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City of Anaheim, California and
City of Riverside, California

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of SOUTHERN CALIFORNIA EDISON COMPANY, ET AL. (San Onofre Nuclear Generating Station, Units 2 and 3)	Docket Nos. 50-361 OL 50-362 OL APPLICANTS' PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW ON GEOLOGY/SEISMOLOGY ISSUES

SOUTHERN CALIFORNIA EDISON COMPANY, SAN DIEGO GAS & ELECTRIC COMPANY, CITY OF ANAHEIM, CALIFORNIA, and CITY OF RIVERSIDE CALIFORNIA ("Applicants") hereby submit "Applications Proposed Findings of Fact and Conclusions of Law on Geology/

D503
S 0/1

Seismology Issues" pursuant to oral stipulation of July 31, 1981 (Tr. 6009-6013) between the parties to the above proceeding and 10 C.F.R. §2.754.

Dated: September 3, 1981

Respectively Submitted,

DAVID R. PIGOTT
EDWARD B. ROGIN
SAMUEL B. CASEY
JOHN A. MENDEZ
Of ORRICK, HERRINGTON & SUTCLIFFE
A Professional Corporation

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By John A. Mendez
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Attorneys for Applicants

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PARAGRAPHS

(CONTENTION 4 CONTINUED)

PARAGRAPHS

(CONTENTION 3 CONTINUED)

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In the Matter of SOUTHERN CALIFORNIA EDISON COMPANY, ET AL. (San Onofre Nuclear Generating Station, Units 2 and 3)	Docket Nos. 50-361 50-362

APPLICANTS' PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW ON GEOLOGY/SEISMOLOGY ISSUES

INTRODUCTION

1. Southern California Edison Company, San Diego Gas and Electric Company, City of Anaheim and City of Riverside ("Applicants") are co-owners of San Onofre Nuclear Generating Station, Units 2 and 3 ("SONGS 2 & 3"). Applicants were initially granted Construction Permits for those two units on or about October 18, 1973. It is projected that Unit 2 will be ready for fuel loading by October 15, 1981.

2. On or about March 22, 1977, Applicants filed their Application for Operating Licenses for SONGS 2 & 3. On April 7, 1977, notice of filing that application was published in the Federal Register, 42 Fed. Reg. 18460.

Pursuant to said notice, various petitions to intervene were filed and subsequently allowed. Thus, this was a contested proceeding by reason of the intervention of Intervenors Friends of the Earth, et al.1/ ("FOE" et al.) and Groups United Against Radiation Danger (GUARD). [10 C.F.R. § 2.4 (n)]

3. By Memorandum and Order of January 27, 1978, the Board determined that certain contentions alleged by FOE, et al. and GUARD were suitable for discovery purposes. The Board allowed contentions on emergency planning, geology, seismology, the effects of certain site dewatering well cavities, and the escalation of uranium prices.

4. On or about June 9, 1980 Applicants filed a motion for summary disposition of Intervenors contentions on the site dewatering well cavity and the escalation of uranium fuel costs. The NRC Staff also filed a motion for summary disposition of the same two contentions. By Memorandum and Order of January 26, 1981, the Board granted the Applicants' and Staff's Motion on uranium fuel costs and granted, in part, and denied, in part, the Applicants' and Staff's motion for summary disposition on dewatering well cavities.

5. In February, 1981, the "Safety Evaluation Report ("SER") By the Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Related to the Operation

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1/ FOE et al. was also referred to as "Intervenors Carstens et al." at the licensing hearings. For purposes of these Findings of Fact and Conclusions of Law they will be identified as FOE et al.

of San Onofre Nuclear Generating Station Units 2 and 3" (NUREG 0712) was issued. (Staff Exhibit No. 1) Supplement No. 1 to the SER was issued in February 1981. (Staff Exhibit No. 2) and Supplement No. 2 to the SER was issued in May, 1981. (Staff Exhibit No. 3) The NRC Staff Final Environmental Statement, (NUREG 0490) was issued in April, 1981. (Staff Exhibit No. 4)

6. In January and February 1981, the Advisory Committee on Reactor Safeguards ("ACRS") conducted its review relative to Applicants' application for operating licenses for SONGS 2 and 3. The ACRS issued favorable letters on February 10, 1981 (Appendix C, SER Supplement No. 1 - Staff Exhibit No. 2A) and on March 17, 1981, (Appendix B, SER Supplement No. 2 - Staff Exhibit No. 3A).

7. On or about March, 1981 the Nuclear Regulatory Commission appointed Mr. James Kelley, Esq., Chairman and Mrs. Elizabeth Johnson to the Atomic Safety and Licensing Board in this proceeding. Chairman Kelley and Mrs. Johnson joined Dr. Cadet Hand to complete the Board that presided at the licensing hearing on the seismology/geology contentions.

8. Special prehearing conferences were held pursuant to 10 C.F.R. § 2.751a on December 6, 1977 and July 17, 1980. A final prehearing conference on the seismology and geology issues was held pursuant to 10 C.F.R. § 2.752 on April 29, 1981.

9. Public hearings on the seismology/geology contentions were held commencing on June 22, 1981, July 8, 1981, and July 27, 1981. On August 4, 1981, after some 25 days of public hearing sessions (excluding limited appearances sessions), public hearings on the geology and seismology issues were completed and on August 4, 1981, the record was closed on the geology and seismology issues and it was stipulated by all interested parties that Findings of Fact and Conclusions of Law be submitted on such issues (Tr. 6009-6013).

PARTIES

10. By Memorandum and Order of October 26, 1977, the following parties were admitted in this proceeding in accordance with the provisions of 10 C.F.R. §§ 2.714 and 2.715: The Public Utilities Commission of the State of California, GUARD, FOE, August and Rose Carstens, Lloyd and Selma Von Haden, Donald May, and Mrs. Donif Dazey.

11. Several hundred persons made limited appearances pursuant to the provisions of 10 C.R.R. § 2.715a at sessions held by the Board on June 27, 1981, July 1, 1981, July 11, 1981 and July 29, 1981.

12. The Applicants, the NRC Staff and FOE were represented by counsel, presented evidence, and cross-examined witnesses, at all hearing sessions on the

geology and seismology contentions. Intervenor GUARD did not participate in the geology/seismology portion of the licensing hearing but instead chose to limit its participation to the emergency planning portion of the proceedings.

EVIDENTIARY HEARING AND ISSUES

13. By Memorandum and Order of May 28, 1981 the following contentions were admitted for the seismology and geology portion of the licensing hearings:

> 1. Whether as a result of ground motion analysis techniques developed subsequent to issuance of the construction permit or data gathered from earthquakes which occurred subsequent to issuance of the construction permit, the seismic design basis for SONGS 2 & 3 is inadequate to protect the public health and safety.
>
> 2. Whether characterization of certain offshore geologic features as a zone of deformation, referred to as the Cristianitos Zone of Deformation (CZD), or whether any additional information about the CZD which became available subsequent to issuance of the construction permit render the seismic design basis for SONGS 2 & 3 inadequate to protect the public health and safety.
>
> 3. Whether the seismic design basis for SONGS 2 & 3 is inadequate to protect the public health and safety as a result of discovery subsequent to issuance of the construction permit of the following geologic features:
>
> (1) ABCD features at the site

(2) Features located at Trail 6, Target Canyon, Dead Dog Canyon, Horno Canyon and "Onshore Faults E and F"

(3) Such other features as the parties may agree are relevant to the seismology of the SONGS site or with respect to which Intervenor Friends of the Earth makes a threshold showing of relevance.

4. Whether based on the geologic and seismic characteristics of the OZD, including its length, assignment of M_s7 as the maximum magnitude earthquake for the OZD renders the seismic design basis for SONGS 2 and 3 inadequate to protect the public health and safety.

14. The order in which testimony was presented was prescribed by the Board in its Memorandum and Order of May 28, 1981. Applicants presented their entire case first followed by FOE, followed by the NRC Staff and concluding with Applicants' rebuttal. Applicants determined that in order to present its case in a manner that allowed the most logical progression through the questions presented they addressed the issues in reverse order, i.e., 4, 3, 2, and 1. The order of presentation was also varied somewhat at the hearings for the convenience of NRC Staff witnesses Dr. H. Gary Greene and Dr. Michael P. Kennedy, for the Intervenors subpoenaed witnesses and for the Board's witness Dr. J. Enrique Luco. The complete list of witnesses that appeared at the geology/seismology portion of the hearings that were held from June 22, 1981 through August 4, 1981 is as follows:

ASLB LICENSING HEARINGS
SONGS 2 & 3
JUNE 22 - AUGUST 4, 1981

WITNESSES

APPLICANTS' DIRECT

Contention #4:

Mr. Jay L. Smith
Dr. Perry L. Ehlig
Mr. Edward G. Heath
Dr. Stewart W. Smith
Mr. Lawrence H. Wight
Dr. Gerald A. Frazier
Dr. I.M. Idriss
Dr. Robert L. McNeill

Contention #3

Mr. Jay L. Smith
Dr. Perry L. Ehlig

Contention #2

Dr. David G. Moore
Dr. Roy J. Shlemon

Contention #1

Dr. Stewart W. Smith
Dr. Gerald A. Frazier
Dr. I.M. Idriss
Dr. Shawn Biehler
Dr. Robert L. McNeill

APPLICANTS' REBUTTAL

Dr. David G. Moore
Dr. Perry L. Ehlig
Dr. Stewart W. Smith
Dr. David M. Hadley
Dr. Gerald A. Frazier
Dr. Kenneth W. Campbell

INTERVENORS' DIRECT

Dr. Michael P. Kennedy
Dr. James Brune
Dr. John Anderson
Dr. Clarence Allen
Mr. Richard Simon
(testimony struck)
Dr. David Boore
Dr. Gordon Gastil
Mr. Mark Legg

NRC STAFF DIRECT

Contention #4 and #1:

Mr. James Devine
Dr. D. Burton Slemmons
Dr. Leon Reiter
Mr. A. Thomas Cardone

Contention #3:

Mr. A. Thomas Cardone

Contention #2

Dr. H. Gary Greene
Dr. Michael P. Kennedy
Mr. Robert H. Morris
Mr. James Devine
Mr. A. Thomas Cardone

ATOMIC SAFETY AND LICENSING BOARD

Dr. J. Enrique Luco

15. At the licensing hearings the following exhibits were identified, and where indicated, admitted into evidence:

APPLICANTS' EXHIBITS

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
1	A. Application of Southern California Edison Company, San Diego Gas and Electric Company, City of Anaheim, and City of Riverside, for a Class 103 license to acquire, possess, and use two utilization facilities and related licenses in connection with Units Nos. 2 and 3 of the San Onofre Nuclear Generating Station of Southern California Edison Company, San Diego Gas and Electric Company, City of Anaheim and City of Riverside.	692	947
	B. Response to NRC action plan - NUREG 0660		
	C. Final Safety Analysis Report Nuclear Generating Station, Units 2 and 3, Volumes 1-24.		
	D. Responses to NRC Questions, San Onofre Nuclear Generating Station, Units 2 and 3, Volumes 1-5.		
2	Environmental Report--Operating License Stage, San Onofre Nuclear Generating Station, Units 2 and 3, Volumes 1-3.	692	947
3, EGH-1	NRC Staff Question 361.28 and parts (a), (b), and (d) of Response.	693	1120

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
4,EGH-2	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Appendix A, Tectonic Setting of the Offshore Zone of Deformation.	694	1120
5,EGH-3	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Appendix B, Estimates of Displacement Along the Newport-Inglewood Zone of Deformation Based on E-Log Correlations.	694	1120
6,EGH-4	NRC Staff Question 361.61 and Response.	695	1120
7,EGH-5	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Appendix D, South Coast Offshore Zone of Deformation Geophysical Data.	695	1120
8,EGH-6	NRC Staff Question 361.44 and part K of Response.	695	1120
9,EGH-7	NRC Staff Question 361.45 and part (e) of Response.	696	1120

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
10,EGH-8	NRC Staff Question 361.47 and Response.	696	1120
11,LHW-1	Evaluation of Peak Horizontal Ground Acceleration Associated with the Offshore Zone of Deformation at San Onofre Nuclear Generating Station, August 1980 by Lawrence H. Wight.	696, 1576	1577
12,LHW-2	Reduction in Free Field Ground Motion due to the Presence of Structures, August 1980, witness Lawrence H. Wight.	697, 1576	1577
13,IMI-1	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Section 5, Maximum Site Ground Motion Parameters, Figures 8, 9, 10, and 11.	697	1700
14,IMI-2	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Appendix J, Development of Attenuation Relationships for SONGS.	698	1700
15-IMI-3	NRC Staff Question 361.52 and Response.	698	1700

