRS EXTREME EXTERNAL PHENOMENA SUBCOMMITTEE MEETING MINUTES SEPTEMBER 16-17, 1991 SAN LUIS OBISPO, CALIFORNIA

The ACRS Subcommittee on Extreme External Phenomena met on September 16-17, 1991, in San Luis Obispo, California, to review and discuss the Diablo Canyon long-term seismic reevaluation program.

Notice of the meeting was published in the Federal Register on July 24, 1991. Items covered in the meeting and handouts are kept with the office copy. There were 25 oral presentations from the members of the public and one written statement received. The meeting was open to the public. E. Igne was cognizant ACRS staff member for the meeting.

PRINCIPAL ATTENDEES

ACRS

C. Siess, Chairman
D. Ward, ACRS Member
P. Shewmon, ACRS Member
H. Lewis, ACRS Member
W. Kerr, ACRS Member
I. Catton, ACRS Member
B. Page, ACRS Consultant
G. Thompson, ACRS Consultant
J. Stevenson, ACRS Consultant
P. Davis, ACRS Consultant
R. Fraley, ACRS Staff Member
E. Igne, ACRS Staff Member

NRC and Consultants

J. Richardson, NRR
R. Rothman, NRR
R. McMullen, RES
P. Sobel, NRR
H. Vandermolen, RES
G. Bagchi, NRR
N. Chokski, RES
G. Cook, GPA (Reg. V)
H. Rood, NRR
K. Campbell, Dames & Moore
C. Constantino, CUNY
A. Veletsos, Rice University
M. Bohn, SNL
R. Brown, USGS
S. Lewis, USGS
R. Fitzpatrick, BNL
G. Bozoki, BNL

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ORAL PRESENTERS

Michelle Becker, Mothers for Peace
Sandy Silver, Mothers for Peace
Jim Crouch, Mothers for Peace
Randy Davis, Resident, County of San Luis Obispo
Jay Namson, Concerned Citizen
Michael Mowry, IBEW
Theodore Hall, IBEW
Andrew Mognagh, San Luis Obispo Building Trades Council
Owen Betts, Laborers Union #1464
Sid Stolper, UAW #403
Earl Patton, Carpenters #1800
Louis Zucco, Local #775
Kip Johnson, UAW #669
Doug Hehnke, Sheet Metal Workers
Jill Zamek, Mothers for Peace
Evelyn Delany, Member, Board of Supervisors, County of San Luis Obispo
Rita Camp, Diablo Vigilance Researchers in South County
Chris Pillsbury, Citizens for Adequate Energy
Ted Waddell, Citizens for Adequate Energy
Ralph Vorhies, Citizens for Adequate Energy
Kurt Kupper, The Environmental Center
Richard Kranzdor, California Polytechnical State University Faculty
Sheila Waynne, Life on Planet Earth
Raymond MacKenzie, Peace and Freedom Party of California
David Blakely, Membe, Board of Supervisors, County of San Luis Obispo

PACIFIC GAS & ELECTRIC CORP. AND CONSULTANTS

Lloyd Cluff
William Savage
Norman Abrahamson
Paul Somerville
Kevin Coppersmith
Shankar Bhattacharga
Robert P. Kennedy
Raymond Thierry
Dennis Bley
Bruce Smith
Dennis Hennesy
Y. Justin Liu
Michael Emerson, PLG, Inc.
Jan Rietman
Bruce Smith
Nicki Malenfant
Ross Sadigh
C. Allen
Kathryn Hanson
Marcia McLaren
Janet Cluff
Lawrence Thomas

OTHERS

R. Osborne, SCE
R. Zahn
J. Merkel, Sierra Club
L. Apfelbey, Mothers for Peace
R. Comp, Mothers for Peace
H. Heifitz, Mothers for Peace
A. McAfee, San Luis Obispo Public Awareness Forum
D. Lortz, Citizens for Responsible Energy
I. Ing, Resident
L. Kahele, Resident
S. Biesek, Mothers for Peace
A. Jenkens, Sierra Club

HIGHLIGHTS

1. C. Siess, Chairman, read the opening meeting statements and announced that he plans to hear public comments from 8:45 am - 12:30 pm. If the allotted time is not sufficient to hear all public comments, he stated that additional time will be allotted after the conclusion of the first day agenda at 5:30 pm.

