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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING APPEAL BOARD

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In the Matter of	)	
	)	
PACIFIC GAS AND ELECTRIC COMPANY	)	Docket No. 50-275
	)	Docket No. ~~50-323~~
Diablo Canyon Nuclear Power Plant Units 1 and 2	)	(Seismic Issues)
	)	21 Nov 80

PROPOSED FINDINGS OF FACT

AND

CONCLUSIONS OF LAW

SUBMITTED BY

PACIFIC GAS AND ELECTRIC COMPANY

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FINDINGS OF FACT

A. Prior Proceedings

On September 27, 1979 the Atomic Safety and Licensing Board issued a partial initial decision dealing with issues concerning the geology of the Diablo Canyon site, the adequacy of the seismic design of the Diablo Canyon plant, potential aircraft or missile crashes into the plant, and the site security plan. (10 NRC 453) The partial initial decision did not include conclusions of law or form of order because of unresolved issues arising from the accident at the Three Mile Island Plant. Two separate and independent appeals were taken from the decision. One of them was filed on behalf of the San Luis Obispo Mothers for Peace relating to the Licensing Board's findings on the adequacy of the site security plan. This appeal is being handled as a completely separate proceeding before a reconstituted Appeal Board. The other appeal, which is the subject of these findings of fact, was filed by the San Luis Obispo Mothers for Peace and certain other intervenors, who are hereinafter referred to as the Joint Intervenors (J.I.), and is concerned with the Licensing Board's findings on the seismic issues in this case.

Exceptions to the Licensing Board's decision and supporting briefs were reviewed by this Board. On March 28, 1980 Joint Intervenors filed a Motion To Reopen to receive new evidence on, among other things, data developed from an

earthquake which occurred in the Imperial Valley in California and Mexico on October 15, 1979. Briefs and supporting affidavits in opposition to the motion were filed by PGandE and the NRC Staff. On June 24, 1980 this Board issued its decision (ALAB-598, 11 NRC 876) granting in part Joint Intervenors' motion to reopen and directing the parties to file written testimony on nine questions set forth in an appendix to the decision.

In a Memorandum and Order dated August 7, 1980 this Board directed Dr. Mihailo D. Trifunac and Dr. J. Enrique Luco, witnesses subpoened by the Licensing Board in the proceeding below, to review and comment upon as witnesses of this Board the testimony furnished by the parties.

B. <u>Evidentiary Hearing</u>

The evidentiary hearing was held from October 20 1/ through October 25, 1980. Governor Edmund G. Brown, Jr. was the only new party to the proceeding, having been admitted by the Licensing Board as representative of an interested state pursuant to 10 CFR 2.715(c) (ASLB order dated November 16, 1979). At the hearing the following exhibits were numbered for identification and, where indicated, received into evidence:

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Applicant

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2/ Certain portions excluded. See Appeal Board Order dated November 5, 1980.

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The order in which testimony was to be received was prescribed in the Appeal Board's Order dated October 6, 1980 as supplemented by its Order dated October 15, 1980. This order of presentation was varied somewhat at the hearing for the convenience of one of the Staff witnesses. In any event the questions propounded in the Appendix to ALAB-598 and the testimony offered in response are set forth following in numerical order:

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Question I. The October 15, 1979, Imperial Valley Earthquake (IV-79, M_L = 6.4-6.9) provided an extensive set of strong motion records in the near field of a rather severe earthquake. The parties should compare the horizontal peak acceleration values recorded for various instrument positions with earlier predictions and compilations of such motion, <u>e.g.</u>, those contained in the Final Safety Analysis Report (FSAR) on the Diablo Canyon Nuclear Power Plant, Amendment 50, Appendix D LL 11B, Figures 2, 3, and 4; and the United States Geological Survey (USGS) Circular 795, Figures 4, 24, 47, and 48. Those comparisons should (if possible) address whether there is magnitude independence or a saturation effect for ground motion intensity in the near field of earthquakes.

The Imperial Valley earthquake of October 15, 1979 (IV-79 earthquake) yielded an extensive amount of near-field seismic data. In general the revised and corrected data for the earthquake give results that are not greater than those used in nuclear reactor design as exemplified by the design criteria specified for the Diablo Canyon facility (Newmark 11; Blume I-1 thru I-5). The new data from the IV-79 earthquake clearly show that statistical results for motions recorded at distances greater than ten km should not be extrapolated linearly to directly determine the peak accelerations likely to develop in the near-field, and that there is a clear indication of a saturation effect of peak ground motion in the near-field with values very near the fault being no greater than those at a distance of about six or seven km from the fault (Blume I-5 through I-7; Edwards VII-1, VII-2; Seed I-1, I-2, Rothman 9). The saturation effects of interest are two-fold; saturation with decreasing distance to the fault rupture surface, and saturation with

increasing magnitude (Smith I-1 thru I-3; Tr. 122, 126, 133-135, 150, 151, 171; Applicant (App.) Ex. R-5, R-6). The results of the IV-79 earthquake fell within predictions made by, among others, Drs. Blume, Seed, and Smith and the United States Geological Survey (USGS) in Circular 795 (Blume I-5, I-7; Seed I-2, Seed Figure I-2; Smith I-1; Tr. 110, 116, 168, 169). Predictions of peak ground acceleration (PGA) for conditions at. Diablo Canyon demonstrated the conservatism of the 0.75g reanalysis value (Smith I-1, Tr. 550, 1374, 1375, 1413).

Other witnesses (Luco 2-3, Young 20; Tr. 613, 614) offered predictive correlations based upon defining distance from a postulated zone of energy release, the epicenter or hypocenter. Dr. Young could not give a basis for using epicentral distance to predict peak ground accelerations (PGA) within 10 kilometers of a fault (Tr. 1069). Dr. Smith found it very unlikely, both geologically and seismologically, that the center of energy release is a point source for a large earthquake, and that the epicenter or hypocenter is the most probable location for that point (Tr. 1378). Dr. Smith (Tr. 55-62, App. Ex. R-1) explained the various distance models and indicated the bases (statistical, physical intuition and predictive capability) for perferring normal distance to the fault or distance to the nearest point of fault rupture or energy release as used

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by most experts in the near field of large earthquakes (Tr. 62, 169, 549, J.I. Ex. R-1).

A report by TERA Corporation entitled "Final Report - Evaluation of Peak Horizontal Ground Acceleration Associated with the Hosgri Fault at Diablo Canyon Nuclear Power Plant, (Ex. 1 to Smith testimony on Question I), hereafter referred to as the TERA Report, which incorporates the IV-79 data, has extended the analysis of horizontal PGA in the near source region. This analysis supports the conclusion that PGA does saturate with increasing magnitude in the near source region. In a conservative analysis, i.e., when both North American and non-North American earthquake data are included in a multiple regression analysis of near source PGA recordings, the predicted median value for a magnitude 7.5 earthquake at a distance of 5.8 km is 0.48g for instrumental ground motion. Using only North American data the figure is .41g. If a regression model is chosen which assumes complete saturation of PGA with increasing magnitude (supported on theoretical grounds and by North American data), the predicted motion for DCNPP is little influenced by whether the regression analysis is constrained to require "complete" magnitude saturation. Because the regression analysis established that the median plus one-standard-deviation value is 1.52 times the median, the median plus one-standard-deviation acceleration is 0.62g (TERA Report 1-3; Smith I-2, I-3; Tr. 380). The similar

figure using both North American and non-North American data is .72g (TERA Report 1-3.)