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
16,IMI-4	Report of the Evaluation of Maximum Earthquake and Site Ground Motion Parameters Associated with Offshore Zone of Deformation, San Onofre Nuclear Generating Station, June 1979; Appendix I, Development of Peak-Acceleration Attenuation Relationships for Soil Site and Combined Soil and Rock Site Data Sets.	698	1700
17,IMI-5	NRC Staff Question 361.53 and Response.	699	1700
18,IMI-6	NRC Staff Questions 361.54 and Response.	699	1700
19,IMI-7	NRC Staff Question 361.55 and Response.	699	1700
20,IMI-8	NRC Staff Question 3461.57 and Response.	700	1700
21,GAF-1	Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1, Final Report, May 1978, by Dr. Gerald A. Frazier.	700	1775
22,GAF-2	Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1, Supplement I, July 1979, by Dr. Gerald A. Frazier.	701	1775
23,GAF-3	Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1, Supplement II, August 1980, by Dr. Gerald A. Frazier,	701	1775

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
24,GAF-4	Simulation of Earthquake Ground Motions for San Onofre Nuclear Generating Station, Unit 1, Supplement III, August 1980, by Dr. Gerald A. Frazier.	701	1775
25,JLS-1	Analysis of Geologic Features at the San Onofre Nuclear Generating Station, July 1974, by Jay L. Smith.	702	2652
26,JLS-2	Analysis of C and D type features at the San Onofre Nuclear Generating Station, November 1974, by Jay L. Smith.	702	2652
27,JLS-3	Final Report on Geologic Features at the San Onofre Nuclear Generating Station, Units 2 and 3, August 1976, by Jay L. Smith.	702	2652
28,RJS-1	Late Quaternary Evolution of the Camp Pendleton-San Onofre State Beach Coastal Area, Northwestern San Diego County, California, January 1978, by Roy J. Shlemon.	703	3117
29,RJS-2	Late Quaternary Rates of Deformation, Laguna Beach-San Onofre State Beach, Orange and San Diego Counties, California, October 1978, by Roy J. Shlemon.	703	3117
30,RJS-3	Late Cenozoic Stratigraphy, Capistrano Embayment Coastal Area, Orange County, California, July 1979, by Roy J. Shlemon.	703	3117

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
31,SB-1	Seismological Investigations of the San Juan Capistrano Area, Orange County, California, November 1975, by Dr. Shawn Biehler.	704	3652
32,IMI-9	NRC Staff Question and Response 361.64.	704	3631
33,EGH-9	CDMG Geologic Map of Southern California Faults (Long Beach Sheet)	1140	-
34,EGH-10	Addendum to Table 361.45-3	1614	4035
35,LHW-3	High Frequency Spectral Amplitudes, Imperial Valley 1979 Free Field Stations.	2617	2647
36,DGM-L	Geologic Interpretation, Marine Advisors, Inc.	2980	4070
37,DGM-M	Nekton 30	2980	2996
38,DGM-N	Marine Advisors Line No. S-26	3056	4078
39	Letter from K.P. Baskin to Director, Office of Nuclear Reactor Regulation (April 18, 1980).	3032	3225
40,JNB-1X	Seismic Risk at El Capitan Dam.	4323	4396
41,JNB-2X	Saturation of Peak Parameters	4495	-

APPLICANTS' EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
42,DGM-1	Four Figures--OZD Profiles Drawn to Scale.	4905	4907
43	Focal Mechanism May 27, 1980 Event (Convict Lake) Mammoth Lake Earthquakes.	4908	6386
44	"Agenda-Site Specific Earthquake Program" (Delta Report)	5084	6431
45, DGM-1R	Track Lines--CFault Expedition	6331, 6345	6333
46,DGM-2R	Bathymetry--Coronado Bank/Punta Banda Region	6331, 6345	6333
47,DGM-3R	Structural Interpretation of CFault Geophysical Data (July 1981)	6331, 6345	6333
48,DGM-4R	"Gulf of California: A Result of Ocean Floor Spreading and Transform Faulting" by Larson, Menard and Smith (1968)	6345	(Bound into Transcript ff. 6346)
49,DGM-5R	"Plate-Edge Deformation and Crustal Growth, Gulf of California Structural Province" by D. Moore (1973)	6347	(Bound into Transcript ff. 6347)
50,DGM-6R	"The Geotectonic Development of California" W.G. Ernst, ed., Chapter 10, "Origin and Tectonic History of the Basement Terrane of the San Gabriel Mountains, Central Transverse Ranges" by P. L. Ehlig (pp. 277-282)	6348	(Bound into Transcript ff. 6348)

INTERVENORS FOE, ET AL.'S EXHIBITS

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
1	USGS Open-File Report 81-115 "Scenarious of Possible Earthquakes Affecting Major California Population Centers, with Estimates of Intensity and Ground Shaking" (1981)	1687, 1690	-
2	"A Geological and Seismological Investigation of the Lawrence Livermore Laboratory Site", L.H. Wight (June 3, 1974) [four pages from report]	1687	-
3	Map Sheet 42, "Recency and Character of Faulting Offshore from Metropolitan San Diego, California, Pt. La Jolla to Baja California", by Kennedy, Clark, Greene & Legg (1980)	2264	2319
3a	Explanatory Booklet accompanying Map Sheet 42	2319	2319
4	Letter dated August 11, 1980 from Kennedy and Davis (CDMG) to Bob Jackson (NRC)	2461	2462
5	<u>Earthquakes and Other Perils, San Diego Region</u>: Figure 1 (p. 22) of article "Implications of Fault Patterns of the Inner California Continental Borderland between San Pedro and San Diego", by Greene, Bailey, Clark, Heining, and Kennedy., [Figure 1--"Preliminary Map of Major Structural Features, Gulf of Santa Catalina, San Diego Trough"]	2523	-
6	"Earthquake Mechanics and Near-Field Ground Motions" by Frazier, Jurkevics, Apsel (25-27 August, 1980) [Published in USGS Open File Report 81-437]	3621	3621

INTERVENORS FOE, ET AL.'S
EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
1,6, or 7	"Geotechnical Evaluation of Potential Island and Off-shore California LNG Import Terminal Sites", Woodward Clyde Consultants (1978)	1320 *(Heath identifies entire report) 3056-3069 (pages 12-1-12-4- Figure 2 identified by D. Moore) 4079-4082 (further discussion regarding exhibit)	-
8	Resume of John Anderson	4616	4644
9	Map of Lake Crowley Area showing epicenter, May 27, 1980, 1450 GMT (Mammoth Lakes Earthquake)	4624	4644
10	Chart showing Acceleration and Time for Convict Lake, May 27, 1980, 1450 GMT, Mammoth Lakes, California	4629	4644
11	Copy of Handwritten Notations Prepared by J. Anderson Demonstrating Relationship between Maximum Magnitude, Slip Rate, and Interval between Occurrences of Maximum Earthquakes	4634	4644
12	Figure 361.45-2, "Data Range Analysis Geologic Slip Rate vs Historical Magnitude for Strike-Slip Faults" with additional lines drawn by J. Anderson	4638	4646
13	"Earthquake Research for the Safer Siting of Critical Facilities", National Academy of Sciences (1980)	4696	Denied (4700)

INTERVENORS FOE, ET AL.'S EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
14	"Relationship Between Seismicity and Geologic Structure in the Southern California Region", by Allen, Amand, Richter, and Nordquist (August, 1965)	4701	4712
15	"Earthquakes, Faulting, and Nuclear Reactors" by C. Allen (Nov., 1967)	4713	4903
16	"Geological-Seismological Factors Pertaining to the Proposed Construction of a Nuclear Power Desalting Plant at Bolsa Island, California" A Report to Stewart L. Udall, Secretary of the Interior, (Oct., 1967)	4718	4741 (p. 18-p. 19, 1st full para-) graph)
17	"Peak Acceleration From Strong-Motion Records: A Postscript", by Boore and Porcella (December, 1980) [Bulletin of Seismological Society of America, Vol. 70, No. 6, pp. 2295-2297]	4744	4747
18	"The Influence of Rupture Incoherence on Seismic Directivity", by Boore and Joyner (April, 1978) [Bulletin of Seismological Society of America, Vol, 68, No. 2, pp. 283-300]	4747	4773
19	Review of Report, "Simulation of the Earthquake Ground Motions for San Onofre...Unit 1" A Report Prepared for the NRC by J. Enrique Luco, 12 July, 1978	5009	5028

INTERVENORS FOE, ET AL.'S EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
20	Review of Report, "Simulation of Earthquake Ground Motions for San Onofre--Unit 1, Supplement 1", by J. Enrique Luco, 8 October 1979	5009	5028
21	Review of Report, "Simulation of Earthquake Ground Motions for San Onofre...Unit 1, Supplement III, August 1980" by J. Enrique Luco, 28 September September 1980	5009	5028
22	Map showing global tectonic and volcanic activity in the last one million years, Goddard Space Flight Center, October 1979	5129	-
23	Figure 11: Part of Baja, California, showing Quaternary structures visible on space photographs---from <u>Recognition on Space Photographs of Structural Elements of Baja California by Warren Hamilton</u>, p. 14 (1971)	5138	-
24	Kennedy and Welday, 1980, Map showing Spanish Bight, Coronado, and Silver Strand Faults	5229	-
25	Kennedy and Welday, 1980, Figure 2--"Generalized fault map of offshore area studied and immediately adjacent onshore area" [Southern Rose Canyon Area]	5229	-

INTERVENORS FOE, ET AL.'S
EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
26	"Summary of Meeting on San Onofre Seismology and Geology", Docket No. 50-361/362, October 16, 1980, signed by Harry Rood	5386	-
27	Miscellaneous Paper S-73-1, "State of the Art for Assessing Earthquake Hazards in the United States" by D.B. Slemmons-- cover page, p. 94 (Table 11), p. 95 (Table 12), p. 96 (Table 13), p. 97 (Table 14), p. 98 (Table 15)	6229	-
28	Revised USGS 81-365 (to be published in Bulletin of the Seismological Society of America) "Peak Horizontal Acceleration and Velocity from Strong Motion Records Including Records from the 1979 Imperial Valley, California, Earthquake" by Boore and Joyner	6550	6550

NRC STAFF'S EXHIBITS

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
1	Safety Evaluation Report, NUREG 0712, (Feb., 1981)	952	952
2	Safety Evaluation Report, Supplement No. 1, NUREG-0712 (Feb., 1981)	952	952
2a	Letter From Advisory Committee on Reactor Safeguards Dated February 10, 1981 [Appendix C, Safety Evaluation Report, Supp. No. 1]	952	952
3	Safety Evaluation Report, Supplement No. 2, NUREG-0712 (May, 1981)	952	952
3a	Letter From Advisory Committee on Reactor Safeguards Dated March 17, 1981 [Appendix B, Safety Evaluation Report, Supp. No. 2]	952	952
4	Final Environmental Statement, NUREG-0490, (April, 1981)	952	952
4a	Staff errata to Final Environmental Statement (one page)	978	978
1, DBS	Corrected version of Appendix E to Safety Evaluation Report [Slemmons Report]	5465	5465
5	Worldwide Data; All Fault Types: Data Quality 1-3	5500	Withdrawn (6099)
5A	Data Base for Worldwide Data (Staff Exhibit No. 5)	5633	Withdrawn (6099)
6	Chart: Earthquake Magnitude (M): M =A + Log L, for Quality 1, North American Data	5507	Withdrawn (6099)

NRC STAFF'S EXHIBITS (Continued)

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
6A	Computer Readout For Data Base Utilized for Regression Analysis (Staff Exhibit 6)	5511	Withdrawn (6099)
6B	Regression of M =A + B Log L(m) for Quality 1, Strike-Slip, North American Faults (more complete version of Staff Exhibit 6A)	5633	Withdrawn (609J)
7	Graph Based on Table on p 14 Appendix E of SER: "Relationship Between Total Length of Fault Zones and the Maximum M Earthquake Magnitude for Strike-Slip Faults With Historic Earthquake of Above M =6	5514	Withdrawn (6099)
8	(Graph): "Total Length of Fault (KM) vs. Percentage of Length Ruptured During Highest Magnitude Historic Earthquake"	5519	Withdrawn (6099)
9	"Safety Evaluation of the Geologic Features at the Site of the San Onofre Nuclear Generating Station", July 8, 1975	6618	6620

ATOMIC SAFETY AND LICENSING BOARD
EXHIBIT

NO.	EXHIBIT	IDENTIFIED	ADMITTED INTO EVIDENCE
1	Letter dated August 18, 1980 from Robert E. Jackson (NRC) to James F. Davis (CDMG)	2508	-

16. All of Applicants' and NRC Staff's pre-filed written testimony (with figures attached) was admitted into evidence at the licensing hearing. The following testimony and portions of testimony submitted by FOE were <u>not admitted into evidence</u>:

Written Testimony of Richard S. Simons	--	Entire Testimony (Tr.5187-5196)
Written Testimony of Mark R. Legg	--	Page 5., paragraph 2 beginning with "Biehler states that" to Page 6, line 3 (Tr. 5313)
Written Testimony of James Brune	--	a) Abstract by Christopher H. Scholz entitled "Scaling Laws for Large Earthquakes Consequences For Physical Models" [27 pp. text and 10 figures]
		b) Page 44-sentence reading "Both Greene and Kennedy (personal communication 1981) have indicated that this is a reasonable interpretation of the existing data" (Tr. 4487)
		c) Page 74-discussion entitled "Mammoth earthquake accelerations (John Anderson personal communication, 1981)" and two accompanying figures (Tr. 4489)
		d) Page 75 discussion entitled "Ground Motion From Possible Slip on the Cristianitos Fault" (Tr. 4490)

17. Applicants pre-filed written testimony (and accompanying figures) was placed into the record following the transcript of June 22, 1981 (following Tr. 941). The testimony is bound by Contention (thus there are four (4) separate volumes) with the exception that the written testimony of J. Smith on Contention 4 may be found in the transcript of June 22, 1981 at pp. 887-941.