C. Siess, before hearing public comments, briefly reviewed ACRS involvement in the seismic design of the Diablo Canyon nuclear plant. ACRS in its letters approved a construction permit for Unit 1 in December 1967 and for Unit 2 in October 1969. In both cases, no particular concern was expressed about the seismic design bases, which was 0.2g for the Design Earthquake and 0.4g for the Double-Design Earthquake. It was noted that Appendix A had not yet been adopted and the Hosgri Fault zone had not yet been discovered. In 1971, the Hosgri Fault became known and the seismic design bases were reviewed and revised over the next few years. During this period the ACRS had ten subcommittee meetings as part of the Operating License review, of which seven of these meetings were related to seismic matters. Three of these meetings were held in San Luis Obispo, two in Los Angeles and one Washington, DC. ACRS approval of the Diablo Canyon operating license was given in its letter of July 14, 1978. That letter included extensive discussion of the seismic design bases, the reasons for finding them acceptable and recommended that the seismic design of Diablo Canyon nuclear power plant be reevaluated in about ten years, taking into account applicable new information. This recommendation led the NRC to include in the Diablo Canyon operating license a License Condition requiring what is now known as the Long-Term Seismic Program (LTSP). The LTSP began in July 1985 and was completed in July 1988, in three years, as required by the license condition.

During this time the ACRS reviewed the progress of the program. Our consultants in the areas of geology and seismology attended numerous meetings at which results of the program were presented and discussed by the licensee, the NRC staff, and other interested and knowledgeable persons.

2. Twenty-four oral presentations were heard from members of the public. We received one written comment from a member of the public. Four presenters appeared on behalf of Mothers for Peace, seven on behalf of the Building Trades Council, three on behalf of Citizens for Adequate Energy, five representing self, one each representing the Environmental Center, Life on Planet Earth, Peace and Freedom Party of California, and two from the Board of Supervisors, County of San Luis Obispo.

J. Crouch, on behalf of Mothers for Peace, suggested to the subcommittee that ... "The NRC staff's SSER 34 conclusions are unreliable for the purposes of judging the adequacy of Diablo Canyon's seismic safety margins and that the only way that you can get reliable information and make a prudent recommendation as to the plant's safety is to call for an independent investigation." The need for an independent investigation was the theme that presenters for Mothers for Peace stressed. J. Crouch stated that the NRC staff's conclusions are unreliable because on a number of critical geoseismic issues regarding the Hosgri Fault, the NRC staff has unjustifiably biased their conclusions toward those of the licensee (PG&E), and have virtually ignored the reasonable conclusions and legitimate concerns of their own independent geoseismic consultants, the USGS.

J. Crouch concluded by noting, for the record, that he is not opposed to nuclear power in general, nor Diablo Canyon specifically. He is opposed to the misuse of science and to

what he perceives to be a flawed regulatory review process, which Dr. Crouch characterized as a process which relies on investigative material assembled and presented by a licensee who has a multi-billion dollar investment and income base to protect.

J. Namson, addressed some technical issues concerning the geological report written by PG&E consultants. He stated that he has done research in the area, which was funded by the U. S. geological survey (USGS), National Earthquake Hazard Reduction Program, and that his report which documented his findings was published in the American Association of Petroleum Geologists Bulletin. He further stated that he is neither pro-nuclear nor anti-nuclear, and had not been paid by PG&E or any other group to do the research. The nature of his research was to understand the origin of large folds or fault geometry in the area by the construction of regional cross-sections and by integrating surface geology and oil well data. The object of this study is to try to predict where and what the faults are doing at depth. As a result of this study, J. Namson stated that there exist a blind thrust that underlies the Point San Luis incline and that PG&E was told a couple of years ago that they need to consider the risk of this thrust underneath the plant.

3. L. Cluff, PG&E, presented an overview of the results of the LTSP. The program was organized under the license condition which has four elements. The first element is geology, seismology and geophysics; element two, earthquake magnitude; element three, earthquake ground motions; and element four, seismic margin evaluation.

Element one describes the regional earthquake potential. In this element pertinent information was gathered, new data

obtained, if required, and inquiries made about scientific studies by the USGS, various universities and researchers. These data and studies were then integrated in order to have a letter understanding of regional geology, seismology and tectonics that are important to understanding the earthquake potential surrounding the Diablo Canyon site.

In element two, the information from element one was then used to evaluate the potential for earthquakes occurring on various seismic sources and specifically to determine the frequency of occurrence and maximum magnitude that could be related to each seismic source.

In element three, information from elements one and two was then used to characterize site-specific ground motions.

Element four used information from element three to perform engineering analyses of systems, structures and components in order to determine their seismic margins. This evaluation was performed using both deterministic and probabilistic methods.

The milestone of the program were discussed. When the final report was completed in July 1988, the final report review process commenced and was completed in July 1991. The review process was conducted by the NRC, its consultants, the ACRS and its consultants and interested and knowledgeable persons. Numerous workshops/meetings were held in open meetings.

L. Cluff presented a summary of conclusions from the LTSP: The Hosgri Fault dominates the seismic hazard, both probabilistically and deterministically at the Diablo Canyon site, and the fault is capable of a magnitude of 7.2 earthquake. The horizontal spectra basically envelope the Hosgri spectra. The vertical spectra are higher at some

points in the frequency range, but was found not to affect the seismic margins significantly. Soil-structure interaction was found to reduce seismic response of plant structures, and confirms Dr. Newmark's development of the "tau" effect. The PRA shows the seismic risk to be relatively low and similar to that of many other nuclear power plants that have been licensed, and that Diablo Canyon does have sufficient margins to accommodate the maximum ground motion that can occur at the plant.