J.I. witness James Brune testified that the horizontal accelerations for the IV-79 earthquake were in general agreement with the 70% prediction intervals in USGS Circular 795 for a M=6.4 earthquake. He stated further that they represent the average expected, and that other earthquakes of the same magnitude could be expected to generate considerably higher and in other cases considerably lower average accelerations, although he had low confidence in this conclusion because of lack of sufficient data (Brune 4, 5). He also stated that the data indicate that acceleration increases with decreasing distance but with a flattening slope at close distances (Brune 4; Tr. 772, 857). On the stand Dr. Brune took issue with Dr. Blume's position that the Imperial fault was considered a vertical plane of energy release (Tr. 613). Dr. Brune advanced a novel theory that about 50% of the total energy released by the IV-79 earthquake was released in a zone about ten km in length at a depth of six to ten km which he called a zone of "concentrated energy release" (Tr. 613, 843). He illustrated this zone on J.I. Ex. R-12 and stated it was not a point source (Tr. 775, 854). However, on cross-examination he was unable to locate the zone with any degree of specificity or describe its dimensions (Tr. 776, 778, 779, 788, 854). Further, it developed that Dr. Brune

had not plotted the data points on J.I. Ex. R-12, was unable to testify as to what point he had plotted from, and his testimony on these matters was stricken (Tr. 894, 1201). Finally he concluded that his zone of concentrated energy release was not a final result but only a possible fit to the data, he acknowledged that it should not be used "for anything other than simply getting a general idea of the different ways that that would plot," and that he did not want to "stick [his] neck out" regarding the location of the zone (Tr. 793, 841, 853, 886). Applicant witnesses Frazier and Smith saw no evidence of localized high zones of energy release in the IV-79 records (Tr. 335, 1378).

Brown witness George A. Young testified in comparing the curves of Circular 795 and the IV-79 data that the Blume curves are low, the Trifunac curves too high, the Schnabel and Seed curve for magnitude 6.6 plots as an approximate mean curve to the IV-79 data, and that peak ground accelerations are magnitude dependent in the near field (Young 5, 6; Tr. 1054, 1084). Dr. Young also testified that he would predict a mean peak horizontal ground acceleration of 1.0 g at the Diablo site for a magnitude 7.5 earthquake on the Hosgri Fault (Young 15; Tr. 1013). At the hearing Dr. Young testified that he could name no new project on which he had been given the responsibility of providing the overall criteria for the design of the plant (Tr. 609). He also testified that he

used only 15 stations in comparing Dr. Blume's SAM V equation and the IV-79 data whereas Dr. Blume had used data from all the stations (Tr. 740, 972). However, in discussing the TERA report he stated that all data should be used unless there are serious questions regarding its accuracy (Tr. 745, 972, 973). In an exhibit prepared by Dr. Young (Brown Ex. R-12) when plotted no data points fell below a mean minus one-standard-deviation, and only one fell above the mean plus one-standard-deviation, which is statistically improper (Tr. 979-981).

Question II. Response spectra have been developed from the near-field (1 to 11 km) ground motion records produced by IV-79. The records contain horizontal peak acceleration values in the range of 0.81g to about 0.2g. The applicant calculated a mean peak acceleration of 0.36g for IV-70 at the 5.8 km site-to-fault distance that characterizes the Diablo Canyon site (Applicant's Brief). Despite the fact that the IV-79 peak acceleration values are generally lower than the 1.15g peak acceleration or 0.75g zero-period acceleration used as the design basis for the Diablo Canyon plant (resulting from a postulated 7.5M event on the Hosgri fault), there are instances (although only those from the El Centro Arrays are significant) for which the IV-79 horizontal responses exceed the Newmark Design Response Spectrum for Diablo Canyon. (See staff brief at page 9; Brune Affidavit, Attachments A and B.) In view of this, the parties should discuss whether the Newmark Spectrum is an appropriate and sufficiently conservative representation of the 7.5M event at Hosgri. 5/

5/ In other words, if the various IV-79 near field response spectra were used to generate a smoother, average response spectrum for a zero-period acceleration appropriate to that event (in accordance with techniques explained in Blume's testimony fol. Tr. 6099 at page 6 and pages 39 and 40), and if this spectrum were scaled to a 0.75g zero-period acceleration, would the resulting response spectrum be bounded by the Newmark Spectrum for Diablo Canyon?

In order to study the characteristics of the response spectra shapes obtained from the IV-79 records the 24 available horizontal records within eleven km of the fault were collected and plotted (Blume Figure II-1). The calculated mean of the 24 horizontal spectra, including the extremely high spectrum for Bonds Corner, were plotted on Blume Figure II-2 6/ (Tr. 187, 188). The results clearly demonstrate the substantial margin between the Diablo design spectra and the mean Imperial Valley spectrum. Dr. Blume also prepared a figure showing the peak ground acceleration of the mean Imperial Valley spectrum normalized to 0.75 g, and the results showed that the Imperial Valley spectrum falls within the Diablo Canyon design spectrum within the periods of interest (Blume II-2; Blume Figure II-3; Tr. 189). Dr. Seed demonstrated that "applying the best corrections we can to the Imperial Valley data to translate those records to the Diablo Canyon site, that we in fact find the resulting spectral shapes will not be greater than those required by the Newmark-Hosgri spectrum" (Tr. 1415; App. Ex. R-20). In summary the Newmark and Blume design response spectra used for the Diablo Canyon Hosgri reanalysis remain appropriate and conservative in view of the data obtained from the IV-79 earthquake (Blume II-2;

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6/ The averaging of spectra to arrive at a design spectrum is an accepted method (Blume II-2).

Newmark 13, 14, 19; Tr. 1353, 1355-1357, 1414, 1415; App. Exs. R-10, R-20). These results were confirmed by the modeling work performed by Applicant's witness Frazier (Frazier VII-4 to VII-13; Frazier Figs. VII-4, VII-5; TERA Report).

Brown witness Young offered testimony on Question II. He concluded that based on Figure 7 in his testimony that an appropriate point upon which to anchor his response spectrum would be 1.4g (Tr. 1007, 1008). The witness could not name any other building in the world where the design response spectra was anchored at a level of 1.4g or higher (Tr. 1009), and that the highest anchor point he knew of was the 0.75g for Diablo Canyon (Tr. 1010). After testifying that he expected to see a mean peak horizontal ground acceleration at the site of 1.0g and that his opinions on the subject had not changed significantly in the last four or five years, it developed on cross-examination that he was the author of a report dated December 1977 concerning seismic criteria and design concepts for the Point Conception LNG Import Terminal which recommended that the peak ground acceleration from the safe-shutdown earthquake be between .5g and .6g although "Additional study by the applicant may justify lower values" (App. Ex. R-9, p. x; Tr. 1026, 1030, 1034-1048, 1069, 1070-1078). The earthquake described as the major seismic hazard to the LNG site was a magnitude 7.0 to 7.6 assigned to a fault one portion of

which ran within three miles offshore from the site (App. Ex. R-9, pp. 38, 39; Tr. 1070). The report also provided as follows:

> "It was concluded that the same level of conservatism in design for safe shutdown of the plant should be practiced as required for nuclear power plants . . ." [App. Ex. R-9, pp. vi, vii.]

Question III. We are told that IV-79 data are not relevant to the Diablo Canyon seismic analysis because that plant is a "rock" site, whereas the Imperial Valley data were obtained on soil sites. (Rothman - Kuo Affidavit at page 3; Blume Affidavit, Paragraph 8.) What is the significance of this difference in view of the conclusion of the authors of USGS Circular 795 (based on an analysis of data provided in that document) that, for comparable earthquake magnitude and distance, there are no significant differences between peak horizontal accelerations measured on soil or rock? (USGS Circular 795 at pages 1, 17, and 26.) This question should be considered in light of statements by applicant's witness Blume to the effect that acceleration, rather than velocity or displacement, is the critical parameter in the design of Diablo Canyon (Blume Affidavit, Paragraph 9; Testimony fol. Tr. 6099, p. 33).