18. Any conclusion of law which is more properly a finding of fact is hereby incorporated in these findings of fact.

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FINDINGS OF FACT

CONTENTION 4

Whether based on the geologic and seismic characteristics of the OZD, including its length, assignment of M_s 7 as the maximum magnitude earthquake for the OZD renders the seismic design basis for SONGS 2 and 3 inadequate to protect the public health and safety.

I. INTRODUCTION

19. Mr. J. L. Smith, Dr. P. L. Ehlig, Mr. E. G. Heath, and Dr. S. W. Smith were the primary witnesses for the Applicants, Dr. James Brune and Mr. Mark Legg were the primary witnesses for FOE, and Mr. A. T. Cardone, Dr. L. Reiter, Mr. J. F. Devine, Mr. R. F. Morris and Dr. D. B. Slemmons were the primary witnesses for the Staff, regarding the geology and seismology of the SONGS region as the bases for assigning M 7 as the maximum magnitude earthquake for the OZD. (J. Smith, written testimony, p. 7; Ehlig, written testimony, p. 3; Heath, written testimony, p. 5; S. Smith written testimony, pp. 4-5; Brune, written testimony, ff. Tr. 4122, Legg, written testimony, ff Tr. 5213 Staff Exhibit 1, SER, Sections 2.5.1.2, 2.5.1.11, 2.5.2.1 2.5.2.3.1, 2.5.2.3.2, 2.5.2.3.4, 2.5.2.4; Cardone, supplemental testimony, ff. Tr. 5560; Reiter, supplemental testimony, ff. 5566; Slemmons, Tr. 5458; SER, Appendix E and Appendix G.

20. Mr. L. H. Wight, Dr. I. M. Idriss, Dr. G. A. Frazier and Dr. R. L. McNeill were the primary witnesses for

the Applicants, Dr. James Brune was the primary witness for FOE, and Dr. L. Reiter was the primary witness for the Staff, regarding earthquake ground motion and the conservatism of the Design Basis Earthquake (DBE) for SONGS Units 2 & 3. (Wight, written testimony, pp. 4-5; Idriss written testimony, p. 7; Frazier, written testimony, p. 3; McNeill, written testimony, pp. 5-6; Brune, written testimony, ff. 4122; Reiter, supplemental testimony, ff. Tr. 5566; SER, Section 2.5.2).

II. DESCRIPTION AND EXTENT OF GEOLOGIC INVESTIGATIONS

A. General Findings

21. The geologic investigations for SONGS have been extensive and numerous since 1969, and have included field and literature studies of both onshore and offshore areas before and after the construction permit. Adequate knowledge exists now for licensing purposes on the geology within a 200-mile radius of SONGS. The most significant geologic elements within a 100-mile radius of the site have been investigated in detail appropriate to their importance and proximity to the site. (J. Smith, written testimony, pp. 10, 17, 21, 22-37; Tr. 805).

22. The results of Applicants' extensive investigations were reviewed by the NRC staff and the Advisory Committee on Reactor Safeguards, and conclusions were reached on the geologic and seismic matters. Based upon the Staff's review of the Applicants' submittals, they find

no reason to change the conclusion reached in the SER for the Construction Permit approving a Safe Shutdown Earthquake (SSE) of .67g for San Onofre Units 2 & 3. (Staff Exhibit #2a, pp. C-2, C-3; SER, Section 2.5.1.1).

23. In his introductory remarks to his direct testimony, Staff witness Dr. D. B. Slemmons stated his belief that "the quality, the variety and the scope of the various data supplied by [Applicants] is adequate to arrive at decisions on the seismotectonic mapping and the maximum earthquake to be expected from the OZD." (Slemmons, Tr. 5460).

B. Onshore Investigations

24. Geologic investigations for SONGS 2 & 3 fall into three main categories: (1) regional or areal studies to obtain general knowledge on basic geology; (2) studies of specific features in detail; and (3) monitoring at the site during construction. (J. Smith, written testimony, p. 33).

25. The regional and areal studies included mapping and logging of trenches to evaluate the capability of faults in the vicinity of SONGS, particularly the Cristianitos fault; mapping of structure and stratigraphy to evaluate regional relationships, particularly the evolution of the Capistrano Embayment and the Cristianitos fault; and geomorphic analyses and study of the Quaternary stratigraphy, particularly the Pleistocene terraces. (J. Smith, written testimony, pp. 33-35).

26. Studies of specific features included mapping to search for projections of the Rose Canyon Fault Zone to the north and south; mapping and exploration of the Cristianitos fault and the onshore Faults E and F; and mapping and exploration of landslides and offsets in terrace deposits. (J. Smith, written testimony, pp. 35-36).

27. Monitoring activities during construction involved mapping of exposures provided by excavation at the site and analysis of geologic features found therein, particularly the ABCD features. (J. Smith, written testimony, pp. 36-37).

C. Offshore Investigations

28. Offshore investigations for the Applicants were extensive and were conducted by several companies beginning in 1970. In addition, data from nine seismic reflection surveys performed in the offshore SONGS vicinity during the last 10 years were obtained to identify geologic structure offshore San Onofre and between Newport Beach and La Jolla. (J. Smith, written testimony, pp. 17, 21, 22; Figures JLS-I and JLS-J; SER, Appendix F, p. F-3).

29. Data on offshore geology were collected chiefly by seismic reflection profiling and by drilling and dart core sampling. (J. Smith, written testimony, Figure JLS-J, and Figure JLS-K.).

30. The data most relevant for evaluating geologic structure offshore SONGS are those along and landward of the South Coast Offshore Fault, which is approximately 8 km offshore of the site. Particularly relevant to evaluating the seaward extension of the Cristianitos fault are the data in the first 10 km southeast of the site. (J. Smith, written testimony, p. 21).

31. In the immediate vicinity of SONGS, more than 1,000 km of profiling, with an average spacing between lines of less than 500 meters and an average density of more than two line-kilometers per square km of area, provided data on offshore geology. An additional 1500 km of profiling was done beyond the site vicinity and extended north to San Pedro and south to San Diego. (J. Smith, written testimony, p. 22; Moore, written testimony p. 7; Figure DGM-C).

32. During 1970, seismic reflection profiling was performed by Marine Advisers Inc. for the Applicants. Data was derived from Sparker, High Resolution Boomer, and 7 kHz High Resolution systems, Side Scan Sonar, and jet probing by diving geologists. (J Smith, written testimony, pp. 22-23; Moore, Exhibit #36,DGM-L).

33. The Applicants convened a group of experts during 1970 in the fields of geology and seismology to make an independent review of offshore geologic structure, regional tectonics and site response to earthquakes. Called the Board of Technical Review (BTR), the group reviewed

existing data and recommended additional studies including seismic reflection profiling and dart-coring by General Oceanographics, Inc. (J. Smith, written testimony, p. 24).

34. During September, 1971 to March, 1972, Western Geophysical Company (Western) investigated a region much larger than the immediate vicinity of the SONGS site, and provided additional definition of offshore geology to depths of 10,000 feet or more. Western's survey included seismic reflection profiling, seismic refraction and magnetic surveys. (J. Smith, written testimony, p. 26).

35. Western surveyed the region between Long Beach and San Diego and extending about 30 miles offshore from the coastline. In this region 350 miles of new seismic reflection data were collected for the Applicants and were also combined with 650 miles of proprietary data acquired for other purposes by Western during 1969-70. Ninety-six miles of these profiles lie within 15 km of SONGS. Seven refraction profiles and 450 miles of seaborne magnetometer data were also acquired by Western for the Applicants. (J. Smith, written testimony, pp. 26-27; Tr. 834-835; Moore, Tr. 3003).

36. Major products of the Western survey were maps of the sea floor (Horizon A), a subseafloor horizon in Upper Miocene rocks at depths varying between 1,000 and 3,000 feet (Horizon B), and of the acoustic basement (Horizon C) representing the base of coherent reflection horizons

penetrated to depths on the order of 10,000 feet or more beneath the sea floor. (J. Smith, written testimony, p. 27).

37. Woodward-Clyde Consultants, using boomer data collected by Oceanographic Services in 1974, investigated the thickness of Holocene sediments overlying the Miocene bedrock immediately offshore of San Onofre. Data from this survey do not define any faulting but confirmed a gentle seaward dip of bedrock strata. (J. Smith, written testimony, p. 28).

38. Fugro, Inc. collected seismic reflection data offshore of SONGS in 1978 to test and calibrate its high resolution sonar equipment. The data from this survey were acquired by the Applicants and reviewed. The profiles provided reliable data directly offshore SONGS, but they were too far west to cross the seaward extension of the Cristianitos fault. (J. Smith, written testimony, p. 29; Tr. 862, 883).

39. Woodward-Clyde Consultants performed a seismic reflection survey in 1978 of about 10 square kilometers offshore and southeast of SONGS. The data were collected at close line-spacing and allowed better definition of faulting than earlier investigations. The Woodward-Clyde transects are very important in determining the offshore geologic structure. (J. Smith, written testimony, p. 29; Tr. 863; Moore, written testimony, pp. 8-9).

40. The Applicants obtained data and a series of maps of the offshore region prepared during 1979 by the

California State University at Northridge and San Diego. (J. Smith, written testimony, p. 31).

41. In 1980, Nekton Inc. performed a seismic reflection survey involving over 109 km of profiling using a watergun, a 3.5kHz high-resolution system, and side-scan sonar. The 1980 Nekton survey lines were designed to cover the area of the offshore projection of the Cristianitos fault which had been postulated to intersect the South Coast Offshore Fault. (J. Smith, written testimony, Figure JLS-J; Moore, written testimony, p. 9).

42. The Applicants' offshore investigation included bottom sampling at 22 locations along seismic reflection lines 5-6 miles south of SONGS. The sampling was performed by General Oceanographics in 1970. (J. Smith, written testimony, p. 31; Figure JLS-K; Tr. 858).

43. Sea floor and subsurface samples were also taken at 10 locations in the vicinity of the cooling water conduits offshore of SONGS by Woodward-McNeill & Associates in 1974. (J. Smith, written testimony, pp. 31-32; Tr. 858).

44. In 1978, Woodward-Clyde Associates drilled eight shallow borings along the conduit alignment, and one deep boring approximately 10,000 feet offshore along projection of the conduit alignment to obtain bedrock samples at depth for microfossil analysis. (J. Smith, written testimony, [illegible], Figure JLS-K).

45. At the request of the NRC staff in 1980, a comprehensive review of all relevant marine geophysical data offshore SONGS was made by Dr. H. G. Greene of the USGS and Dr. M. P. Kennedy of the California Division of Mines and Geology. (SER, Section 2.5.1.12(3) to (5); SER, Appendices F and G; Morris, Tr. 6036; Greene, Tr. 2132-2134).

46. Dr. Greene and Dr. Kennedy stated that the seismic profile lines offshore of SONGS were extremely tight and were of the greatest density they had ever dealt with for an area of this size. (Greene, Tr. 2282; Kennedy, Tr. 2282-2283).

III. <u>SITE DESCRIPTION</u>

47. The SONGS site is within the Camp Pendleton Marine Corps base on the coast of southern California, in northern San Diego County, approximately 62 miles southwest of Los Angeles and approximately 51 miles northwest of San Diego. (J. Smith, written testimony, p. 8; Figure JLS-A).

48. The site lies on a rather narrow, gently sloping coastal plain that extends seaward from the mountain upland on the east and is terminated by a line of sea cliffs having a narrow beach at their base. The sea cliffs rise to heights of 60-100 feet above sea level, and are incised by eroding gullies and large ephemeral streams that drain the mountains northeast and southeast of the site. The major drainage channels are San Mateo Creek approximately 2-3/4 miles northwest of the site, San Onofre Creek approximately

1 mile northwest of the site, and Las Flores Creek approximately 7-1/2 miles southeast of the site. (J. Smith, written testimony, p. 8; Figures JLS-B, JLS-C).

49. A rectangular area has been excavated approximately 60-80 feet below the original surface of the coastal plain to accommodate the site facilities. The excavated area is bounded by cut slopes that provide excellent exposures of soil and rock units at the site. (J. Smith, written testimony, p. 9; Figure JLS-D).

50. The beach at SONGS is covered by thin sand layer -- up to ten feet thick -- and is horizontal for about 50 to 100 feet from the sea cliff before sloping an additional 100 to 150 feet into the tidal zone at a slope of about 5%. (J. Smith, written testimony, p. 9).