L. Cluff concluded his presentation by stating that the LTSP was very comprehensive. It had been conducted in the highest professional manner with very competent scientists and engineers which resulted in very high quality data. The program has been thoroughly reviewed by not one but many completely independent reviewers and individuals, and this process has taken place over the last six years in a very open and public manner, with participation on many occasions by some of the public technical individuals that were here this morning.

4. H. Rood, NRC, in his introductory statement introduced the staff reviewers and staff consultants, and discussed the key milestones in the review of the LTSP by the staff. H. Rood then summarized the staff's conclusions. First, the staff finds that PG&E has met the letter and intent of the license condition requiring PG&E to conduct a seismic reevaluation program; and second, the Diablo Canyon seismic design continues to be acceptable. He stated further that the staff would be pleased to have comments from the Committee regarding the LTSP, and absent recommendations to the contrary, the staff plans no additional activity on the LTSP in the future, other than to verify that the confirmatory item identified in the SSER has been satisfactorily resolved.

5. W. Savage, PG&E, discussed the results of the geoscience and seismic source characterization aspects of the LTSP. In summarizing the tectonic setting studies, he stated that they have identified the Los Osos - Santa Maria domain as a transitional region, bounded by the Hosgri fault zone on the West, and, within this domain, the San Luis Obispo block has no internal deformation and is bounded by the Los Osos Fault on the Northeast and the Southwestern faults on the Southwest. The Hosgri fault zone is the dominant seismic source in the region of the Diablo Canyon nuclear power plant.

In response to a subcommittee question, W. Savage believes that PG&E tectonic model is valid. He further stated that PG&E has considered J. Namson's model and hypothesis very carefully. They have applied his model to applicable data sets relevant to evaluating earthquake potential within this region and found his hypothesis inappropriate to use, he believes that the evidence is overwhelming that it simply cannot represent an active seismic source.

In response to another subcommittee question on whether PG&E prepared a critique of J. Namson's work, W. Savage stated that yes, a critique was prepared. Further, questions by the subcommittee on why the critique was received by the author only recently, W. Savage stated that he can't speak from J. Namson's perspective, but PG&E was in personal communication with him, and that part of their review materials has been presented at professional society meetings with J. Namson in attendance. Therefore, he was, in large part, aware of the details of the points of concern and outcome.

W. Savage then focused on the Hosgri fault zone and the particular issue of geometry and the slip of the Hosgri zone. PG&E has approached this question from many different aspects,

i.e., reviewing published evaluations of the Hosgri Fault zone, conducting interviews with individuals who have different view points on the Hosgri zone, conducting independent evaluations of existing data, and acquiring additional datasets, in developing an improved understanding of the down-dip geometry and the sense of slip of the Hosgri.

The Hosgri fault zone is part of the coastal fault system and consists of the San Gregorio, Sur, San Simeon. These are complicated faults and where these faults are observed on land and are amenable to trenching and other paleo-seismic study, The faults are quite clearly predominantly strike-slip faults. They do have associated minor dip-slip components, but the characterization of the faults to the north of Hosgri is well defined as a strike-slip. The linearity and the continuity of this zone is also typical of strike-slip faults. Regional kinematic relationships of the behavior of the Los Osos - Santa Maria domain also produces a component of strike-slip along the Hosgri Fault zone.

Other factors in assessing the Hosgri sensitivity to slip involve the relationship to the San Simon fault. PG&E conducted paleoseismic investigations from excavations. They also conducted marine terrace investigations. These investigations and regional onshore geologic mapping led PG&E to conclude that the San Simeon fault was slipping horizontally at a rate of approximately 1-3 mm/yr. This horizontal slip rate is tightly constrained by the onshore geological data in this area and is compatible with the linearity of the fault and the San Simeon fault's position along this coastal fault system. An important question is what happens to the slip rate as one approaches the Hosgri fault zone? Based on both geophysical and reflection studies in the offshore area and diver geology studies on the near

offshore sea floor, PG&E found that the San Simeon fault and the Hosgri fault zone are not directly connected, but interact with one another across a small quaternary basin. Hence the slip is transferred across this quaternary basin in a step-over, that is typical of strike-slip faults, not only in California, but worldwide. The San Andreas, the Hayward, the San Jacinto faults all exhibit this characteristic step-over behavior between individual fault elements.

In response to a subcommittee question on the relevance of the slip being transferred by step-over behavior and its relationship to the potential fault length and thus the higher magnitude of the earthquake, W. Savage stated that the critical point here is to understand the tectonic relationship between the San Simeon and Hosgri faults and affirms the horizontal slip rate we established on the Hosgri fault zone.