The shape of the response spectrum for a soil site differs from that of a rock site for a given magnitude earthquake, the degree of variation depending on the frequency range considered. In the high frequency portion of the spectrum most experts indicated that there is relatively little difference in the spectrum shape between soil and rock sites (TERA Report p. 3-4; Blume III-1, III-2, Trifunac III.1). In the medium and low frequency portions of the spectrum, the difference in spectrum shapes between rock and soil sites is more significant. The high frequency portion of the response spectrum is predominately influenced

by the level of peak acceleration. USGS Circular 795 stated that "In the distance range used in the regression analysis (15-100 km) the values of peak horizontal acceleration recorded at soil sites in the San Fernando earthquake are not significantly different from the values at rock sites . . ." This conclusion is supported by examination of near field ground motion recordings (TERA Report p. 3-5) and the results of almost three thousand records from point-source, large underground nuclear explosions in Nevada and elsewhere, where at short distances from the source the average accelerations on rock and on alluvium were found to be about the same (Blume III-1, III-2).

The medium and low frequency portions of the response spectrum are primarily influenced by peak velocities and displacements, respectively. It is generally recognized that velocity and displacement are greater in soft alluvium than on rock. Thus, with regard to the Imperial Valley, it would be expected that its deep, soft (low shear velocity) alluvium and high water table would have a greater velocity and displacement for comparable earthquake magnitudes than for a rock site such as Diablo Canyon (Blume III-2; Newmark 17; Tr. 192).

Thus, while the high frequency portion of the response spectrum (dominated by peak accelerations) for a rock and a soil site for a given magnitude earthquake will not differ significantly, there will be significant

differences in the medium to low frequency portions of the spectrum (Blume III-2).

Applicant witness Dr. H. B. Seed is of the opinion that accelerations on rock would be about 30 percent higher than accelerations on deep soil (Tr. 234). Others who do not see this difference do not separate stiff soil sites and very deep soil sites which give the difference. (Tr. 250, 251).

The matter of relative importance of acceleration, velocity, and displacement in the Hosgri reanalysis of Diablo Canyon has been addressed. The significant natural frequencies of the Diablo Canyon structures are all higher than 2 Hz. As shown on the 4-way log plot spectral diagrams of Figure 41-A (D-LL 42 of Amendment 53), the velocity and/or displacement could be arbitrarily increased to a considerable degree without affecting the design motion for these rigid, short-period structures and facilities. In other words, in the high frequency range, as for Diablo Canyon, acceleration, and not velocity or displacement, is the critical parameter in design (Blume III-2, III-3).

In conclusion, the response of rigid structures, such as those at Diablo Canyon, is predominantly governed by acceleration, but since displacement and velocity also influence the shape of the response spectrum, it is inappropriate to use data from soil sites to derive response spectra for rock sites (Blume III-3).

Question IV. The magnitude of vertical and horizontal acceleration values measured at IV-79 are generally comparable. (Mean values calculated at a distance of 5.8 km from the fault are virtually identical.) The response spectra developed for vertical motion within 11 km of the Imperial Fault during IV-79 appear to show generally equivalent values of vertical and horizontal response for periods less than about 0.2 seconds (i.e., frequencies in excess of 5 cps). Finally, in some instances the higher frequency portions of the IV-79 response spectra for vertical motion exceed comparable portions of the Diablo Canyon Design Response Spectrum.

Observations made of the IV-79 data and response spectra appear to be consistent with the criteria set forth in NRC Regulatory Guide 1.60. These require that vertical accelerations in the higher frequency range be equal to horizontal accelerations. As the guide states:

> It should be noted that the vertical Design Response Spectra are 2/3 those of the horizontal Design Response Spectra for Frequencies less than 0.25; for frequencies higher than 3.5 they are the same, while the ratio varies between 2/3 and 1 for frequencies between 0.25 and 3.5.

The references to vertical motion made in the Diablo Canyon record, however, indicate that a 2/3 ratio between vertical and horizontal motion was apparently utilized at all frequencies. The parties should address this apparent inconsistency and explain it, if possible. Should there be substantive and relevant analyses suggesting that vertical motion records do not reflect the true vertical motion, these should be provided.

Some vertical accelerations recorded for the IV-79 earthquake were unusually high in relation to recorded horizontal accelerations. These data are presented in Frazier Table IV-1 for the strong motion stations positioned as shown in Frazier Figure IV-1. At close distances, the peak vertical accelerations were as high, on the average, as the peak horizontal accelerations. A few of the stations

recorded vertical peaks that were substantially higher than the horizontal peaks. While vertical accelerations that rival or exceed the peak horizontal accelerations are unusual, they are not without precedent. However, the peak vertical acceleration of 1.74 g (later corrected to 1.52 g) recorded for Station 6 is without precedent (Frazier IV-1).

Dr. Newmark indicated that high vertical-to-horizontal peak acceleration ratios are caused by instrument "over-registration" unless firmly attached and could be discounted (Tr. 426, 427 587-589). As a result Dr. Newmark stated the two-thirds ratio of vertical-to-horizontal motion used at Diablo Canyon was justified (Newmark 8, 9, 12). Dr. Blume also concluded that "vertical recordings are too high" (Blume IV-5).

In interpreting the unusually high vertical accelerations recorded during the IV-79 event, it is important to examine the different characteristics of seismic waves. Acoustic waves in the earth are referred to as compressional waves or "P waves." The particle motion for these waves is along the direction of propagation. Waves with shearing motions, particle motion perpendicular to the direction of propagation, are referred to as shear waves or "S waves." The velocity of P waves is always larger than that of S waves. Hence, the first motions to occur during an earthquake are due to P waves. Because these waves emerge steeply, and because the particle motion

is along the direction of propagation, P waves appear principally on vertical recordings. S waves arrive later and typically provide the preponderance of seismic energy on both horizontal and vertical recordings of earthquakes. It is these waves that account for most earthquake damage to structures (Frazier IV-2; Tr. 255).

For typical Southern California earth structures, vertically polarized shear waves (S waves), and not P waves, account for the largest vertical accelerations. Furthermore, the vertical-to-horizontal amplitude ratio for the S waves is typically less than one. This ratio is controlled by the tangent of the angle of the emerging S waves with respect to vertical. The angle is small since material velocities, which increase with depth, cause the high frequency waves to emerge steeply. Consequently, vertical accelerations are typically lower than horizontal accelerations (Frazier IV-2; Tr. 286).

In the Imperial Valley, however, the situation is atypical. The deep sedimentary layering there causes unusually large P-wave amplitudes. Examination of the recordings for IV-79 indicate that the large vertical accelerations resulted from high frequency P waves, not S waves. The unusually large P waves that appear in the vertical recordings from IV-79 are due to the uncommon wave properties of the deep sedimentary basin found in the Imperial Valley, illustrated in Frazier Figure IV-2.

Material velocities increase nearly linearly with depth from low values within the 300 meters or so of surface alluvium to values typical of bedrock at a depth of 6 kilometers. The properties of this deep sedimentary basin are markedly different from other regions of California where rock is encountered within 1 or 2 km of the earth's surface as illustrated in Frazier Figure IV-2 (Frazier IV-3; Tr. 255, 256).