51. The sea floor off San Onofre slopes less than about 1% for the first 13,000 feet, and then 1.25% out to the edge of the continental shelf at a distance of 4.6 miles, where the water depth is about 300 feet. Beyond this the continental slope is also gentle, sloping between 9-10% to a depth of 2400 feet at 8.8 miles from shore. (J. Smith, written testimony, p. 9).

IV. REGIONAL GEOLOGY

A. Geomorphic Provinces

52. The geomorphic provinces of southern California display distinctive geomorphic and tectonic characteristics, and thereby provide a useful framework for

discussion of regional geology. SONGS lies near the western edge of the Peninsular Ranges Province, which includes the Los Angeles Basin at its north and a series of mountain ranges and valleys trending northwest and extending southward into Mexico. The rocks of this province are chiefly granitic and intrusive rocks that are 80-120 million yers old; older rocks of sedimentary and volcanic origin metamorphosed by the intrusive rocks; and marine and nonmarine strata of Late Cretaceous, Tertiary and Quaternary age. The rocks of this province most important to SONGS are the Miocene and younger sedimentary units including the San Onofre Breccia, the Monterey, Capistrano and San Mateo Formations, and Pleistocene terrace and alluvial deposits. (J. Smith, written testimony, pp. 10-11; Figures JLS-E, JLS-F).

53. West of the Peninsular Ranges Province lies the Continental Borderland Province of southern California. It includes the offshore basins and ridges between the continental shelf and the continental slope approximately 200 miles offshore, the western edge of the Los Angeles Basin and the Palos Verdes Peninsula, and the islands of Santa Catalina and San Clemente. The basement rocks of this province are largely metamorphic, and are referred to as Catalina schist or Franciscan-type basement. The contact between this basement lithology and the granitic or continental basement of the Peninsular Ranges is generally believed to coincide at depth with the Newport-Inglewood zone of folds and faults in

the Los Angeles basin. Sedimentary rocks overlying the basement are thick and widespread, and range in age from late Miocene to Late Pleistocene age. Stratification of these formations and their contacts with other formations are readily discernible in offshore seismic reflection profiles because the formations have contrasting geophysical properties which permit recognition of structural features, important time lines, and zones of deformation. (J. Smith, written testimony, pp. 11-12; Figure JLS-E).

54. North of the Continental Borderlands and Peninsular Ranges Provinces, the east-west trend of the Transverse Ranges Province lies across the northwest grain of California geology. The rocks of the Transverse Ranges include granitic and metamorphic rocks of pre-Tertiary age and deformed Tertiary sedimentary rocks. The transverse orientation of the province is attributed to crustal shortening, folding and uplift of major blocks within the western part of the province that took place largely prior to about 13 million years ago. Subsequently, thrust faulting has been active along the southern margin, and translation along the San Andreas fault zone has caused a right-lateral offset of the eastern end of the province. (J. Smith, written testimony, pp. 12-13; Figure JLS-E).

55. The Salton Trough Province lies east of the Peninsular Ranges, and, at its closest approach, is about 70 miles from San Onofre. It constitutes a series of

increasingly broad valleys draining southward toward the Gulf of California. Basement rocks in this province are granitic and metamorphic rocks of pre-Cenozoic age, and they are overlain by thick sedimentary and volcanic rocks of late Tertiary age. Tectonic activity is intense in this province because of translation along the crustal plate-boundary and lateral extension across active spreading centers in the southern part of the province. (J. Smith, written testimony, p. 13; Figure JLS-E).

B. Tectonic Framework

56. The tectonic framework of the site region consists of faults and other expressions of deformation. The site region is dominated by the San Andreas fault zone, a crustal dislocation extending over 600 miles from north of San Francisco, south through California and into the Gulf of Mexico, having a cumulative strike-slip displacement of more than 300 miles. Northwest of the Transverse Ranges the fault zone has a relatively simple pattern of long and narrow breaks, whereas to the southeast it bends broadly and splits into the San Andreas and the San Jacinto zones. The entire series of faults constituting the San Andreas-San Jacinto fault zone is about 30 miles wide at the latitude of San Onofre and marks the rupture boundary along which two major crustal plates have been moving for millions of years. The nearest approach of this zone to San Onofre is about 45

miles. (J. Smith, written testimony, p. 14; Figure JLS-G; Tr. 808, 813)

57. Northwest-trending structural zones in southern California came into being about 30 million years ago. Although the San Jacinto fault developed much later, both it and the San Andreas have been continuously active and characterized by high slip rates during Pleistocene time and by modern seismicity. Surface expression of recent faulting is more prominent and continuous for the San Andreas-San Jacinto zone than for any other fault in southern California. (J. Smith, written testimony, pp. 14-15; Figure JLS-G; Tr. 815-816).

58. The Whittier-Elsinore fault is roughly parallel with the San Andreas-San Jacinto zone and lies about 23 miles east of SONGS. It extends from the southern boundary of the Tansverse Ranges to the Mexican border, a distance of approximately 145 miles. Its principal movements have been a combination of lateral and dip-slip motion. Cumulative horizontal displacement is small, approximately 8-13 km. During the last five million years, major lateral motion on the zone has been buttressed on the north by the Transverse Ranges. (J. Smith, written testimony, p. 15; Figure JLS-G; Tr. 820)

59. The Santa Monica-Malibu Coast fault is a north-dipping reverse fault forming the northern boundary between the Transverse Ranges and the geomorphic provinces to

the south. Although early movement on the fault may have been left-lateral slip, much of the movement during the last five million years has been reverse dip-slip (thrust), reflecting north-south compression associated with the San Andreas stress-strain system. (J. Smith, written testimony, p. 15; Figure JLS-G).

60. The Newport-Inglewood zone of folds and faults crosses the Los Angeles basin from the northwest, where it is terminated at the surface by the Santa Monica-Malibu fault zone, southward to Newport Beach where it projects offshore to the southeast. (J. Smith, written testimony, p. 16; Figure JLS-G).

61. Discontinuous en echelon folds and faults are believed to reflect right-lateral strike-slip on a major basement rock discontinuity at great depth which juxtaposes continental terrane on the east and Franciscan terrane on the west. Deformation above this zone in the sedimentary section was initiated during Late Miocene time and has continued through Pleistocene time, with earthquakes occurring during historic time. (J. Smith, written testimony, p. 16; Tr. 810-811, 813-814).

62. Some geologists have believed that the Newport-Inglewood zone continues offshore for a great distance, and is coincident with the edge of the continental shelf south of Newport Beach to a latitude near La Jolla, where it is presumed to go onshore and coincide with the Rose

Canyon fault. Even so, south of Newport Beach the zone is recognized as being less continuous than it is toward Santa Monica. (J. Smith, written testimony, p. 16; Allen, Tr. 4880). Other geologists have held that the Newport-Inglewood zone splays and dies out toward the south against the San Joaquin Hills Structural High. (J. Smith, written testimony, p. 16).

63. There was a general lack of knowledge on the offshore structure along the seaward projection of the Newport-Inglewood zone and the shelf prior to the Applicants' studies in 1970. (J. Smith, written testimony, p. 17).

64. Applicants' findings from these offshore investigations along the southeastward projection of the Newport-Inglewood zone were that northwest-trending folds and faults discontinuously exist along the shelf edge, but that their characteristics change along trend, differing in some respects from those of the Newport-Inglewood zone to the north and Rose Canyon fault to the south. (J. Smith, written testimony, p. 17).

65. Applicants believe the offshore structures along the Newport-Inglewood trend do not overlie the granitic/Catalina schist basement discontinuity, which instead is interpreted to be offset seaward across the San Joaquin Hills Structural High, passing 10-13 miles southwest of the shelf edge opposite San Onofre. (J. Smith, written testimony, p. 17; Tr. 878).

66. A corehole drilled off Point Loma by Shell Oil Company indicated that the presumed basement discontinuity along the southern reach of the presumed extension of the Newport-Inglewood zone lay farther offshore than the shelf edge. Also, the Rose Canyon fault does not mark the boundary between two different basement rock types. (J. Smith, written testimony, p. 17; Ehlig, Tr. 1017).

67. Prior to the construction permit stage, Applicants' conclusion was that deformation offshore of SONGS was independent from that of the Newport-Inglewood zone, and that faults of limited length should be evaluated for their seismic potential. (J. Smith, written testimony, p. 18).

68. At the construction permit stage the USGS and the NRC staff contended that the Newport-Inglewood zone and offshore folds and faults along the shelf edge, together with the Rose Canyon fault zone, constituted a linear zone of deformation extending from the Santa Monica Mountains to at least Baja California. (J. Smith, written testimony, p. 18).

69. They considered that the Santa Monica to Baja California zone of deformation would be capable of generating an earthquake that would be commensurate with the length of the zone. (J. Smith, written testimony, p. 18).

70. Prior to the construction permit hearing in 1973, the Applicants stipulated that the USGS/NRC staff model of the zone of deformation would be used for the seismic design of SONGS 2 & 3. (J. Smith, written testimony, p. 18).

71. Subsequent to the ASLB construction permit hearings, the controlling earthquake source for SONGS 2 & 3 became known as the Offshore Zone of Deformation (OZD), representing the entire length from the Santa Monica mountains to San Diego. (J. Smith, written testimony, p. 18).

C. Offshore Zone of Deformation (OZD)

72. The OZD comprises three sections including the Newport-Inglewood Zone of Deformation (NIZD), the South Coast Offshore Zone of Deformation (SCOZD), and the Rose Canyon Fault Zone (RCFZ). (J. Smith, written testimony, p. 19)

73. The NIZD is the northern element of the OZD extending 45 miles southeastward from the Santa Monica-Malibu fault zone. The NIZD changes from well-developed folds and faults crossing the Los Angeles Basin to a series of fault splays essentially unaccompanied by folds in the Newport Beach area adjacent to the San Joaquin Hills. (J. Smith, written testimony, p. 19; Heath, written testimony, pp. 11-13)

74. The San Joaquin Hills trend north-south and extend offshore in the vicinity between Newport Beach on the northwest and Dana Point on the southeast. These hills mark the locus of uplift and complex faulting occurring from Late Miocene time through Quaternary time. Their offshore structural counterpart, termed the San Joaquin Hills Structural High, has served to interrupt the southeast continuation of the NIZD and to offset the

granitic/Franciscan discontinuity southward by several miles. (J. Smith, written testimony, p. 19; Tr. 878)

75. The San Joaquin Hills and the corresponding offshore structural high have provided lateral boundaries to the Los Angeles Basin on the west and the Capistrano Embayment on the east. (J. Smith, written testimony, p. 19)

76. On the basis of structural, gravity, and stratigraphic evidence, the NIZD terminates at its south end against the San Joaquin Hills Structural High. (J. Smith, written testimony, p. 20)

77. The central part of the OZD is a section called the SCOZD, extending approximately 42 miles from the east flank of the San Joaquin Hills Structural High to slightly southwest of Oceanside. The SCOZD is expressed as a zone of branching and discontinuous folds and faults whose length, continuity and apparent displacement diminish upward in the section. The zone's expression in upper Miocene rocks is a series of short discontinuous breaks along the crest and flanks of a prominent anticline. The existence of a basement rock contact beneath the SCOZD is speculation. The SCOZD dies out southwest of Oceanside without emerging onshore. (J. Smith, written testimony, p. 20; Heath, written testimony, p. 13; Ehlig, Tr. 1017)

78. The following elements exist within and adjacent to the SCOZD: The San Onofre Shelf Anticline (SOSA), the San Onofre Syncline (SOSS), the Southcoast

Offshore Fault (SCOF), prominent unconformities between stratigraphic units interpreted to be San Onofre Breccia, Monterey and Capistrano Formations; wave-cut terrace platforms and their overlying Pleistocene deposits; and minor folds and faults. (J. Smith, written testimony, p. 20; Moore, written testimony, pp. 9, 12-14)

79. The RCFZ is considered to be the southernmost section of the OZD even though it does not mark a basement rock boundary. Lying southeast of the SCOZD, the RCFZ is coincident with a sublinear north- northwest-trending topographic depression from La Jolla Cove to Rose Canyon and along the east side of Mission Bay to San Diego Bay, where it turns westward and dies out seaward. At its north end the RCFZ extends offshore to the Oceanside area and either dies out or emerges onshore without connection to the SCOZD. Its total length is approximately 45 miles, and displacement is interpreted to have a horizontal component as well as a vertical separation, with alternative sides being up and down from north to south. (J. Smith, written testimony, p. 21; Heath, written testimony, p. 14)

D. <u>Purported OZD Extension Into Baja California</u>

80. Applicants have on several occasions investigated faults in Baja California that lie southerly of the Rose Canyon fault zone to determine whether they are related to the OZD. The investigations involved at least ten days and included literature review, or examination of aerial

photographs, and field reconnaissance. The faults in question are the Vallecitos fault, the Tijuana lineament, and the San Miguel fault. (P. Ehlig, written testimony, p. 29-33; Tr. 1086-1088)

81. There is no apparent association between the Rose Canyon fault and the Vallecitos fault because the northern end of the Vallecitos either dies out or is overlapped by Eocene-age conglomerate, and no lineament or other features suggestive of a through-going fault along the projected trend of the Vallecitos fault can be observed in aerial photographs. Furthermore, in a few places northeast-trending geologic features extend without visible offset across the projected trend of the Vallecitos fault. (Ehlig, written testimony, pp. 29-30; Tr. 975-977; S. Smith, Tr. 6376)