Analyses were performed on the small step-over basin in order to assess the consistency of the dimensions of the basin with respect to possible slip rates and amount of exchange of slip between the San Simeon and the Hosgri fault zone. Results of these analyses indicate that the dimensions are consistent with the entire slip rate of 1-3 mm/yr of the San Simeon fault being transferred to the Hosgri.

In response to a subcommittee question on the possibility that the San Simeon and Hosgri are one continuous fault as alluded to in earlier presentation, W. Savage stated that they have identified this step-over basin as a segmentation point between the San Simeon and Hosgri faults. The presence of the step-over basis and the nature of the relationship between the two faults is important. It is important to determine whether they are continuous or represent a step-over basin accommodating the horizontal slip rate as they have shown.

A major portion of the LTSP has involved evaluating and interpreting seismic reflection data, from the thousands of kilometers of lines collected along the entire length of the Hosgri fault zone. In interpreting reflection line PG&E-3, it was observed that the Hosgri fault is near vertical in the upper few kilometers. This feature was observed on hundreds of lines crossing the Hosgri fault. Also noted on the geophysical image or seismic reflection are up-dip displacement along the fault, which is one of the characteristic features of strike-slip faults. Up-dip displacements were also seen in other lines.

In response to a subcommittee question on the results of lines PG&E -2 and -1 which are closer to the nuclear power plant, W. Savage stated that these lines have been presented in previous submittals. The predominant continuity of these lines in question show high-angle traces. In response to further questions on other possible interpretations of these lines, W. Savage stated that other geophysical interpretations are possible, but these interpretations when tested by structural geological analysis are not validated.

The vertical component of slip along the entire length of the Hosgri Fault zone was obtained by looking at the same set of geophysical lines. The vertical component of slip is needed because the style of a fault is defined by its components of slip. The definition of strike-slip that is commonly used in geological literature is a ratio of horizontal slip to vertical slip equal to two-one or greater. In the case of the San Simeon fault, the horizontal-to-vertical appears to be ten-to-one, which defines the San Simeon Fault as possessing a strike-slip character. A thrust or reverse fault is defined as a fault that has a predominate component of dip-slip, or the horizontal-to-vertical slips ratio one-to-two (or

greater). The largest rate of vertical separation at the Hosgri Fault zone occurs opposite the ends of these uplifting blocks within the Los Osos and Santa Marie domain, and that rate of vertical separation has a maximum value of 0.4 mm/yr. Hence, by definition the Hosgri fault zone is a strike-slip fault.

In summary, PG&E has concluded that the Hosgri fault zone is a strike-slip fault, with a steep down-dip geometry that appears to be vertical in some locations or steeply dipping in other locations. PG&E consider the dip to be in the range of 70 to 90 degrees.

W. Savage, next discussed the assessment of the maximum earthquake magnitude. PG&E has also used the multiple approach methodology in order to determine the maximum earthquake magnitude of the Hosgri fault. In a response to a subcommittee question on the definition of magnitude, W. Savage stated that magnitude measure has two requirements; it must be associated with an empirical measure of magnitude that makes sense in a geometrical fashion and it must be based on a long period of measurement. The items assessed for magnitude are fault rupture area, fault rupture length, seismic moment, and fault displacement per event. These four items represent characterization of maximum magnitude that are functions of the geometry of a fault. Other items assessed in the determination of the maximum earthquake magnitude are maximum historical earthquake and total fault length.

In response to a subcommittee question regarding the use of the word magnitude as referring to surface wave magnitude, W. Savage stated that he cannot vouch for all the magnitude numbers heard today referred to surface wave magnitude, only PG&E numbers. Further, for the surface wave magnitude and the

moment magnitude to be numerically identical, the magnitude must be about 7. With respect to a subcommittee question regarding the reason for assessing the long period (very low frequency) portion of the spectrum, which is not very important to the damage potential for plant structures, W. Savage stated that a relationship is needed of assessing the size of an earthquake that is measurable by large-scale features ... one can't look at very high frequency measures of earthquakes when the fault features are tens of kilometers long. In reply to W. Savage's answer, a subcommittee member stated that, in order to have confidence in the magnitude at the high-frequency end of the spectrum, we need reasonably good information about the high-frequency end, in which case the question is why not use it directly, unless you are going to fudge it. W. Savage responded by stating that there is no clearly-identified direct measurement one can make of some geologic parameters obtained from field measurements.