The substantial velocity gradient with depth at Imperial Valley causes waves to bend (refract) toward the earth's surface along circular paths in accordance with Snell's law. The sedimentary basin acts somewhat like an echo chamber due to the extreme bending of waves toward the earth's surface. For example, at Imperial Valley only about 10% of the seismic energy (P and S waves) emanating from earthquake rupture at a depth of 3 km escapes into the underlying bedrock (e.g. Ray "D" on Frazier Figure IV-3). The remaining 90% emerges at the earth's surface within an epicentral distance of 20 km. In a more typical situation, such as at Diablo Canyon, the energy within 20 km is about 60 percent. Therefore, the unusual echo chamber effect at Imperial Valley which concentrates seismic energy would not be expected at Diablo Canyon (Frazier IV-4; Tr. 256, 257, 258, 277, 435, 437, 438).

While the echo chamber effect at Imperial Valley would tend to increase both P and S wave amplitudes, the

unique velocity profile there (Frazier Figure IV-2) preferentially amplifies P-wave amplitudes. Due to the conservation of energy, the amplitude of a seismic wave increases as it propagates into a medium of decreasing stiffness. Consequently, the amplitudes of the emerging waves increase rather dramatically as they approach the earth's surface. However, high frequency S waves are severely attentuated in the shallow sediments, thereby compensating for the amplification of the sedimentary basin. P waves, on the other hand, can travel efficiently in the soft surface materials. In the shallow sediments at Imperial Valley, S waves above 10 Hz can be attenuated by a factor of ten within one kilometer, while P waves above 10 Hz are attenuated only about 20% over the same distance (Frazier IV-4; Tr. 257, 258, 287).

The large and uniform velocity gradient with depth in the Imperial Valley preferentially amplifies the P waves and thus yields higher vertical acceleration peaks than horizontal peaks. This effect is due to the unique earth structure at Imperial Valley and since the earth structure at Diablo Canyon is substantially different, such high verticals are not expected (Frazier IV-4; Tr. 277).

Comparative calculations have been performed to examine how differences in earth structure between Imperial Valley and Diablo Canyon lead to differences in surface motions. Frazier Figure IV-2 illustrates the differences in

two earth structures with lower material velocities present in the Imperial Valley to a depth of about 6 km. Surface motions have been calculated for small (point) earthquake ruptures positioned at varying hypocentral depths and epicentral distances for layered representations of these two earth structures. The results, termed Green's functions, include all wave types (including P, S, and surface waves) over the frequency band from 0 to 20 Hz (Frazier IV-5).

The most notable difference was the ratio of peak vertical to peak horizontal accelerations. These vertical-to-horizontal ratios were computed and averaged over epicentral distances less than 10 km. These ratios, averaged over the near field, are presented in Frazier Table IV-2. The vertical-to-horizontal ratio of peak acceleration is about three to ten times higher for Imperial Valley than for Diablo Canyon for both strike-slip and dip-slip rupture over the range of hypocentral depths that were tested. These results indicate the trend to be expected in actual earthquake motions, namely, considerably reduced vertical to horizontal ratios of accelerations at Diablo Canyon as compared to the corresponding ratios recorded for the Imperial Valley earthquake (Frazier IV-5; Tr. 282, 283, 443).

Further discussion of computed ground motions at Diablo Canyon due to a major hypothesized earthquake along the Hosgri fault may be found in Dr. Frazier's response to

Question VII. The results of earthquake modeling yield vertical accelerations less than half the horizontal accelerations (Frazier IV-6).

Even accounting for the effects of the unique earth structure at Imperial Valley, the large vertical acceleration recorded at Station 6 (1.74 g later corrected to 1.52 g) during the 1979 Imperial Valley earthquake poses an enigma. Station 7, which is about 1 km SW of Station 6, recorded a peak vertical acceleration of .65 g (corrected to .51 g), and Station 5, which is approximately 3 km NE of Station 6, recorded a peak vertical of .71 g (corrected to .44 g). It is clear from field observations that the Imperial Fault passes between Station 6 and Station 7 and the Brawley Fault passes between Station 6 and Station 5. It is important to note that the motion of the wedge-shaped block, upon which Station 6 is located, is <u>downward</u> relative to the adjacent blocks (Frazier IV-6).

Of significance is the observation that the S waves at Station 6 were delayed by .5 seconds relative to Station 7. Station 6 is underlain by material of lower velocity than is Station 7. The lower velocities may be due to the down-dropping of the wedge-shaped block between the Imperial and Brawley Faults upon which Station 6 is located. This would result in a greater accumulation of lower velocity sediments beneath Station 6 that would extend deeper than beneath either Station 7 or 5. However, due to

rapid depositional processes, the surface velocities would likely be similar beneath all of these stations. A laterally heterogeneous earth structure, which exhibits a column of low velocity material beneath the vicinity of Station 6, would trap obliquely emerging waves by refracting the wave toward the region of lower velocities (i.e., into the wedge). This is believed to be the cause of the significant amplification of vertical accelerations recorded at Station 6. Material attenuation, as cited above, prevented severe amplification of the high frequency S waves, which represent the major contributor to the horizontal ground acceleration (Frazier IV-7, IV-8).

Extensive geologic investigations at the Diablo Canyon site indicate that similar local amplifications of ground motion should not occur at that site. Therefore, such unusual recordings as that for Station 6 do not provide suitable analogs for use in evaluating the seismic criteria at Diablo Canyon (Frazier IV-8).

While some of the peak vertical accelerations recorded at IV-79 were unusually high, little damage occurred. This can partially be explained by two facts. First, the few large vertical pulses are isolated and, while large in amplitude, they are relatively low in energy. Second, the P waves with the high peak vertical accelerations arrive well before the onset of the S waves. Thus, observed recordings of the IV-79 earthquake do not pose as

severe a threat to structures as their peak accelerations might suggest due to phase differences in the individual components (Frazier IV-10).

A study of earthquake time histories reveals not only that the horizontal peaks are usually well separated in the time domain, but that the vertical peaks are separated from the horizontal peaks by even more time, up to several seconds. IV-79 was no exception. The Hosgri reanalysis, however, required that all three components be considered simultaneously, with responses combined on a square-root-of-the-sum-of-the-squares process. In addition, the Hosgri reanalysis required two equal horizontal components; in actuality, one horizontal component always exceeds the other, sometimes substantially. The conclusion is that the combining procedure for the three earthquake components, and the assumption of equal horizontal components is a conservative procedure (Blume IV-5; Tr. 285, 286).

In summary, the vertical accelerations recorded during the 1979 Imperial Valley earthquake are large due to the wave properties of the deep sedimentary basin. Such large vertical accelerations are not likely at Diablo Canyon. In addition, the required simultaneous combination of the three components of ground motion for Diablo Canyon conservatively ignores the actual recorded large phase

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differences between the vertical and horizontal components (Frazier IV-10).

In the Diablo Canyon original design vertical accelerations were taken at 2/3rds of the horizontal. At the time Diablo Canyon was designed the 2/3 rule was in nearly universal effect for nuclear plants. In the opinion of Applicant witness Blume the two-thirds ratio is appropriate for rock sites (Tr. 420). The Diablo Canyon structures, however, are in fact capable of accommodating far more than a 2/3 ratio (Blume IV-2; Tr. 419). In the reanalysis for the Hosgri fault exposure more than 2/3 was actually used in most cases. The Blume written testimony in the Licensing Board seismic hearings presented in Figures 8 through 17 to that testimony gives the Hosgri spectra by Blume and Newmark anchored to 0.50g at zero period without any tau reduction. The 0.50g was simply 2/3 of the 0.75g value where tau was zero. A tau reduction could have been taken as well for the vertical spectra due to the lack of wave coherence, embedment and other reasons, but it was not. Using the Newmark horizontal spectrum as an example, the ratios of the peak vertical effective acceleration to the peak horizontal are as follows:

Miscellaneous Small Structures:	0.50/0.75 = 0.67
Containment and Intake:	0.50/0.60 = 0.83
Auxiliary:	0.50/0.55 = 0.91
Turbine:	0.50/0.50 = 1.00

Thus, for the most important structures, the effective ratio of peak vertical to peak horizontal acceleration is more than 0.67 (Blume IV-2, IV-3; Tr. 416, 419).