82. The San Miguel and Vallecitos faults are roughly parallel with each other, and are right stepping en echelon, but they do not align with the Rose Canyon fault, and the Vallecitos and Rose Canyon do not fit an en echelon model. (Ehlig, Tr. 975-917, 1080)

83. The Imperial fault and the Cerro Prieto fault are not aligned with each other but are separated by an active spreading center. Consequently, there is a mechanism there for transferring the motion from one nonaligned fault to the other. However, no such mechanism exists between the

Vallecitos and San Miguel faults in Baja California. (Ehlig, Tr. 1076-1077)

84. Evidence for a possible concealed fault along the Tijuana Valley is equivocal, and the causes of the so-called Tijuana lineament may result from other than faulting. Within exposed basement rock terrane there is no northwest-trending feature nor geomorphic evidence coinciding with a hypothetical fault along the Tijuana lineament, suggesting that the lineament is not a fault-controlled feature and does not connect with the Rose Canyon fault. (Ehlig, written testimony, 30-31; Tr. 1074, 1085-1086)

85. In southern California and Baja California it is possible to have a deep linear fault in the basement rock that does not express itself at the surface only if the displacement is very small and only if the rocks are reasonably flexible, such as sediments or sedimentary rocks. (Ehlig, Tr. 1077). In very rigid rocks exposed at the surface, it is not possible to have a throughgoing zone without having some combination of surface interconnection between the various faults. (Ehlig, Tr. 1078). Therefore, it is not theoretically possible for the RCFZ, the Vallecitos fault zone, and the San Miguel fault zone to be connected by a deep linear break in the basement rock. (Ehlig, Tr. 1079; S. Smith, Tr. 6378)

86. Investigation of the area between the southern extent of the Vallecitos fault and the San Miguel fault

indicates there is no apparent relationship between the two faults. They have subparallel trends, but remain about 7 km apart at their closest approach. Both faults have small displacements, and the Vallecitos fault appears to be old and inactive. (Ehlig, written testimony, p. 31; Figure PLE-P)

87. The northern part of the San Miguel fault is overlain by old alluvium many thousands of years old, and displays no evidence of Holocene activity. The San Miguel fault terminates near the northwest corner of Valle San Rafael, and exhibits only about 200 meters of total displacement. The overlapping presence of dikes across the fault precludes the existence of a northwest-trending strike-slip fault of significant displacement along the San Miguel fault. (Ehlig, written testimony, p. 32; Tr. 1069)

88. The trace of the Vallecitos fault is well marked by canyons and other topographical features, but geologic contacts appear to extend across the trace without detectable offset. Intrusive dikes and old alluvium lie across the Vallecitos fault and indicate no evidence of young displacement. Gordon Gastil reports no evidence of any Quaternary displacement or even Cenozoic displacement across the Vallecitos fault. Thus, the Vallecitos fault lacks significant displacement in the vicinity of its approach with the San Miguel fault. There is no basis for estimating the slip rate of the Vallecitos fault because there is not solid evidence on the amount of total displacement and the period

of time over which it was active. (Ehlig, written testimony, p. 33; Figure PLE-P; Tr. 1070-1071, 1089)

89. There is no relationship between the Vallecitos and the San Miguel faults, and there is an absence of significant strike-slip faults crossing that part of Baja California. (Ehlig, written testimony, p. 33)

E. Purported OZD Extension Offshore Baja California

90. A connection between the Rose Canyon fault and the Agua Blanca-Coronado Banks fault offshore Baja California has been postulated by Intervenors' witness Mr. Mark Legg. (Legg, written testimony, pp. 2-5)

91. During the course of the hearing, the Applicants had a subpoena issued to the custodian of the Geological Data Center of the Scripps Institution of Oceanography to obtain documentation that Mark Legg relied upon in putting together his testimony. Subsequently, the seismic reflection profiling data and navigational data were obtained and were reviewed by Dr. D. Moore. (Moore, Tr. 6329-6331)

92. Seismic reflection profiling data from two cruises called CFaults 1 and CFaults 2 were obtained for examination. Also, a computer printout of the navigation that is the ship's track for the first cruise was obtained. The track for the second cruise was reconstructed utilizing data from the deck log of the research vessel _Ellen B. Scripps_ because this was not available from the data center.

The deck logs contained all course and speed changes as well as navigational fixes at three times during the day, morning, noon and afternoon. (Moore, Tr. 6330-6331)

93. The offshore topography in the area of Mark Legg's studies is shown in Exhibit #46,DGM-2R. It shows the relatively narrow shelf out to a depth of 100 meters and the steep basin slopes of the San Diego Trough and the Descanso Plain. A prominent submarine canyon heads to the eastern or landward side of the island that lies north of Punta Bunda. It has a bowl-shaped depression at the head of the canyon. The canyon trends seaward and turns to the northwest paralleling the regional structural trend. (Moore, Tr. 6334-6335)

94. The track map of the survey vessel Ellen B. Scripps is depicted in Exhibit #45,DGM-1R. The first cruise CFaults 1 is a computer plot and the second cruise track of CFaults 2 is reconstructed from the ship's deck log data. These are only approximations of the actual track of the ship during these cruises. It is probable that some of the tracks will have to be adjusted either seaward or landward. (Moore, Tr. 6336-6337)

95. Dr. D. Moore presented testimony describing the structural interpretation of the CFaults 1 and CFaults 2 geophysical data which is shown in Exhibit #47,DGM-3R and which is based on the interpretations of Dr. Moore. (Moore, Tr. 6338)

96. In the area mapped between Santa Tomas Point on the south and Point Loma on the north, and extending to the seaward limits of the survey, there are three principal faults that are quite linear and surprisingly well-defined. The outer fault is the San Clemente-San Ysidro fault. The central fault is the San Diego Trough fault, and the fault closest to shore and farthest to the northeast is the Agua Blanca fault. Onshore, the Agua Blanca fault lies along the northern side of Punta Bunda and has a branch along the south side. Where the fault projects offshore it trends more northerly and clearly connects with the faults of the Coronado Banks fault zone. A complication in this interpretation is a probable navigation error on the track that lies just north of Punta Salsipuedes. On this line at crossings of each of the three faults, the fault appeared to be offset to the northeast by an equal distance and it is necessary to shift that track to align or collate the data along each of those faults. If the shift is not done the interpretation of the faults is much less straight forward. (Moore, Tr. 6338-6340)

97. The Coronado Banks fault has been mapped by Kennedy and others and has been known for many years but had not been traced far to the south in any detail. As a result of Dr. Moore's interpretation of the CFaults data, it is now apparent that the Coronado Banks fault does connect to the Agua Blanca fault onshore to the south. It is equally clear

that there are no major branches of the Coronado Banks fault that trend off to the north. Several older faults, which lie deep in the section and are no longer active, lie east of the Agua Blanca-Coronado Banks fault, but it is not geologically plausible or logical to connect these into the obviously presently-active trace of the Coronado Banks-Agua Blanca fault. (Moore, Tr. 6340-6341, 6342-6343)

98. In conclusion, seismic data from CFaults do not support a connection between the Agua Blanca-Coronado Banks fault and the Rose Canyon fault zone. (Moore, Tr. 6343)

F. <u>Cristianitos Fault</u>

99. The Cristianitos fault, the closest significant structural feature to the SONGS site, was evaluated for SONGS Unit 1 as far back as the construction permit and determined to be an inactive fault. (<u>In the Matter of Southern California Edison, et al.</u>, 2 AEC 366 (1964)) Since then. 10 CFR, Part 100, Appendix A, "Seismic and Geologic Siting Criteria For Nuclear Power Plants", was promulgated. It describes the investigations required for seismic design purposes. Accordingly, additional mapping of the Cristianitos fault was performed in 1969, 1970, and in 1977 by geologic consultants for the Applicants. (J. Smith, written testimony, p. 37) In the construction permit phase of Units 2 & 3, the Staff Safety Evaluation Report, Section 3.1.4, concluded: "All of the available evidence indicates that the Cristianitos Fault is inactive when evaluated using

procedures described in the proposed 10 CFR, Part 100, Appendix A . . ."

100. The Cristianitos fault trends north-northwesterly for approximately 25-30 miles from the exposure in the sea cliff 1/2 mile south of SONGS. It is a discrete, normal fault, west side down, dipping steeply west-southwest. Displacement is greatest across the central part of the fault near San Juan Creek and diminishes north and south, dying out seaward within about 6,000 feet offshore. (J. Smith, written testimony, p. 37; J. Smith Tr. 829, Tr. 840-846, Tr. 870-873; Ehlig, written testimony, pp. 16-18; Ehlig, Tr. 1097, 1108; Moore, written testimony, pp. 44-45)

101. The fault is narrow and sharply expressed in the sea cliff. Fractures and minor shears parallel to the fault contact extend 200-300 feet on each side, but no significant branch or subsidiary fault could be found. (J. Smith, written testimony, p. 37; Ehlig, Tr. 2900, 2903-2905; Slemmons, Staff Exhibit #1-DBS, p. 10)

102. Natural sea cliff exposures and trenches excavated across the fault clearly demonstrate unbroken continuity of the stage 5e marine terrace platform and its deposits across the entire width of the fault, indicating that the minimum age of last displacement on the Cristianitos fault is 125,000 years. (J. Smith, written testimony, pp. 37-38)

G. Capistrano Embayment

103. The Capistrano Embayment is a north-south trending structural trough about 22 miles long that is bounded by the Cristianitos fault on the east and the San Joaquin Hills on the west. The trough has a narrow wedge-shape that opens southward and is about 9 miles wide at the coast. (J. Smith, written testimony, p. 38)

104. Mapping and interpretation of subsurface data indicate that the Capistrano Embayment is a downwarp produced by westward extension and gravity sliding in the upper crust between the Cristianitos fault and the Los Angeles Basin between about 10-4 million years before present. Further opening of the Embayment and renewed movement on the Cristianitos fault are precluded now because crustal stresses have changed direction and the Los Angeles basin is now filled with sediments that prevent sliding. (J. Smith, written testimony, p. 38; Ehlig, written testimony, pp. 17-18, 28-29; Tr. 971-974)

V. GEOLOGIC EVOLUTION OF SONGS REGION

105. The geologic evolution of the SONGS region has been complex and has produced significant structural features and stratigraphic units. Beginning about 200 million years (m.y.) ago eastward subduction in the vicinity of the Peninsular Ranges brought together oceanic crust and continental crust. Sediments accreted against the continental crust during Triassic and Jurassic time, and

volcanic rocks were emplaced over them in Late Jurassic and Early Cretaceous time. From 120 m.y. to 85 m.y. ago (Cretaceous time) the sedimentary/volcanic sequence was intruded by granitic batholiths accompanied by uplift and erosion. Subsequent subsidence along the western margin of the Peninsular Ranges permitted the sea to transgress eastward, forming a shoreline and depositing sediments against the batholithic rocks along a tectonic hinge line called the Santillan-Barrera line. (Ehlig, written testimony, p. 4-6; Figures PLE-A, PLE-B)

106. From Late Cretaceous through Early Miocene time (90-20 m.y. ago), the coastline changed and transgressed landward across the Santillan-Barerra line. During Early Miocene time (about 20 m.y. ago) the shoreline was west of SONGS and trended north-northwesterly. (Ehlig, written testimony, p. 6-7; Figure PLE-C)

107. Conditions changed radically about 16 m.y. ago (Middle Miocene time), resulting in: the appearance of Catalina Schist at the surface offshore; shedding of schist debris northeasterly to form the San Onofre Breccia; widespread volcanism within and north of the San Joaquin Hills; and crustal extension causing opening of the Los Angeles Basin and development of northwest-trending ridges and basins in the Continental Borderland. (Ehlig, written testimony, p. 7-8; Figures PLE-D, PLE-E)

108. The Continental Basement of the Peninsular Ranges became juxtaposed with the Franciscan schist basement offshore along a major zone of faulting. The juxtaposition of different basement rocks is important because the two formed in very different environments and indicate emplacement against each other by faulting. (Ehlig, written testimony, pp. 8-9; Figure PLE-F)

109. The contact between the different basement rocks near SONGS probably lies offshore along the OZD, but the presence of a thick sedimentary cover inhibits verification. (Ehlig, written testimony, pp. 8-9; Figure PLE-F)

110. During Middle Miocene time a southward-plunging uplift developed in the San Joaquin Hills simultaneously with emplacement of volcanic rocks and the possible intrusion of gabbro in the underlying basement. (Ehlig, written testimony, p. 11)

111. In the period from 16 to 14.5 million years ago the Los Angeles Basin began to open and subsidence progressed throughout the area to produce a deep water basin conducive to accumulation of laminated diatomaceous shale of the Monterey formation. The Monterey formation interfingers with massive sandstone deposited as small submarine fans along the coast southeast of SONGS, reflecting the presence of a relatively steep submarine slope along the western

margin of the Peninsular Ranges. (Ehlig, written testimony, pp. 11-12)