The maximum historical earthquake was the 1927 Lompoc which originally was located well offshore of Diablo Canyon. In 1978, Gawthrop USGS, did an analyses of the earthquake location and magnitude. This study resulted in moving the epicenter much closer to Diablo Canyon and assigning a general magnitude of 7.3 - 7.5. After further study of this earthquake, the USGS concluded that the 1927 Lompoc earthquake could not be precluded from the Hosgri fault zone. PG&E has performed a study to determine both the magnitude and the location of the LOMPAC earthquake. Review of original papers by Guttenberg and Richter at Cal Tech had calculated a surface wave magnitude of 7.0. Studies based on recordings that were made at tide gauges in several areas within the Eastern Pacific and using modern technology of Tsunami wave propagation analysis, resulted in the epicenter location of the Lompoc earthquake to be 35 kilometers off-shore, and

significantly separated from the very near shore location of the Hosgri fault zone.

PG&E also considered an assessment of the total fault length. There are relationships between total fault length and maximum earthquake magnitude that are available in the literature. From these considerations, PG&E concluded that the maximum earthquake magnitude for the Hosgri fault zone is 7.2.

In conclusion, W. Savage stated that with respect to the Hosgri fault zone characteristics, the style of faulting is strike-slip with a subordinate component of dip-slip. The dip is steep, either vertical or dipping steeply to the Northeast. The closest distance from the site to the Hosgri Fault zone is 4.5 kilometers, and the maximum magnitude is 7.2.

In response to a subcommittee question, W. Savage stated that if the down dip geometry decreased, the magnitude would increase slightly because of a larger rupture area, but other parameters of the earthquake, such as length, would be coupled to the down dip decrease and might offset the magnitude increase. With respect to the 1927 earthquake, W. Savage stated that it is not a significant factor in defining the maximum magnitude for the Hosgri. With respect to the uncertainty associated with the maximum earthquake, W. Savage stated that the value 7.2 is at the upper limit of the range of uncertainty. Further, in clarifying subcommittee questions regarding uncertainties of the magnitude of the Hosgri, L. Cluff stated that in their hazard analysis, a full range of magnitudes and uncertainty distributions were considered, not only for the Hosgri, but for every fault investigated. The distribution showed a median magnitude to be 7.0, to which they are added 0.2 for a reasonable upper bound to obtain 7.2. Regarding a question on obtaining the acceleration at the

plant in a roundabout way by concentrating on the surface wave magnitude at low frequencies, L. Cluff stated that this matter will be discussed when ground motion is presented.

6. R. McMullen, NRC, discussed the staff's activities and review of the geology, tectonics, and geophysics. The staff agrees with the PG&E findings except the angle of dip. PG&E and the University of Nevada conclude that the dip angle is 70-90 degrees to the Northeast; USGS 50-90 degrees and the NRC 60-90 degrees. All agree that the maximum magnitude on the Hosgri fault is 7.2. Again, the subcommittee questioned the uncertainty of the magnitude of 7.2. R. Rothman, NRC, attempted to answer the question but was not successful. Further, the subcommittee asked if the 7.2 magnitude value was independently derived. R. Rothman stated that no, the value was not independently derived by the staff, but is based on the staff's reviews of PG&E's findings and analyses. Regarding dip angles, the subcommittee noted that four different groups of people evaluating one set of data produced three different answers.

In response to a subcommittee question, R. McMullen stated that there is general agreement among the four groups that the Hosgri fault dominates the other seismic sources.

In conclusion, R. McMullen stated that the magnitude of the Hosgri fault is 7.2 at 4.5 kilometers from the site, with a displacement characterized as two-thirds strike-slip and one-third reverse-slip. There are no capable faults in the site vicinity. With respect to a subcommittee question on the basis for the numbers two-thirds and one-third, R. McMullen stated that the NRC staff arrived at those numbers from siting studies at San Simeon, where it was determined that the horizontal slip was about 1-3 mm/yrs; and from the marine

terraces and San Luis Pismo structural block, the vertical rate was determined to be .10 - .44 mm/yrs.

7. R. Brown, USGS, a consultant for the NRC, summarized USGS findings with respect to geology, tectonics and geophysics. The earthquakes of most importance to the Diablo Canyon nuclear power plant are the Hosgri, Los Osos and Southwest boundary faults whose estimated magnitudes of expected earthquakes are 7.2, 6.8 and 6.0, respectively. When questioned by the subcommittee, R. Brown stated that review of the PG&E report by a group of people from USGS found that the value of the magnitude is an estimated upper bound, with a plus/minus variation of 0.1 magnitude. The Hosgri at 4.5 kilometers from the plant dominates the seismic hazard. USGS stated that the fault mechanism that generates a 7.2 magnitude on the Hosgri is a result of an oblique-slip on the fault dipping 50-70 degrees Northeast which differs from the PG&E interpretation as occurring as a result of a strike-slip on a near vertical fault plane.

In response to a question by the subcommittee, R. Brown stated that the fault mechanism is a more important issue in determining the ground motion than a tenth of a magnitude increase on the upper bound earthquake value. Concerning a question on the consequence of a 50 degree dip in the fault plane, R. Brown stated that it could place the epicenter right below the plant ... but stipulated that the Hosgri model at depth is not accurate.