When the ratio of vertical to horizontal is studied on a spectral basis, we see that the ratio varies depending on the period of vibration. Blume Figures IV-1 and IV-2 show the ratio of vertical design spectrum to horizontal design spectrum for the Blume and Newmark Hosgri spectra, respectively. The figures demonstrate that within the period range of interest (less than 0.5 sec) only the ratios for the miscellaneous structures approach two-thirds. The primary Category 1 structures are designed to ratios greater than two-thirds, and in the case of the Turbine Building the ratio approaches 1.4 at about 0.10 seconds for the Blume spectrum. The ratio specified by NRC Reg. Guide 1.60 is also shown on the figures for reference. Thus, while the Hosgri reevaluation criteria specified a two-thirds ratio of vertical to horizontal, the facts are that the primary structures and components have been analyzed for ratios greater than two-thirds (Blume IV-3).

Dr. Smith showed that the incoherence of high frequency motion was such that the vertical PGA across a building could be reduced in a manner similar to the included in the "tau effect" for horizontal PGA (Tr. 1391-6). Such a reduction was not included for Diablo

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Canyon and therefore an additional element of conservatism is present (Blume IV-2).

Question V. Peak horizontal acceleration values measured at the base of the Imperial Valley Services Building during IV-79 exceed those measured in the free field 103 meters away from the building. The motion records are described as showing similar amplitudes but greater low frequency motion in the building than in the free field. No response spectra for the two recording locations have been provided. The acceleration data, however, may be taken to indicate that no reduction in building motion due to the tau effect was realized in this instance.

Based on these observations, intervenors question the validity of the tau concept as well as its use to reduce the higher frequency portions of the Diablo Canyon Design Spectrum. The staff and the applicant answer that, because the Imperial County Services Building was supported on piles in a deep soil structure, these observations are irrelevant to the use of a tau effect in the seismic reanalysis of Diablo Canyon, which is built on a rock site. Staff witness Newmark, however, used recorded earthquake motions at the Hollywood Storage Building to demonstrate the use of a tau effect analysis. The Hollywood Storage Building itself is built on piles in soil. Thus, the "build-on-piles" rationale appears insufficient to explain why no tau effect was evident at the Imperial Valley Services Building.

One feature distinguishing the two buildings that no party commented upon is that the Hollywood Storage Building has a basement and the Services Building does not. Intervenors' witness, Dr. Luco, used this fact to explain in part why he believes the Hollywood building should have a large tau value. Rojahn and Ragsdale's discussion implies that to some extent ground level instrumental responses within the Imperial Valley Services Building may have been influenced by the response (and failure) of the building itself.

In any event, given the apparent similarities between the structural foundations of the two buildings, the explanations provided thus far for a seeming lack of a tau effect at the Imperial Valley Services Building are inadequate. The parties should provide additional information on this point and relate their analyses to both geologic and structural conditions prevailing at the Diablo Canyon site.

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Geology

Applicant's geological witness Douglas Hamilton described the differences between the Imperial Fault and the Hosgri Fault. His testimony included three tables which presented comparisons of the faults on three bases: character of the crust in the region of each fault; character of the fault itself; and character of sites near each fault. The information contained in the three tables indicates that, except for the facts the two faults have roughly comparable lengths, and each has a component of right-lateral strike slip in its sense of offset, the faults are dissimilar in nearly all respects. Sites located between five and six km (as well as over a much wider range of distances) from the fault traces also are highly dissimilar. He therefore concluded that the geological conditions which gave rise to the ground response effects recorded during the IV-79 earthquake do not exist at the Diablo Canyon site (Hamilton V-11 through V-15).

Structures

There are major structural and foundation differences between the Hollywood Storage Building ("HSB"), the Imperial County Services Building ("ISCB") and the Diablo Canyon structures. The HSB has a basement with heavy and continuous basement walls and it has a full-area concrete base slab extended to these walls. Thus its base in effect constitutes a rigid horizontal plate girder with a

web (slab) and flanges (walls). The base of this structure is very stiff horizontally. Moreover, there is passive resistance of the soil against the basement walls (Blume V-2).

The ICSB, on the other hand, has no basement; it has only one short segment of wall at its first story perimeter, and its base slab does not extend to either line of foundations in the longitudinal direction. There are small ties between the pile caps but these have little rigidity to act as a horizontal rigid frame. The connection of the slab to the few interior first-story wall segments is minimal. Moreover, the connection of the ICSB slab to the structure is not such as to make even this minor rigidity effective. Therefore, the ICSB does not have adequate lateral stiffness at its base to develop much, if any, "tau effect," whereas the HSB has sufficient stiffness. The ICSB is founded on much softer and deeper soil than the HSB. The ICSB also has relatively long (45 ft to 60 ft) piles which do not reach to a significantly harder material. The shear velocity of the soil in which these relatively flexible ICSB piles are embedded is only in the range of 400 to 700 fps and the material below the pile tips does not reach 1050 fps velocity until a depth of over 200 feet. At the HSB the piles are relatively short (12 ft to 30 ft) and thus stiffer, and since they extend into a much firmer layer of material the lateral stiffness of the two buildings differs

greatly. The size and shape of the two buildings vary as well, so the buildings are not comparable in size or proportion. Further, the HSB has much more total pile capacity per square foot of building area than the ICSB because it is higher and is designed for heavy storage loading (Blume V-3).

In summary as to the comparison of the two buildings, they are not at all alike in spite of both having piles. The ICSB is much more flexible in soil and/or pile movement horizontally and since the horizontal rigidity of the ICSB structure at its base level is only a fraction of that of the HSB it is considered inadequate to support a "tau effect." To state that these two buildings are alike because they both have piles is similar to stating that they are alike because both have walls and roofing (Blume V-4).

The Diablo Canyon structures are obviously a great deal more rigid laterally than the HSB for the following reasons:

- They are based on rock
- They are embedded in the rock
- They are large
- They are massive
- Their base slabs and walls are very thick

In short, the Diablo Canyon plant is far better suited for the tau concept than even the HSB or for that matter any building in Los Angeles or San Francisco (Blume V-4, V-5).

ICSB Record

The acceleration records in the ICSB show higher values than the records of free-field motions and thus could lead to the conclusion that tau-effect is not realized in this instance. Such a conclusion is not warranted, however, on the basis of this data. At least two good explanations exist for the apparent absence of a tau-effect in this case:

1. Since there is invariably some scatter in observed levels of peak acceleration at nearby locations in the free-field, the record of free-field peak acceleration values is not necessarily representative of the general free-field conditions in the region surrounding the ICSB. Thus if additional free-field records had been obtained at other locations nearer to or on other sides of the building, they are likely to have shown peak acceleration values different from those of the single free-field station installed about 300 feet from the building. The occurrence of scatter within a limited area may easily result in motions that vary by a factor of 1.5 or more. The ICSB free-field record is lower than several other records at greater distances from the fault. Thus the average free-field motions in the vicinity of the ICSB may easily have been as high as 0.33 g (0.22 x 1.5) at other surrounding points in the free-field. In fact they may have been even higher since the motions shown by the single recording in the free-field near the ICSB were unusually low

as compared to other recordings at comparable distances. Based on the entire set of data available the average acceleration at a distance of 7-1/2 km from the fault was about 0.34 g, also suggesting that higher values might have been developed in some locations in this general area. More importantly it suggests that the motions within the building were apparently about the same as the average for the free-field. This still shows no apparent tau-effect for this building -- and this is to be expected because other factors which might cause differential base motions at other sites would not be expected to be significant at the ICSB.

e.g., (a) Because of the deep soil layer overlying the entire area around the building, incoming waves are likely to be essentially vertical. This fact, combined with the limited dimension of the ICSB would cause differential times of arrival due to inclined wave effects to be negligible in this case.