112. Approximately 10 million years ago the Cristianitos fault began to move in association with subsidence in the Capistrano Embayment concurrent with continued opening of the Los Angeles Basin. (Ehlig, written testimony, p. 12)

113. The Cristianitos fault is a west-facing normal fault dipping 57 degrees west with slickensides oriented down the dip. The west side is down and reverse drag on the downthrown side indicates a flattening of the fault plane with depth. (Ehlig, written testimony, p. 16)

114. The Cretaceous strata beneath the Capistrano Embayment and east of the Cristianitos fault dips about 15 degrees west, thus providing a structure suitable for westward sliding. The base of the Cretaceous sediments is likely to continue to dip westward beneath the Capistrano Embayment and possibly westward beneath the San Joaquin Hills Structural High. The Cristianitos fault is likely to flatten with depth, becoming a bedding-plane fault near the base of the Cretaceous sediments. (Ehlig, written testimony, p. 17)

115. Movement on the Cristianitos fault started when the area was below sea level, and is marked by a change in sedimentation from laminated strata of the Monterey formation to the poorly bedded mudstone, siltstone and sandstone of the Capistrano formation. Beds within the two

formations are gradational within the interior of the embayment, but are discordant and change abruptly from shale to sandstone adjacent to the Cristianitos fault. (Ehlig, written testimony, pp. 13-14)

116. Two large submarine fans had their heads along the base of a west-facing submarine scarp along the Cristianitos fault. The southerly fan had its head along the Cristianitos fault in the area between SONGS and San Mateo Creek, and it interfingers with the fine grained sediments of the Capistrano formation. The fan was fed by a submarine canyon cut into the scarp along the Cristianitos fault, probably by the ancestral San Mateo Creek. (Ehlig, written testimony, pp. 13-14; Figure PLE-J)

117. As the Capistrano Embayment developed from 10-8 million years ago, the Los Angeles Basin deepened rapidly within the vicinity of Newport Bay on the west side of the submarine ridge now represented by the San Joaquin Hills. Water depths at that time were at least 3,000 meters (approximately 10,000 feet) in the Newport Bay area and at least 2,500 meters (8,200 feet) in the Dana Point-Capistrano area at the mouth of the Capistrano Embayment. A relatively steep south-facing submarine slope existed at the mouth of the Capistrano Embayment with a deep ocean basin to the south. (Ehlig, written testimony, p. 15; Figure PLE-J)

118. Movement on the Cristianitos fault was caused by gravity gliding of the hanging wall block resulting from

inadequate lateral support within the Los Angeles Basin where the ocean floor was very deep and where Middle Miocene and older rocks have been removed by crustal extension and/or strike-slip faulting. (Ehlig, written testimony, pp. 17-18)

119. Vertical relief between the Capistrano Embayment and the Los Angeles Basin has provided the driving force for gravitational gliding, and was assisted by loss of gravitational support because of deep-seated extension beneath the Los Angeles Basin. (Ehlig, written testimony, p. 18)

120. The displacement along the Cristianitos fault is greatest near the center of the Capistrano Embayment and increases both north and south. Near the center of the embayment, stratigraphic separation of Cretaceous strata across the fault is about 3500 feet, and at the south end of the embayment near SONGS the Monterey formation has a dip separation of about 600 feet across the Cristianitos fault. Displacement appears to die out completely 6000 feet offshore from SONGS. (Ehlig, written testimony, p. 19; Moore, written testimony, p. 44)

121. Mechanically, the Cristianitos fault should die out in the nearshore area before reaching the OZD because of a change in the physiographic and geologic structure which existed in the vicinity of the present coast during Late Miocene and Early Pliocene time, which mitigated the tendency for sliding offshore. (Ehlig, written testimony. p. 20)

122. Thus, as evidenced by the geologic evolution of the SONGS region, there is no structural relationship between the Cristianitos fault and the OZD. (Ehlig, written testimony, p. 20)

VI. REGIONAL SEISMICITY

123. The principal factors to be examined in assessing the maximum magnitude of earthquake to be generated from a particular structure are the seismic history of the area, the geologic record of deformation, the regional stress as inferred from focal mechanisms, and the faulting characteristics of the particular structure. (S. Smith, written testimony, pp. 4-5)

124. The south coast region has not been an area of high seismic activity during either the instrumental or pre-instrumental historic period dating back to 1769. (S. Smith, written testimony, p. 5)

125. Although earthquakes less than magnitude 4 are widely distributed over southern California, they show a clustering along major faults on which larger earthquakes have occurred. Localized stress concentrations associated with microearthquakes occurring throughout California has little bearing on the pervasive regional stress required to generate significant damaging earthquakes. No significant zone of seismic activity has existed during the nearly half century during which accurate recording of earthquake location has been possible. This data supports the idea that

the principal plate boundary at the latitude of SONGS occurs on the San Andreas and San Jacinto fault systems, and that activity generally decreases westward away from these faults. (S. Smith, written testimony, pp. 5-6; Figures SWS-A, SWS-B, SWS-C, SWS-D; Tr. 1553)

126. The seismicity on the OZD is, on an average, no higher than on the Whittier-Elsinore fault zone. Seismicity is lower along the OZD than for other major strike-slip fault zones in southern California. (Heath, Tr. 1361)

127. The geologic record of deformation on the OZD for Quaternary time is relevant to the maximum earthquake magnitude assigned to it because several centuries of seismic record are not a sole indicator of future possible activity. The geologic record of past fault movement is preserved in the rocks of a fault zone and provides an assessment of the prehistoric level of earthquake activity that may have occurred. (S. Smith, written testimony, pp. 6-7; Allen, Tr. 4687, 4868-4869)

128. All known major earthquakes throughout the world have occurred on faults with pre-existing Quaternary displacement. Every single major earthquake that has occurred in southern California has occurred on a fault that either had been or could have been recognized by modern techniques as a seismogenic fault. (Allen, Tr. 4735).

129. The rate of deformation, or slip rate, over about the last 10,000-20,000 years is the most important geologic information for assessing the seismic potential of a fault system. (S. Smith, written testimony, p. 7; Allen, Tr. 4899, 4901)

130. The measured slip rate for the OZD over the past several million years ranges from 0.5 to 1.0mm per year in contrast with other faults of greater activity such as the San Jacinto which has 3.0 mm per year or the San Andreas, which has 37.0 mm per year slip rates. Slip-rate data on the NIZD was developed by interpreting subsurface geology provided by oil well electric logs. (Heath, written testimony, pp. 23-24; Tr. 1379, 1615-1616; Exhibit #5,EGH-3 and Exhibit #6,EGH-4; S. Smith, written testimony, p. 7)

131. Earthquakes larger than about 6.5 to 7.0 M could not have occurred with any regularity over the past million years without producing a record of geologic deformation mcuh more impressive than what is seen in the region of the OZD. (S. Smith, written testimony, p. 7)

132. The rate of vertical uplift and downwarping is often used as a measure of the vigor of tectonism, and indicates that the south coast region has been a stable area compared with the more active regions of California over the past several hundred thousand years. Four different time scales involving four different types of data reveal a consistent picture of relative stability in the south coast

region: (1) the instrumental record of a half century, (2) the historical record of several centuries, (3) the geomorphic record of several hundred thousand years, and (4) the geologic record of several million years. Taken together, these types of data and the time scales they represent provide conclusive evidence that large earthquakes have not and will not occur in the south coast region. (S. Smith, written testimony, p. 8)

133. The nature of the stress fields operative at the present time, and at the time of development of the OZD, have been investigated to arrive at an assignment of maximum magnitude. To compare this with the contemporary record of seismicity, earthquake focal mechnisms have been determined to provide the most direct way of estimating slip directions of faults during earthquakes. From the slip direction or focal mechanism during earthquakes, the direction of principal stresses can be inferred. (S. Smith, written testimony, pp. 8-9).

134. Despite difficulties of limited seismographic coverage up until the last decade in southern California, and the continuing lack of seismographic coverage on all sides of a coastal site, some information on focal mechanisms in the southern California coastal region is available. The principal conclusion drawn from the focal mechanisms, whose pattern is irregular with little preference for any one slip direction, except some preference for a general northerly

direction for the compressive axis, is that regional stress levels are not high along the south coast region. If the SONGS areas were part of the active section of a plate margin, much more consistency in focal mechanism and a higher level of seismcity would be expected. (S. Smith, written testimony, pp. 8-10)

135. Where stress levels are not dominated by a regional stress field, then residual stresses that are much more influenced by local geologic conditions, which are more irregular, will be the ones revealed by current seismic activity. (S. Smith, written testimony, p. 10)

136. The NIZD is representative of the overall OZD in terms of seismological characteristics. Because the 1933 Long Beach earthquake is the largest and most significant earthquake on this zone, it is the basis of the assignment of seismologic characteristics to the overall OZD. (S. Smith, written testimony, p. 10; Heath, written testimony, p. 17)

137. The mechanism of the Long Beach earthquake of 1933 was primarily right-lateral strike-slip, and involved an average slip of 41cm over a rupture length of about 33 km, and the depth of energy release was approximately 11 km. Thus, future significant earthquakes on the OZD can best be characterized as being strike-slip, responding to a northerly direction of compresssion, and would involve rupture and energy release to depths of about 12-15 km. (S. Smith, written testimony, p. 11)

138. The OZD consists of a complex series of short and sinuous sections of faults and folds. It is clear that large earthquakes require large rupture zones, that future earthquakes are unlikely to form on new ruptures but rather on existing ones and, thus, it seems unlikely that a long continuous or throughgoing rupture could develop on the OZD. (S. Smith, written testimony, p. 12; Tr. 6378; Allen, Tr. 4730, 4732, 4880)

VII. WRENCH TECTONICS

139. During the hearing, several attempts were made to characterize the OZD and other faults in terms of "wrench tectonics." Current theories of wrench tectonics attempt to relate certain types and patterns of shallow folding and faulting to horizontal shearing strain within the underlying crystalline crust, based on experimental deformation produced in clay models. In wrench fault modeling, surface deformation develops directly above the shear zone at depth. Consequently, such deformation cannot be extrapolated for great distances away from the fault to attribute all of the regional deformation to wrench faulting, particularly as suggested by simple laboratory experiments. (Ehlig, written testimony, p. 23; Tr. 1023, 1026, 1027)

140. The basic concepts of wrench tectonics have been known for several decades in association with studies of strike-slip faults, but they have become popular recently because they may permit the identification of zones along

which petroleum-bearing structures may occur in a systematic pattern. Because petroleum interest is in the overlying sediments, basement rock at depth is modelled to produce the deformation seen in the near surface, which may not be appropriate for normal rock and which does not indicate what is happening at depth. (Ehlig, Tr. 1023). Aside from establishing a sense of shear, however, wrench tectonic concepts do not deal with the nature, origin and causes of deepseated basement deformation. (Ehlig, written testimony, pp. 23-24; Tr. 1025)

141. The theory of wrench fault tectonics makes many simplified assumptions that lead to very simple patterns so that one can explain any pattern of deformation given the right scheme. However, to be correct it is necessary to put the deformation into the context of a given region. (Ehlig, Tr. 975)

142. The concept of wrench fault tectonics as used by Wilcox and others (1973) and Moody and Hill (1956), involves ways to produce every type of deformation seen. This is objectionable because, unless one looks at the details on a local basis, one cannot conclude whether or not something is the result of complex motion in a lateral shear system. (Ehlig, Tr. 1030-1031)

143. Wrenching is the process of deforming near-surface rocks by horizontal shearing strain along a steeply-inclined zone or fault within the underlying

basement. A wrench fault is a high-angle strike-slip fault of great linear extent which involves basement deformation. A wrench zone is a swath of terrane deformed by wrenching prior to and concurrently with strike-slip along the throughgoing wrench fault. (Ehlig, written testimony, p. 24)

144. Among the major weaknesses of wrench tectonic concepts is the fact that local stress fields change orientation through time due to interaction between the crustal plates, with the result that faults and folds formed during one stage of the tectonic evolution of a region may be inactive during a later stage when other types of deformation may be taking place along a new orientation. Furthermore, most of the earth's crust is inhomogeneous and new ruptures tend to follow surfaces of weakness. Thus, the geometry of faulting is influenced by the fabric of the crust and not just the orientation of the stress field. Although wrench tectonic concepts and models may be used to identify wrench zones underlain by deepseated strike-slip faults, the concepts are of little value when interpreting regional tectonic history. (Ehlig, written testimony, pp. 25-26)

145. The OZD does not fit into a wrench tectonic system because of its geologic evolution. For example, assuming the OZD marks the boundary between the Peninsular Range basement and the Catalina Schist, the OZD originated about 15 to 16 million years ago during the Middle Miocene. At that time the OZD was probably part of a system of

right-lateral wrench faults which formed the Pacific-North American plate boundary within the California Continental Borderland. Now, however, activity on the OZD is in response to the effects of crustal compression along the Big Bend in the San Andreas fault, or to drag along the plate boundary. Therefore, Quaternary deformation along the OZD is a secondary effect of interaction between the Pacific and North American crustal plates, and the theory of wrench faulting is not applicable to the OZD at the present time. (Ehlig, written testimony, pp. 27-28; Tr. 1016)