In conclusion, R. Brown stated that given our present level of knowledge, earthquakes of moderate to large magnitudes on the Hosgri fault are most likely to result from oblique-slip (approximately equal amounts of reverse and strike-slip) on fault planes dipping ENE at 50-70 degrees (at seismogenic

depths).

G. Bagchi, NRC, in clarifying a point, stated that if the hypo-center of the Hosgri fault lies directly below the plant the ground motion at the surface would be less severe because of its large distance (4-5 kilometers). In addition, G. Bagchi stated that the assumption of equal amounts of reverse and strike-slip, which was the USGS conclusion, resulted in a response spectrum which is completely enveloped by the LTSP spectrum, except at frequencies below 1 Hz. Also, if we assume 100 percent reverse-slop (alluded to by J. Crouch this morning), the response spectrum results in a maximum peak acceleration of 2.1g. The peak acceleration value of 2.1g was then compared and found to be lower than the HCLPF (high-confidence of low probability of failure) value of the turbine building (lowest seismic margin) of 2.21g. This seismic margin according to G. Bagchi is substantial.

8. N. Abrahamson, PG&E, discussed ground motion estimation using newly available strong motion data along with advances in theory and analysis of seismic sources , wave propagation and attenuation theory. Two independent methods were used: the classical analysis of empirical data, and numerical simulations. The results of the classical study provided the horizontal and vertical spectra for Diablo Canyon. For the horizontal spectra, the LTSP Regression (84th percentile) curve envelops the SSER curves except at frequencies below 1 Hz. For the vertical spectra, the SSER curve exceeds the LTSP spectra below 10 Hz. (Confirmatory Issue: PG&E will confirm and document that these exceedances have no adverse effect on the seismic margins of the plant systems, structures and components).

9. P. Somerville, PG&E, next discussed the numerical ground

motion method. He stated that this modeling procedure is suited for sensitivity studies. The model was also able to account for spatial incoherence of ground motions. Many subcommittee questions (mathematical/physical parameter) were asked in order to clarify the equations used in this numerical technique.

In conclusion, P. Somerville, stated that the formal procedure for estimating uncertainty in the numerical ground motion method permitted an estimate of the 84th percentile response spectrum that was compatible with the empirical or classical estimates.

10. K. Coppersmith, PG&E discussed the probabilistic seismic hazard analysis, the output of which provides the input to the PRA. Essentially, the analysis consists of determining four major components: 1) definition of the seismic source geometry, 2) specification of earthquake recurrence relationships, 3) ground motion attenuation relationships, and 4) generation of the seismic hazard curves that essentially reflect the probability of exceeding various level of ground motion. It was noted that, in the analysis, not only the Hosgri fault but other faults within the region were considered in order to determine their contribution to the total ground motions at the site. K. Coppersmith stated that the Hosgri fault contributed about 95 percent of the probabilistic hazard at the site. In this methodology the total variability in seismic characteristics is accounted for by using a logic tree. The use of the logic tree is a simple way of accounting for component parts of each faults, i.e., style, dip, depth, etc., into particular models. In general, the results of this study indicated that the differences between the hazard curves obtained are not very significant and that the sense of slip or style of faulting on the Hosgri

fault is also not significant.

K. Coopersmith stated that he was asked by the staff to consider J. Namson's hypothesis and to consider what effect a blind thrust might have on the probabilistic hazard curve at the Diablo Canyon site. Results indicate that, from a probabilistic point of view, the changes in the hazard curve using Namson's hypothesis is insignificant.

11. Phyllis Sobel, NRC, discussed the ground motions expected for a magnitude 7.2 earthquake associated with the Hosgri fault zone. She stated that an independent assessment of attenuation relationships were performed by Dr. K. Campbell, NRC consultant and formerly with the USGS, and that the review of the PG&E numerical modeling study was performed for the NRC by its consultants Drs. Keiiti, Aki, Archuleta and Day.

The staff conclusion follows:

- The LTSP horizontal spectra are acceptable for frequencies above 1 Hz. At and below the 1 Hz, higher ground motions should be considered.

- The LTSP vertical spectra is lower than the staff's spectra in the range of 1 to 10 Hz. The staff's spectra should be used below 10 Hz.

At this point on the agenda, Mr. Campbell was called to the podium to respond to a question by the subcommittee concerning the completeness of the work done by USGS in order to assess the ground motion for Diablo Canyon. Mr. Campbell stated that he believes that at this point, the work is complete enough to assess ground motions at Diablo Canyon satisfactorily.