(b) Because of the relative homogeneity of the deep soil layer, significant differential times of arrival due to non-homogeneity would not be expected.

(c) Because of the light weight of the building, the influence of soil-structure interaction on the building would be expected to be very low, provided it were firmly embedded on the ground surface.

Thus a tau-effect (or a base slab averaging effect) producing lower motions inside the building than representative free-field values would be expected to be very low in this case (Blume V-9, V-10; Newmark 7, 8; Seed V-1 through V-4; Smith V-1, V-2).

There is also a good possibility that the configuration of the base of the ICSB and the instrument locations on the base may have caused some amplification of free-field motions for this particular building. If the soil had settled away only slightly from the base of the pile caps, as sometimes occurs, the response of the pile/pile cap/ and overlying six feet of fill could be very complex leading to some amplification of the ground motions by the time they reached the base slab, two feet above the ground surface. Furthermore, the motions recorded at the ground floor of the building could have been increased by torsional effects since they were located near the edges, where torsion could affect the response of the building. Thus there are valid reasons why the motions recorded in the building could have been amplified so that they were higher than those in the free-field and this would have nothing to do with the presence or absence of a tau-effect (Blume V-11, VI-2, VI-3; Seed V-5, V-6; VI-5, VI-6).

In summary therefore, there are good reasons why tau-effects should not be expected at this poorly designed building, or why the accelerations recorded on the base slab

of the building might even be amplified over the motions in the underlying soil. It should also be noted that one can not ascribe any value to measurements that are made in a building that is failing (Tr. 688). This situation does not exist at the Diablo Canyon site, however. At Diablo Canyon motions are likely to have much greater non-coherence because of the non-homogeneity of the underlying rock foundation, non-verticality of waves approaching the foundation, and soil-structure effects which instead of amplifying adjacent rock motions would cause some attentuation of these motions. Accordingly, the data from the Imperial County Services Building showing an absence of tau-effects should in no way reflect on the appropriateness of incorporating the tau-effect in the design of the Diablo Canyon plant (Seed V-5, V-6, V-7; Tr. 687, 688).

Tau-Effect - El Centro Array

In the case of large foundations, seismic wave motion may vary significantly from one part of the foundation to another. Three separate and complex base averaging effects have been recognized and described collectively as the tau effect. Processes which may contribute to variations in ground motion across a foundation include non-vertically incident waves, random fluctuations in motion due to non-homogeneities along the path of wave propagation, and soil-structure interaction. When a foundation is subjected to accelerations that are not simultaneous, as for

example when the wave motion is trying to move the ends of the foundation upward and the middle downward, the massive and rigid nature of the foundation will average such motion and thus attentuate it by some factor (Smith V-3).

The USGS Differential Array in the Imperial Valley provides some new information on the spatial variation in the ground motion over distances comparable with large foundations. Since the instruments are located in a free-field situation, the data can only address the questions of angle of incidence, and fluctuations due to inhomogeneities. Although no information on soil structure interaction is available, some important inferences about the other base averaging effects can be made (Smith V-3).

Simple ray tracing from the earthquake source shows that the waves approach the array at an oblique angle such that the total delay across the array is only 20-30 milliseconds (2-3 samples, since the sample rate is 100/second). In this situation, which corresponds to nearly vertical wave incidence, base averaging effects due to the angle of incidence could not be very significant (Smith V-4).

The degree of incoherence in the Differential Array ground motions due to non-homogeneities is investigated in two ways. First, the response spectrum of the array average ground motion for stations 1-3, separated by a maximum distance of 55 meters, was compared to the

average spectrum of the individual recordings. This comparison requires that the recordings be put on an absolute time basis, which is believed to have been done to an accuracy of 1/200 to 1/400 of a second. The results of this analysis indicate that the reduction due to incoherence is about 20% for vertical motions and at least 10% for horizontal motions at frequencies of 20 to 30 hertz. (Tr. 1391-1392).

Another technique, which does not require absolute time, is covariance analysis. In this method the maximum correlation between the ground motion filtered to represent various frequency bonds, for each pair of stations was computed and plotted versus separation distance. Although the peak correlation was 100% for the closest stations, for the 5 to 15 hertz frequency range the peak correlation drops to about 80% at a distance of 50 meters, and for the 15 to 25 hertz frequency range, the peak correlation drops to only 60% at 20 meters (Tr. 1395).

In conclusion, high frequency components of ground motion, particularly above 10 to 15 hertz, are significantly incoherent over distances of 50 to 100 meters -- the reduction in ground motion at these frequencies being at least 10% to 20% for both vertical and horizontal components (Tr. 1395-1396; Smith V-4 to V-6; App. Exs. R-13 through R-16).

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Question VI. Throughout the Licensing Board hearings, parties stressed the role of soil-structure interactions as a mechanism that would reduce the magnitude of structure motion relative to ground motion (e.g., Tr. 8878; 8947-46). Staff and applicant's arguments (in response to intervenors' suggestion of the apparent lack of tau effect during IV-79) point to soil structure interactions as the reason for building motion exceeding that of the ground (Blume Affidavit, Paragraph 10; Rothman - Kuo Affidavit, page 7). (a) Describe and explain the circumstances in which soil-structure interactions produce enhanced or reduced structural response. (b) Discuss the relevance and applicability for such interactions to the seismic response assumed for Diablo Canyon.

Soil-structure interaction is a complex phenomenon which is generally understood to mean the effect of physical interaction between the building and the adjacent soil or rock on both the response of the structure and the motions developed in the base of the structure. However, many engineers have considered the subject to have a broader context and to include such additional effects as

1. The development of strong structural response because of the similarity between the natural period of a building and the characteristic period of the soil formation on which it is constructed.
2. The effects of non-coherence of ground motions at the base of a structure and the homogenizing of these motions by a rigid base slab in a structure.
3. The variations of ground motions with depth and the effects of this variation on structure response (Blume VI-1; Seed VI-1).

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In the testimony presented at the Licensing Board seismic hearing, the term soil-structure interaction was generally used in the more restrictive sense mentioned above. Possible effects of similarities in periods of buildings and site were not given any special terminology, the non-coherence of ground motions at the base of a building was generally referred to as the tau-effect, and variations of motions with depth were not considered because the structures under consideration are relatively near the ground surface (Seed VI-2).

Physical soil-structure interaction of the type discussed above has been investigated extensively over the past 20 years and in general it would appear that the magnitude of the effects depends on

(1) the relative medium on which it rests, and

(2) the physical size or mass of the structure involved.

Thus for example, soil structure interaction effects increase as the ratio of building stiffness to soil stiffness increases, and the effects are greater for massive structures such as nuclear power plants than for more conventional buildings (Seed VI-2).