146. The northwest-trending faults west of the San Andreas fault to the San Clemente fault are strike-slip faults, but they are not all characterized by exclusive strike-slip motion, they have not all been active simultaneously, and they have not necessarily been part of the plate boundary. Thus, it would be inappropriate to consider them as wrenching the blocks between them. (Ehlig, Tr. 1027-1029)

147. There is also no basis in wrench tectonic concepts for relating the onshore Cristianitos fault with the OZD. An indirect relationship may have existed when the Cristianitos fault was active 4-10 million years ago, but only insofar as there may have been an interrelationship between the OZD and other faults involved in the opening of the Los Angeles Basin. (Ehlig, written testimony, p. 28)

148. The Los Angeles Basin stopped opening during the Pliocene about the same time the Gulf of California began to open and the San Andreas fault began to take up most of the Pacific/North American interplate motion in southern California. (Ehlig, written testimony, p. 28)

149. The Los Angeles Basin has subsequently filled with sediments, and since Pliocene time has been experiencing crustal shortening in a northeast and southwest direction. In the vicinity of the Capistrano Embayment, this shortening is causing upwarping near the coast and downwarping within the inland area. Under exiting conditions, the Cristianitos fault is buttressed and cannot move. Consequently, movement on the OZD would not cause movement on the Cristianitos fault. (Ehlig, written testimony, pp. 28-29; Figure PLE-O) Over the last 100,000 years offshore earthquakes have not induced faulting on the Cristianitos fault, therefore it would be very surprising if the next off-shore earthquake did. (Allen, Tr. 4887)

VIII. <u>DETERMINATION OF MAXIMUM MAGNITUDE EARTHQUAKE</u>

A. <u>Introduction To Methodology</u>

150. The principal factors to be examined in assessing the maximum magnitude of earthquake to be generated from a particular structure are the seismic history of the area, the geologic record of deformation, the regional stress as inferred from focal mechanisms, and the faulting

characteristics of the particular structure. (S. Smith, written testimony, p. 4-5)

151. All available qualitative and quantitative methods were used in evaluating the maximum earthquake applicable to the OZD to establish a consistent magnitude estimate. The Applicants' specific approach used comparison of features, such as maximum historical earthquake, fault rupture length, total displacement, degree of deformation, and long-term slip rate on faults as a means of differentiating and ranking faults and evaluating the earthquake potential of the OZD. Quantitative methods involve measuring some parameter on the fault and deriving a number to represent it. Geologic slip-rate, for example, is a quantitative measure of the degree of activity; and fault length, when it can be defined, is also a quantitative measurement. Empirical relationships of rupture-length versus magnitude, and displacement-per-event versus magnitude were also used, but these methodologies alone are not completely adequate. (Heath, written testimony, p. 6; Tr. 1268, 1280-81, 1337, 1437; Exhibit #3,EGH-1)

152. One method of estimating earthquake magnitude, called the degree-of-fault-activity approach, has been proposed since about 1966 and is founded on at least 15 years of background and work by various investigators who suggested that this broad-base multiparameter method of comparing and ranking faults was the right approach in assessing earthquake

potential. (Heath, written testimony, p. 19; SER, Section 2.5.2.3.2) In both assessing risk and estimating the probability of occurrence of an earthquake, slip-rate is an important parameter of the degree-of-fault-activity approach. (S. Smith, written testimony, p. 7; Brune, Tr. 4211, 4272) The slip-rate/magnitude method is an outgrowth of degree-of-fault-activity approach and is a more quantitative measure of earthquake potential. (Heath, Tr. 1280-81, 1437; Exhibit #3,EGH-1; Figure EGH-J)

B. Degree-of-Fault-Activity (Slip-Rate) Magnitude Method

153. The slip rate/magnitude method extends existing knowledge and provides a viable supplement to other methods of estimating maximum magnitude. This method compares the degree-of-fault activity in terms of slip rate on the OZD with that of similar faults in the southern California region and in other similar tectonic environments around the world. The levels of activity of those faults are correlated with their maximum earthquakes, permitting an estimate to be made of maximum earthquake that may be associated with the OZD according to its characteristics. It is a state-of-the-art addition to other methods that have been used in the past. (Heath, written testimony, pp. 6-7; Tr. 1268)

154. The degree-of-fault-activity approach considers the relative behavior of faults in terms of strain release or long-term slip rate, the nature of seismic events

in terms of size, periodicity, and energy release; and the mechancial and compositional properties of the faults as well as their tectonic setting. The degree of activity method of estimating earthquake magnitude is based on observation of geologic characteristics associated with active faults and comparing them in a ranking procedure. (Heath, written testimony, p. 7; Tr. 1340) Because geologic slip rates reflect average fault displacement during a relatively long time interval, the behavior of faults in the past can be evaluated and can provide a basis for projection of fault behavior into the future. (Heath, written testimony, p. 18; Exhibit #3,EGH-1). Fault parameters of the San Andreas, San Jacinto, and Whittier-Elsinore faults, and the hypothesized OZD were described and presented on table EGH-F. (Heath, written testimony, p. 18)

155. The slip-rate/magnitude method involves defining a style of faulting and tectonic setting for the fault of interest, and then comparing it with other faults having the same style and being in a similar tectonic environment. (Heath, Exhibit #3,EGH-1) The geologic assessment of the structural and tectonic environment included the tectonic driving forces, the type and direction of displacements, and the general presence or lack of disparities along fault zones to provide data for estimating a maximum magnitude. (Heath, written testimony, pp. 7-8; Tr. 1281, 1435)

156. Maximum earthquake estimation methods that incorporate only one or two aspects of fault behavior, e.g., fault length versus magnitude or amount of surface displacement-per-event versus magnitude, fail to describe the complexities of fault behavior. (Heath, written testimony, p. 8)

157. Empirical curves based on length of surface rupture are not appropriate for the OZD because the OZD does not have a surface rupture length commensurate with its length. The degree-of-fault-activity methodology is superior because it incorporates these characteristics and compares those of the OZD to other faults within the same or similar tectonic environments. (Heath, written testimony, p. 8; Exhibit #3,EGH-1)

C. Geologic Assessment of the Offshore Zone of Deformation

1. Regional Comparison of Fault Activity

158. The tectonic setting of southern California is dominated by the San Andreas fault system, which is the major boundary between the Pacific and North American plates with a very high percentage of motion between the two plates taken up on the San Andreas. (Moore, Tr. 6349-50). This system is paralleled to the west by other smaller northwest-trending right-slip fault zones or zones of deformation such as the Whittier-Elsinore, OZD and the San Clemente. These smaller faults show a general decrease westward in amount of total

displacement, continuity of surface trace and amount of seismic activity. (Heath, written testimony, p. 10; Exhibit #4,EGH-3, p. A-1, A-2). As noted by Brune, slip rate, seismic activity and maximum magnitude generally decrease away from the plate boundary. (Brune, Tr. 4282)

159. By far the greatest amount of post-Middle Miocene regional displacement has occurred along the San Andreas - San Jacinto fault zone. In the case of the San Andreas fault, which has a very high slip rate and a very straight trace along most of its length, the chances of loading a segment of the fault to the critical point is much greater in any given length of time than for faults of very slow slip rate. (Ehlig, Tr. 987). In fact, the return period of earthquakes on the San Andreas fault appear to be relatively systematic. (Brune, Tr. 4573).

160. The general conclusions drawn from comparing degree-of-activity parameters are: (1) the major plate motions between the North American and the Pacific Plates are occurring along the San Andreas and San Jacinto fault zones and have continued to do so for at least the past 5 million years. This is particularly well demonstrated by comparing total displacement across the faults and the long term geologic slip rates of the faults. (2) There is a consistent decrease in essentially all of the observed parameters westward from the major plate boundary faults to the OZD, suggesting that the OZD is a less significant fault with a

much lower level of earthquake potential than the more active faults along the plate boundary. (Heath, written testimony, pp. 18-19; Exhibit #3,EGH-1)

2. Tectonic Elements of the OZD

161. The OZD, which passes by the SONGS site about 8 km (5 miles) to the west (Heath, written testimony, p. 11), consists of three tectonic elements including the Newport-Inglewood Zone of Deformation (NIZD), the South Coast Offshore Zone of Deformation (SCOZD), and the Rose Canyon Fault Zone (RCFZ). The three elements extend from the Santa Monica Mountains southward to offshore of the Mexican-American international border, a distance of approximately 200 km. The NIZD splays out and ends toward the south before the SCOZD is encountered. The SCOZD has some similar characteristics to the NIZD, but there is no direct connnection between the two zones. Structural, gravity, and stratigraphic evidence indicates that the NIZD terminates at its south end against the San Joaquin Hills Structural High. (J. Smith, written testimony, p. 20). The SCOZD dies out southward and overlaps in an en echelon pattern with the north end of the RCFZ which then continues southward. (Heath, written testimony, pp. 10-11; Tr. 1302, 1342, 1492)

162. Geologic features common to each part of the OZD include north-to northwest-trending, en echelon fault segments, drag-fold anticlines, and numerous smaller

second-order faults intersecting the primary faults, all suggestive of predominant strike-slip faulting. (Heath, written testimony, p. 11; Exhibit #4,EGH-2).

163. The OZD consists of a complex series of short and sinuous sections of faults and folds. It is clear that large earthquakes require large rupture zones, that future earthquakes are unlikely to form on new ruptures but rather on existing ones and, thus, it seems unlikely that a long continuous or throughgoing rupture could develop on the OZD. (S. Smith, written testimony, p. 12). The 240 km-long region of interest for San Onofre does not contain a continuous, single, well-defined fault zone. (Allen, Tr. 4732). The geologic record indicates that earthquakes larger than 6.5 to 7.0 have not occurred on the OZD with any regularity over the last million years. (S. Smith, Tr. 1535). In fact, there probably have not been any M_s 6.5 or 7.0 earthquakes on the SCOZD. The M 7 earthquake reflects uncertainty in such a judgmental decision. (S. Smith, Tr. 1537, 1557).

164. The branching nature of the NIZD and the lack of evidence for continuous recent displacements at the surface are not characteristic of strike-slip faults that have generated truly large earthquakes. (Allen, Tr. 4730). In fact, Allen does not see evidence for continuity of a single structure along the whole offshore zone from Santa Monica down to Baja California that could be compared with major fault zones around the world. (Allen, Tr. 4880).

South of Newport Beach the OZD is even less continuous than it is north towards Santa Monica. (Allen, Tr. 4880).

165 From north to south the style of faulting along the OZD progressively changes between the elements, beginning with direct evidence of right-lateral displacements in post-Miocene sediments of the NIZD and proceeding to the SCOZD where the pattern of folds and faults is indicative of strike-slip faulting, but for which direct evidence of the amount of lateral or vertical displacement is lacking. Farther south, the RCFZ displays evidence for both strike-slip and normal faulting, but lacks conclusive evidence of the amount of either type of displacement. However, apparent reversals of displacement along the Rose Canyon fault that show the western block being raised and dropped at different locations is indicative of strike-slip movement. (Heath, written testimony, pp. 11-12; Exhibit #4,EGH-2).

a. Newport-Inglewood Zone of Deformation (NIZD)

166. The tectonic style of the NIZD is representative of right-lateral, strike-slip faulting. In evaluating the maximum magnitude of the OZD, the NIZD has to be considered as a zone of segmented faults with intervening folds, and not as a throughgoing fault. Although the Transverse Ranges provide an impedance to northern motion on northwest-trending faults west of the San Andreas-San Jacinto

zones, the Newport-Inglewood zone is affected by compression exerted on the Transverse Ranges by the Big Bend in the San Andreas fault. The southern thrusting of the Santa Monica mountains along the Santa Monica-Malibu Coast fault has a driving effect on motion on the NIZD. Consequently, motion is occurring and has resulted in some cumulative slip across the NIZD since late Miocene time. (J. Smith, Tr. 818).