12. S. Bhattacharya, PGA discussed soil-structure interaction (SSI) which is a necessary element in order to determine the seismic margins of the plant using both the deterministic and PRA methods. The soil-structure interactions takes the developed ground motion and develops loads in terms of response spectra or the base shears for the structures in order to obtain seismic margins. Results of parametric studies of SSI/coherent ground motion, are as follows: 1) The foundation embedment has important effects and basemat flexibilities are important for determining the auxiliary and turbine buildings seismic margins, and 2) structure-to-structure interaction effects are insignificant. In addition, significant SSI effects were found for the stiff interior structure of the containment and the auxiliary buildings, while SSI effects are relatively small for the taller, more flexible containment shell. Examination of the "tau" effect in the LTSP has confirmed that the consideration (attenuation or reduction factors) of "tau" during the Hosgri evaluation was appropriate and that Dr. Newmark's approximation and engineering judgement produced values that have been justified by the LTSP studies.

In conclusion, SSI generally reduces seismic responses of plant structures and components and the LTSP margin evaluation has incorporated results of the SSI.

13. R. Rothman, NRC, discussed the staff's review of PG&E's SSI analysis. The staff were assisted in its review by BNL consultants, Professor Costantino, CUNY and Professor Veletsos, Rice University. The overall conclusions of the SSI analyses review indicate that the analytical procedures developed and used by PG&E for performing SSI analyses of major structures are comprehensive, thorough and utilized state-of-the-art methodologies. The SSI analysis have been

performed satisfactorily to compute the responses needed for deterministic and fragility evaluations.

In a response to a question by the subcommittee on benchmarking computer codes, Professor Constantino stated that the computer code was checked against a series of dynamic tests in order to gain confidence in its use.

14. R. Kennedy, PG&E discussed the Diablo Canyon PRA fragility evaluation. The fragility evaluation at Diablo Canyon was performed similar to the fragility evaluations that have been done in over 20 previous seismic PRA studies. The general approach was to obtain the term which has come to be called the high confidence, low probability of failure (HCLPF) capacity which correspond to about the 95 percent confidence of less than a five percent frequency of failure. R. Kennedy stated that he discussed the HCLPF concept at four previous ACRS meetings on other plants and once on Diablo Canyon. He then discussed the improvements made for the final results at Diablo Canyon, in order to improve the quality and confidence in determining the fragility estimates. First, the fragilities were defined in terms of a single ground motion parameter to enable them to be convoluted with the hazard curves in the PRA, and second all Diablo Canyon fragilities are reported in terms of a 5 percent damped, average spectral acceleration over the frequency range from 3 - 8 1/2 Hz. He stated that these improvements best describe damage capabilities of civil structures.

R. Kennedy stated that the civil structure that has the lowest seismic capacity is the turbine building (shear failures of walls). Failure of his structures is an important contributor to the total seismic risk. In order to determine the ruggedness of Diablo Canyon structures and equipment, R.

Kennedy stated that the amplitude of the 5 percent damped, average spectra over the 3 - 8 1;2 Hz range was scaled upward to about 3 g, before it was determined that a reasonable probability of failure could occur to the turbine building. The largest ground motion ever recorded worldwide is the Tabaz earthquake record, which had an average spectral acceleration of 2.25 g; the second largest is the Pacoima Dam earthquake at 1.95 g.

The fragilities were determined for the Diablo Canyon civil structures and equipment. For structures, the turbine and auxiliary buildings have the lowest HCLPF capacities. For equipment, the 230 KV off-site switchgear, the 4160 V switchgear, the diesel generator control panel, and power operated relief valves were found to have the lowest HCLPF capacities.

In response to a question by the subcommittee, R. Kennedy stated that differential support motion was considered in the deterministic analysis but not considered during the fragility evaluation. But a walkdown inspection was made and sources of severe differential displacement problems were not found.

15. M. Bohn, Sandia National Laboratory, and contractor to NRC, discussed the review of PG&E building responses and seismic fragilities. As part of the review, M. Bohn stated they performed a sampling audit based on results of previous PRAs to determine, for example, if the boundary conditions and failure modes are realistic. He cited some cases where incorrect assumptions were made in the PG&E model and, upon discussions with PG&E, the model was corrected.

With respect to relay chatter, PG&E identified all relays that affected safety-related components, and developed capacity

factors based on EPRI generic equipment response spectra. It was found that the capacity factors for these relays were significantly high so as not to contribute to risk, but the 4 kv switchgear had the lowest capacity and vulnerable to vertical accelerations, if these 4 kv switchgears fail, station blackout occurs. However, these relays can be reset both locally or from the control room and consequently did not play a significant part in the total seismic risk.

In conclusion, M. Bohn stated that the review of PG&E fragility evaluation indicates that all Diablo Canyon plant structures and equipment contributing significantly to core damage frequency have a margin of at least 40 percent over the site-specific ground motion.

In response to a question from the subcommittee, M. Bohn stated that the greatest weakness in the fragility study is the lack of actual test data for equipment failures during qualification testing. If the equipment does not fail during qualification testing the equipment is assigned an arbitrary fragility value of 1.8 (1.2 at the on-set of distress x 1.5 additional energy absorbing capacity). It was stated that 1.8 is a conservative value.