Where a conventional building is firmly founded on a soil or rock deposit, it seems to be generally agreed that soil-structure interaction effects tend to reduce the response developed at the base of a building compared with

those developed assuming rigid base conditions. The magnitude of this reduction in conventional buildings generally ranges from zero to a few tens of percent. For nuclear power plants soil structure interaction may be significantly larger, ranging from about 10 to 50 percent (Seed VI-2, VI-3).

The influence of soil-structure interaction at the Diablo Canyon facility was studied by Professors Seed and Lysmer who concluded that the effects would be small (for nuclear power plants). Typical results of the Diablo Canyon study are shown on Seed Figure VI-1 and show that soil-structure interaction would reduce the spectral accelerations for the base slab motions by about 20 percent below those of the free-field motions for frequencies above 4 or 5 Hz. It is in this range of frequencies that the tau-effect has its major influence (Seed VI-3, VI-4).

The Hosgri reanalyses of the structures at Diablo Canyon are based on the assumption that the structures are founded on a rigid base. This neglects completely any soil-structure interaction effects of the type discussed above and illustrated in Seed Figure VI-1 and thus in this respect is conservative. It leads to the result that the base motions are the same as those in the free-field and thus to the use of horizontal base spectral accelerations at frequencies above 4 or 5 Hz which are about 20 percent higher (the actual amount varying with frequency as shown in

the figure) than those which would be computed with allowance for soil-structure interaction effects due to foundation compliance. Other types of soil-structure interaction -- such as the base slab averaging effect due to the non-coherence of ground motions over the area of the slab -- would reduce the design motions still further, perhaps by as much as an additional 20 percent. Thus there are ample grounds to justify the magnitude of the base motions used for the Hosgri reanalysis of the Diablo Canyon NPP structures. While the main justification for using a tau-factor to reduce motions in this case was developed on the basis of non-coherence of ground motions, consideration of all types of soil-structure interaction could have led to even greater reductions than those used (Seed VI-4).

Question VII. Intervenors (Brune Affidavit, page 5) and the applicant (Frazier Affidavit, Paragraph 3) have suggested that the strong motion data obtained from stations along the direction of the Imperial Fault evidence the "focusing" of earthquake motion. Yet, when the acceleration data of two such stations, El Centro Array Numbers 6 and 7, are plotted as a function of distance from the fault (e.g., Blume Affidavit, Figures 1 and 2), the horizontal acceleration values fall well below the regression line mean for the 1 km distance. The vertical acceleration values are also lower than the mean on such a plot.

To the extent possible, the parties should analyze the seismic records for the IV-79 earthquake as they pertain to the focusing phenomenon and relate the results of such analyses to the likelihood that, in the event of an earthquake anywhere along the Hosgri Fault, focusing might result in amplified seismic motion at Diablo Canyon.

Hypotheses which account for changes in the character of the radiation pattern of a point dislocation

strike-slip source due to rupture propagation usually conclude that of the three components of motion associated with the source (transverse, longitudinal, and radial), the transverse component is generally considered the one most strongly affected by rupture propagation, followed in importance by the radial and longitudinal components, respectively. These intensifications of amplitude of motion in the direction of propagation may be loosely termed "rupture focusing" (Edwards VII-1; Frazier VII-1 through VII-3; Tr. 448).

In his testimony at the ASLB seismic hearing, Dr. James Brune stated that the simplest theoretical representations of the phenomenon of rupture focusing suggest that enhanced high frequency accelerations might be produced in a narrow "beam" (±5°) in the direction of rupture propagation under special conditions. A ±5° "beam" in the direction of rupture emanating from the epicenter includes stations 6 and 7 of the El Centro array. If the simple predictions based on Brune's testimony are taken literally, then we must conclude that any rupture propagating on the fault from the epicenter toward stations 6 and 7 would result in focusing being observed at those stations. However, the records from stations 6 and 7 provide no such evidence, according to the data presented in Edwards Figures VII-1 and VII-2 (Edwards VII-2; Frazier VII-4; Tr. 452).

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Both Drs. Brune and Frazier agree that the IV-79 records show no strong evidence of focusing (Tr. 626; Frazier VII-4). Dr. Brune thought this might be caused by the earthquake having been a series of multiple events rather than a continuous rupture (Tr. 627). However, focusing accompanies all earthquakes to a greater or lesser degree. The rough equivalence of the transverse and longitudinal PGA values within a few kilometers of the Imperial fault is not inconsistent with some focusing effect. However, such focusing, if it occurred, did not result in abnormally high PGA values. It seems most significant that any focusing which might exist does not appear to alter the broader tendency toward saturation of PGA values in the near-field. Applicant witness Robert Edwards testified that the rupture focusing phenomenon is not relevant to the Diablo Canyon site in light of the fact that the portion of the Hosgri fault trace which may be "lined-up" with the Diablo Canyon site (±5°) is so far from the site (nearest approach is about 27 km) that any amplification by high frequency focusing would be eliminated through material damping of the high frequency radiation (Edwards VII-3, VII-4; Frazier VII-12; Tr. 294, 295, 453).

PGandE witness Dr. Gerald Frazier presented extensive testimony on a computer model he developed and tested for simulating earthquake processes to provide additional information on ground accelerations and the

effects of focusing at Diablo Canyon. The earthquake model simulates effects due to site specific earth structure, complex rupture sequences, radiation pattern, focusing and stress drop. Stringent tests have been and are currently being performed to simulate near-field recordings from past earthquakes. These tests indicate that the earthquake model is suitable for predicting ground motion close to large magnitude earthquakes, albeit conservatively predicting higher than real peak ground accelerations directly in the maximum beam of focusing (Frazier VII-5, VII-8 thru VII-12; J.I. Exs. R-6 thru R-9; Tr. 302-313, 505, 506, 509, 518).

Frazier described site specific simulations which were performed at Diablo Canyon to examine effects of rupture along the Hosgri Fault focused toward the site in a manner consistent with geologic data. After conducting and analyzing the tests, Frazier concluded as follows:

(a) The effects of rupture focusing are much less apparent for frequencies of interest at the Diablo Plant. Furthermore, the Diablo Canyon site is not positioned for significant focusing from rupture along the Hosgri. Therefore, adverse effects due to rupture focusing are highly unlikely at the Diablo Canyon Site. Dr. Brune did not agree with this conclusion because he believes that the parameters used by Dr. Frazier are such that the

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effects of focusing are not as apparent as they were in the San Onofre study (Tr. 630).

(b) The largest accelerations produced by the earthquake model originated from hypothetical rupture along the northern extent of the Hosgri fault, which was beamed directly at the site, did not contribute significantly to the peak levels of acceleration. The conclusion is drawn that focused rupture along the Hosgri fault cannot produce unusually high levels of ground acceleration at the site.

(c) The computed levels of ground motion are relatively independent of the length of rupture. Consequently, peak acceleration at Diablo Canyon should be basically insensitive to increases in magnitude for magnitudes greater than about 6.5.

(d) The mean values of peak acceleration were well below design levels. Furthermore, calculated free-field response spectra are uniformly below that used in the reanalysis. Thus, the earthquake modeling studies indicate that the Hosgri reanalysis spectrum is substantially conservative even when comparing free-field predictions with actual reanalysis criteria.

(e) The earthquake model when properly applied predicts earthquake motion at least as well as

alternate methods (Frazier VII-5 through VII-13; Tr. 1374, 1375).

Dr. Brune, while agreeing that computer modeling is important to understand strong ground motion, was critical of the Frazier model study on the ground the parameters chosen by Dr. Frazier were not conservative enough or that he (Dr. Brune) did not understand them (Tr. 631-633, 637, 647-649, 652, 653, 821, 823)

J.I. counsel produced a fault map, later withdrawn, purporting to show a strand from the Hosgri Fault pointing straight toward the Diablo plant site. Applicant witness Frazier testified that the strand was taken into account in his modeling in the sense that the data base used takes into account how these features have acted in past earthquakes (Tr. 313). He stated that as the rupture proceeds down the main trend of the fault it "hopscotches" around a bit on these splays or strands but they would not independently be capable of generating more than a magnitude 3 earthquake (Tr. 314-317). J.I. witness Brune testified that the splay could lead to a maximum of focused energy toward the Diablo facility (Tr. 648). However, the official USGS map of the area (J.I. Ex. 11) does not show the splay shown on J.I. Ex. 10 (withdrawn) (Tr. 939). The USGS witness testified that he doubted the splay existed (Tr. 940). Applicant witness Hamilton testified that he did not believe that features such as the splay in question have

large amounts of movement on them and would not likely participate in any significant way in a major earthquake along the Hosgri (Tr. 322-324).

> Question VIII. We have received preliminary reports of the effect of IV-79 on the El Centro Steam Power Station. (Board Notification December 17, 1979, Levin and Martore Observations; Rothman - Kuo Affidavit, page 12). In many respects, the structures and systems of that facility resemble those of the Diablo Canyon plant. Their response to a severe, well instrumented seismic event can be analysed to help confirm or refute analytical techniques and assumptions used in the Diablo Canyon seismic analysis. The parties should prepare and submit such an analysis.

The El Centro Steam Plant is a 4-unit electric generating facility of the Imperial Irrigation District located approximately 5 km from the Imperial fault. Each unit of the facility contains three distinct structures: a steel frame and concrete turbine building, containing mechanical and electrical equipment as well as piping systems; a concrete pedestal supporting the turbine and located within, but structurally separated from, the turbine building; and a boiler structure which is a braced steel frame supporting a hanging boiler and structurally connected to the turbine building (Blume VIII-1).

Each unit of the plant is structurally independent, and since Unit 4 is the most recent unit (constructed in 1968) it was selected by PGandE witness Dr. John A. Blume for detailed study. A USGS strong motion accelerograph is located less than 1 km southeast of the plant (USGS No. 5164 El Centro Differential Array), and its

recorded trace was used to derive time histories and response spectra for the plant analyses.

Dr. Blume outlined the results of his study, which was based upon analytical methods similar to those used in the Diablo Canyon reanalysis. The study results showed that although the plant and its equipment were subjected to seismic accelerations considerably above those for which it had been designed actual damage was minor. These results demonstrate the inherent conservatism in seismic design analytical methods similar to those used in the Diablo reevaluation (Blume VIII-1 through VIII-10).

Dr. Newmark testified that the building was overloaded by a factor of three and suffered no damage (Tr. 711, 712).

Westinghouse also did a study of the El Centro plant's piping and supports, by means of a computer model generated by the same methods used in the generation of computer models for Diablo Canyon and other nuclear projects. Significant reductions in the input seismic excitation still conservatively predict the results in the piping system due to the additional conservatism in the piping analysis itself. This study also demonstrated that the analytical methods and assumptions used by Westinghouse in the evaluation of piping systems at Diablo Canyon contain significant conservatisms (Gangloff VIII-1 through VIII-9).

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Significant reductions in the input seismic excitation still conservatively predict the results in the piping system due to the additional conservatisms in the piping analysis itself. It can, therefore, be concluded that the evaluations performed on Diablo Canyon are conservative and provide substantial margin (perhaps a factor as high as five on stress and deflection)to the results that would be expected from an actual seismic event (Gangloff VIII-1 through VIII-9).

A study conducted for the NRC Staff by Lawrence Livermore National Laboratory was designed to analytically estimate the equipment response which, when compared to actual observation, will indicate the levels of actual equipment capacity. They confirmed, among other things, the low level of damage observed at the plant (Staff Ex. R-1). The study concluded that the inherent seismic resistance of engineered structures, piping and equipment is greater than has been assumed. When even the most modest attention is paid to design significant capability is rendered. Because they are subject to strict and rigorous design procedures, the report concluded that nuclear power plants contain even higher inherent margins than other structures (Staff Ex. R-1, pp. 39-41; Tr. 713, 721, 1340-1342).

Dr. Newmark summarized the significance of these comparisons during the hearing. He stated "The issue is primarily that we can learn about earthquakes from buildings

that survive as much as we can from instruments that measure earthquake motions and that this is not a negligible factor in our experience. And this is one of the points that leads me to believe that what we have done with the [Diablo Canyon] design or strengthening is such that we can be assured that even should a major overload occur because of an earthquake considerably larger than that which we have provided for, the structure would not be in a situation that would cause any hazard at all" (Tr. 713).

> Question IX. In addition to answering our questions about information from the Imperial Valley earthquake, we would like the parties to address Paragraph E on page 6 of the McMullen affidavit (included with the Staff Response to Joint Intervenors' Motion to Reopen). That paragraph states that, "in its geologic and seismologic review of the Point Conception LNG site, the USGS reported that 'Existing evidence favors association of the 4 Nov., 1927 (M 7.3) Lompoc earthquake with an east dipping reverse fault such as the Offshore Lompoc or similar reverse fault 10 km to the south that offsets the seafloor.'" Does this USGS statement reflect either evidence not presented in the Diablo Canyon hearing or a change in the USGS position based on evidence already in the record? In any event, discuss that statement's implications for this case.

The evidence adduced at the hearing clearly indicated a significant shift in the USGS position as to the likely source of the 1927 Lompoc earthquake. The position taken by the USGS in 1976 was that "The 1927 earthquake, therefore, cannot be unequivocally located on any one of these faults" (McMullen 4). The USGS recognized that any of the candidate faults could be the source, or put another way, the Hosgri was at least as likely to be the source as any other fault. In contrast to this relative anonymity of

the identity of the fault, the USGS now clearly favors the Lompoc fault (Tr. 932) and believes that the probability that it could have been the Hosgri has been lowered (Tr. 934, 951). In other words, the residuum of uncertainty that remains as to the fault identity can only sustain a bounding contingency that "does not exclude" (Tr. 933) the Hosgri. This shift in emphasis has been generated by increased knowledge of the Lompoc fault itself. The USGS has changed its mind in regard to the length of the Lompoc fault such that it is now compatible with the magnitude of the 1927 earthquake (Tr. 931) and has identified the existence of sea floor offset, an effect that would also be attributable to the 1927 earthquake (Tr. 952). In fact the USGS witness stated that with the possible exception of a 4.8 magnitude earthquake in May, 1980, he knew "of no others that we can associate [with the Hosgri fault] with any degree of certainty" (Tr. 937).

The significance of this to the seismic evaluation of the Diablo Canyon site is to reaffirm and reinforce the high degree of conservatism of the assumption of a 7.5 M earthquake capability for the Hosgri fault. Or, as characterized by Dr. Buck in a question to the USGS witness, the supposition would be "extremely conservative" (Tr. 953). The USGS's conservative assumption in 1976 of an earthquake of that size was undoubtedly colored by its view, at that time, that an <u>historic</u> earthquake of 7.3 M had likely

occurred on the Hosgri. With the probability of this so diminished, the conclusion is unavoidable that, in fact, the 7.5 M assumption is more representative of a hypothetical limit.

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Dated: November 21, 1980

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

In the Matter of PACIFIC GAS AND ELECTRIC COMPANY Units 1 and 2 Diablo Canyon Site	)	Docket No. 50-275 Docket No. 50-323 (Seismic Issues)

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