16. R. Kennedy, PG&E, discussed seismic margins. For the Diablo Canyon margin review, seismic margins are defined in terms of component and plant HCLPF capacity which corresponds to an earthquake level at which, with considerable confidence, it is extremely unlikely that failure of the component will occur. Mathematically, if a log-normal distribution is assumed, it is 95 percent confidence of less than a five percent frequency of failure. He stressed that an important point is the fact that there is no proverbial cliff or sudden failure which is expected to occur immediately above this HCLPF capacity, since

the median capacities are at least a factor of 2 higher than the HCLPF capacity. At Diablo Canyon, the fragility analysis method was used and benchmarked using the conservative deterministic failure margin (CDFM) methodology that has been documented in EPRI report NP-6041.

In conclusion, R. Kennedy stated that the lowest seismic margin for Diablo Canyon structures and components is about 1.4. Thus, the best estimate seismic margin against the 84 percent non-exceedance probability spectra site-specific ground motion is 2 x 1.4 or 2.8.

17. S. Bhattacharya, PG&E discussed the deterministic margin assessment using the CDFM methodology. This study was performed and compared with the margin estimated using the fragility approach. In addition, CDFM methodology was used in PG&E confirmatory evaluations to study the effect of increase in spectral acceleration specified by the NRC staff in SSER 34. Using the evaluation criteria given in EPRI NP-6041, S. Bhattacharya stated that the results of the CDFM method compare favorably, with those from fragility analyses and that the seismic margins for the plant structures and equipment are acceptable. In applying the CDFM method to the effect of increase in spectral accelerations, it was stated that the increases in spectral acceleration can be accommodated by the seismic margin in existing design.

18. G. Bagchi, NRC, discussed engineering evaluations and seismic margins. In response to a question by the subcommittee on acceptable seismic margins, G. Bagchi stated that there is significant conservatism in the demand estimate and also in the way capacity is calculated. Therefore, the staff would accept a factor of one; that is, the demand and capacity are equal.

G. Bagchi stated that the staff's audit of the engineering calculations found that the PG&E evaluations are well done and acceptable. Major plant structures and equipment at Diablo Canyon have adequate seismic margins against the LTSP earthquake loading subject to quantitative confirmation of certain structures and equipment that may be affected by the ground motion exceedances.

G. Bagchi, as a separate license issue (not related to the LTSP), discussed the evaluation of masonry walls. He stated that PG&E lacked sufficient supporting test data to justify its evaluation of the strength of the masonry wall. As part of the resolution of the issue, PG&E has committed to fix all the safety-related masonry walls.

19. R. Thierry, PG&E and D. Bley, PG&E Consultant, presented the results of the full scope Level 1, PRA as required by Element 4 of the license condition. It was stated that no significant outliers were identified. Some plant improvements were made, but there were no major plant or structural modifications made as a result of the PRA. The total mean core damage frequency (CDF) was determined to be 2E-4/yr, of which seismic events contributed 18 percent of the total. Internal events contributed 63 percent and other external events, 19 percent. Comparisons with other PRAs performed on PWR plants indicate that the Diablo Canyon CDF is similar.

20. N. Chokski, NRC, described the staff's review of the PG&E probabilistic risk assessment for to external events. He concluded that the seismic PRA was performed using state-of-the-art methods, and in some cases advancing the art by accounting for relay chatter. The single largest contributor to seismic CDF is the failure of the turbine building, followed by a loss of the 230-kV offsite power. Components

whose failure could lead to seismic CDF have at least 40 percent margin over the site-specific ground motion. The largest contribution to seismically induced CDF comes from earthquakes with average spectral accelerations in the 2.0 - 3.0g range.

21. At the conclusion of the meeting, C. Siess was informed that an earthquake had recently occurred and was felt by some people in the meeting room in San Luis Obispo. W. Savage, PG&E, stated that the earthquake occurred North of the town of San Simeon, along the coast near the San Simeon fault and beneath the Santa Lucia mountains at 2:04 pm. The magnitude was about 5 and was located about 75 kilometers from the Diablo Canyon plant and about the same distance from San Luis Obispo. The maximum acceleration at the Diablo Canyon site was less than 0.01g..

SUBCOMMITTEE DISCUSSION

C. Siess asked the subcommittee if any Members felt that this matter should not be brought to the Full Committee during our October meeting. No objections were voiced. C. Siess stated that he will recommend that a letter be written.

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NOTE: **Additional meeting details can be obtained from a transcript of this meeting available in the NRC Public Document Room, 2120 L Street, NW, Washington, DC 20006, (202) 634-3273, or can be purchased from Ann Riley and Associates, Ltd., 1612 K Street, NW, Suite 300, Washington, DC 20006, (202) 293-3950.**