167. Tectonic deformation along the NIZD and probably along the SCOZD has occurred at approximately the same rate since Late Miocene time. (Heath, written testimony, pp. 12-13, 19; Tr. 1346; Exhibits #5,EGH-3, #6,EGH-4). Right shear is occurring along the NIZD as shown by the pattern of folds. (Ehlig, Tr. 1017).

b. South Coast Offshore Zone of Deformation (SCOZD)

168. Tectonic deformation along the SCOZD is expressed as a zone of branching and discontinuous faults trending south to southeast about 8 km (5 miles) seaward of the SONGS site as depicted in two deeply buried reflecting horizons by Western Geophysical Company. Both zones are characterized by northwest to west-trending anticlines in shallower horizons which, together with the faulting reflect a similar tectonic style. Total cumulative deformation of Miocene-age units in Horizon B is less on the SCOZD than on the NIZD, suggesting there has been less displacement on faults of the SCOZD. Geologic observations of the NIZD

indicate that more deformation has occurred on that zone than on the SCOZD during the last 1 to 4 million years. (Heath, written testimony, pp. 13-14; Figure EGH-D; Tr. 1347, 1352; Exhibit #7,EGH-5; J. Smith, written testimony, p. 20)

c. Rose Canyon Fault Zone (RCFZ)

169. The RCFZ, which the Applicants' consultants have studied at various times since 1964 (Ehlig, Tr. 6354-6355), consists of a zone of northwest and north-trending faults that lie offshore north of La Jolla and south of Coronado, and occur onshore in the San Diego area between these two locations. The RCFZ displays evidence of right-lateral displacement, with folding that has produced both normal and reverse fault relationships across the RCFZ. Actual measurements of displacements are difficult to corroborate and those in the literature are speculative. Some investigators believe that total displacement on the Rose Canyon fault is less than the 4 to 6 kilometers of strike-slip displacement proposed by Kennedy (Tr. 2338). However, reliable slip-rate data on the Rose Canyon fault are difficult to determine in the absence of a piercing point on each side of the fault. (Heath, written testimony, pp. 14-16; Tr. 1383-84; Exhibit #8,EGH-6)

170. The RCFZ is tending to die out southward offshore from Coronado before reaching the international border. At the south end of the RCFZ in the vicinity of San Diego Bay there is evidence of dip-slip motion with the block

on the east being down. (Heath, written testimony, p. 16). Based on this information, the southerly projection of the Rose Canyon fault would not connect with the Tijuana lineament. (Ehlig, Tr. 1074). Nevertheless, Applicants have considered whether the RCFZ might extend beyond the Mexican Border and connect with faults in Baja California.

d. <u>Nonsignificance of Baja California Faults</u>

171. Geologic evidence suggests that a connection between the Rose Canyon fault and the Vallecitos faults has never happened in the past and there is no reason for us to expect it in the future. (S. Smith, Tr. 6376-6377). For seismological purposes, there is no reason to consider that a single rupture could ever progress along the Rose Canyon/Vallecitos/Calabasas/San Miguel system. (S. Smith, Tr. 6378).

172. The mechanical connection between discontinuous fault segments is dependent upon the distance between the ends of the fault segments and the deformation or slip occurring on the fault strands. When the displacement is very large, dramatic kinds of deformation occur in the region between the two fault stran . An example of this is the right-stepping Cerro Prieto-Imperial faults. Between these two strands there is a spreading center and a volcano. If the displacements on the fault strands are small, then the deformation between the fault strands is reduced and often can be accommodated by elastic or plastic distortion. A

mechanical connection between the faults is therefore not necessary. Faults represent the accommodation of strain in the crust. If large accommodations are necessary, then connections are necessary as well. If the displacements are small, then short faults can accommodate the displacements and no connection is necessary. (S. Smith, Tr. 6373)

173. It is very important to look at the amount of displacement on each of the faults and the style, nature and amount of deformation between the ends of such faults. If there is no significant deformation between them, then there is no need to postulate that they are connected. (S. Smith, Tr. 6374)

174. It is not, therefore, a geologically or seismologically plausible scenario that an earthquake on either the Rose Canyon fault or the Vallecitos fault could propagate from one feature to the other. These faults are not connected at the surface, the total displacements along the faults is small, and there is no significant distortion between the offset fault traces. (S. Smith, Tr. 6376)

3. <u>NIZD as Deformation Model of OZD</u>

175. Applicants' model of deformation along the OZD presumes a similar type of deformation along the NIZD and the SCOZD. The style of faulting for the entire OZD is taken to be represented by that of the NIZD because the greatest amount of definitive information on fault behavior along the OZD is available from the NIZD. Also, the continuity and

magnitude of the folding and faulting, as well as the historical seismicity, on the NIZD are greater than on the other portions of the OZD. Because the NIZD has the greatest seismic potential of the three sections, it serves as a conservative model to characterize the earthquake potential of the SCOZD. (Heath, written testimony, pp. 8-9; Tr. 1347; Exhibit #4,EGH-2; Allen, Tr. 4880)

176. Based on an evaluation of the entire OZD, from Santa Monica, California to the Mexican border, the NIZD is considered the most representative model of the OZD because: (1) of the similarities in structural style among the three elements of the OZD; (2) the data on style and amount of deformation is most extensive and of high quality along the NIZD; and (3) the available surface and subsurface data along the NIZD allow a higher degree of accuracy in assessing fault parameters for the purpose of estimating the maximum magnitude earthquake. (Heath, written testimony, p. 16; Exhibit #4,EGH-2)

177. Additionally, the NIZD is considered to be a conservative model for the other segments because: (1) it has the highest level of historic seismicity; (2) it has the most prominent surficial anticlinal folds and short but prominent fault scarps; (3) it is coincident with a basement rock discontinuity not known to exist beneath the SCOZD and absent along the RCFZ; and (4) it is closest to the area of high stress at the interaction between the San Andreas fault

system and the Transverse Ranges than the other segments of the OZD to the south. (Heath, written testimony, pp. 16-17; Exhibit #4,EGH-2)

D. Seismologic Assessment of OZD

178. The historic record of seismicity in Southern California is about 200 years. Accurate instrumental determinations of earthquake magnitude go back approximately 50 years. (SER, Section 2.5.2.2). The historical seismicity in southern California indicates that: (1) seismicity is lower along the OZD than for other major strike-slip fault zones in southern California; (2) the major interplate motion is occurring on the San Andreas and San Jacinto faults and to a lesser degree on faults to the west; (3) the maximum historic earthquake on the OZD is the 1933 Long Beach event (M_s 6.3); (4) the estimated maximum magnitude for the zone could be expected to be somewhat greater than the historical M_s 6.3, but less than that for the more active zones such as the Elsinore, San Jacinto, and the San Andreas.

179. In a seismic risk analysis study for the El Capitan Dam, Brune has concluded that there is little geologic, geomorphic or tectonic evidence of recent large displacements on the Newport-Inglewood, Rose Canyon faults. These faults are certainly not presently comparable in activity to the San Jacinto or even the Elsinore faults. Nevertheless, because of the magnitude 6.3 Long Beach earthquake of 1933 and the Agua Blanca and San Miguel

earthquakes of 1954 and 1956 it must be assumed that there is a possibility that a similar size event could occur along the zone in San Diego. (Brune, Tr. 4300; Exhibit #43,JNB-1X). And (5) and subsurface rupture length of the 1933 earthquake approaches the maximum fault-segment length measured on several closely-spaced segments in the subsurface for the NIZD and, thus, the M_s 6.3 event may be close to the maximum for the zone. (Heath, written testimony, p 20; Tr. 1361-1364; SER, Section 2.5.2.3.2)

180. The mechanism of the Long Beach earthquake of 1933 was primarily right-lateral strike-slip, and involved an average slip of 41 cm over a rupture length of about 33 km, and the depth of energy release was approximately 11 km. Thus, future significant earthquakes on the OZD can best be characterized as being strike-slip, responding to a northerly direction of compression, and would involve rupture and energy release to depth of about 12-15 km. (S. Smith, written testimony, p. 11)

E. Empirical Methods of Estimating Maximum Magnitude

181. Empirical methods such as surface rupture length or displacement-per-event versus magnitude, are commonly applied by themselves in the absence of other data and sometimes even to the exclusion of other data. This singular application results in a value that has no cross check or verification. The weaknesses of these approaches are apparent in the recognition that style of faulting and

the tectonic setting directly affect the relationship between magnitude and length of surface rupture, or amount of surface displacement, and are not considered. (Heath, written testimony, pp. 20-21)

1. <u>Surface Rupture-Length/Magnitude Method</u>

182. Faults such as the San Jacinto which have experienced ruptures over most of their length in segments during historical time, demonstrate that they do not rupture over half their lengths at any one time. The physical reason why faults do not rupture 100% of their length is that stress conditions on their rupture surface are not high enough to permit the breaking and sliding of material. (S. Smith, Tr. 6377-6378). For example, the San Jacinto has had numerous large events at different times, but each event ruptured only a segment that is less than 30% of the total fault length. This percentage of total fault length used, i.e., 30%, represents the mean plus 1 sigma. (Reiter, Tr. 5795-5796). Applying this to the OZD, the length of the various fault segments provide limits on the maximum magnitude that could be expected from the zone. The longest fault segments in the Miocene-age rocks of each OZD element range from 27 to 48 km. Surface ruptures longer than the subsurface segment lengths are not expected. (Heath, written testimony, pp. 21-22; Brune, Tr. 4300)

183. The value of 22% of total fault length used in the evaluation of maximum magnitude has been derived from

earthquakes ranging in magnitude from 8.25 to 5.9. For faults with a total length of more than 1000 km, the percentage is around 25-30%. In the length range 600-1000 km, the average percentage of the largest observed rupture-to-fault-length approaches the mean value of 22%. Finally, for faults in the range of interest to the OZD, the percentage value is in the range 15-16%. The standard deviation for the value 22% is 7.45%. Therefore, for faults with a length similar to the OZD, 22% may already be an overly conservative v for assessing rupture length. (Slemmons, Staff Exhibit #1-DBS, Table E-14; Tr. 6267, Tr. 6285)

184. The concept of an inter-relationship existing between maximum magnitude, slip rate and recurrence interval, discussed by Dr. Slemmons in "State of the Art for Assessing Earthquake Hazards in the United States," (1977) and in the SER, Section 2.5.2.3.2, is essentially the same as that put forth by Intervenors in Exhibit 12. (Anderson, Tr. 4913). The analysis presented by Intervenors' Exhibit 12 is a simplified one, and would suggest, given a long-enough recurrence interval, that any arbitrarily-large earthquake can occur on any fault. However magnitude 9+ earthquakes on the San Andreas fault, or large earthquakes on short faults, are physically impossible. The geologic and geophysical realities surrounding a fault limit the maximum magnitude, independent of arguments based on recurrence intervals.

(Anderson, Tr. 4915-4918). Applicants' Exhibit #34,EGH-10 contains approximately 180 strike slip faults evaluated against the slip-rate magnitude methodology. This is the type of study that Anderson considered necessary in order to verify the methodology. (Anderson, Tr. 4922)

185. On Slemmons' empirical plot, estimates of maximum magnitude ranging from M 6.6 to M 6.9 result if full rupture length of each segment of the OZD is assumed. However, caution and proper judgment must be applied when using such a technique because the style of faulting must be defined. Curve E of Dr. Slemmons (1977) was developed using strike-slip faults from all over the world, some of which are similar and some are different from the OZD. Rather than just accepting a mixed data base and applying it on a statistical basis alone, it is better to determine which faults are similar and appropriate to use. Conservatism in estimating maximum magnitude earthquake from empirical curves derives from the fault length or the surface rupture length that is assumed, rather than from the use of the curve itself. (Heath, written testimony, pp. 20-21; Tr. 1308, 1310-1313)

186. Good evidence of the amount of surface displacement that has occurred from single major earthquakes is absent along the OZD. (Heath, written testimony, p. 22; Tr. 1336). Applying Slemmons' (1977) empirical relationship between surface displacements and earthquakes of various

magnitudes, an earthquake of magnitude 6-1/2 could produce up to 1 meter of lateral surface rupture; and a magnitude 7 earthquake could produce up to 1.7 meters of displacement. While such displacements appear feasible for the OZD because of the zone's dimensions, evidence of those displacements should be readily visible in the geologic record, which they are not. A hypothetical earthquake of magnitude 7-1/2 on the OZD could produce up to 3.2 meters of surface displacement in a single event, but surface displacements of this amount are not supported by geologic evidence and are certainly not characteristic of even the NIZD. (Heath, written testimony, pp. 22-23; Exhibit #3,EGH-1).

187. Dr. Brune, who has not studied the geology of the OZD to determine the probability of rupture extending over its entire length, asserts that the time frame for assessing probability of 100% fault rupture is the last 100 million years. (Brune, Tr. 4248-4249). Reasonable periods of time for viewing earthquake phenomena in the context of critical facilities is judged by Dr. Smith to be about 10,000-20,000 years. (S. Smith, Tr. 1525) Furthermore, it should be noted that cascading conservatisms at each step in the evaluation of maximum earthquake rapidly results in absurd predictions. (S. Smith, Tr. 1561)

188. An additional evaluation of the value for the maximum magnitude earthquake for the OZD can be obtained through a comparison of the total zone length with other

faults throughout the world. For faults with a length of more than 1000 km, it is possible to have earthquakes of M_s 8 or greater. For fault lengths in the range 400-600 km the observed maximum magnitudes are 7 to 7.5. Finally, for faults with lengths comparable to the OZD, the maximum magnitudes are around M_s 7 or below. (Slemmons, written testimony, Staff Exhibit #1-DBS, Table E-14; Tr. 6267). The branching nature of the OZD and the lack of evidence for continuous recent displacements at the surface are not characteristic of strike-slip faults that have generated ly large earthquakes. (Allen, Tr. 4730)

189. The phrase "commensurate with the length of the zone" applied to the OZD (SER, Section 2.5.1.2, 3rd paragraph) means to consider the whole zone of deformation rather than any particular part. No implication was intended as to the entire zone rupturing at once. (Devine, Tr. 5333). The maximum magnitude earthquake on the OZD was evaluated by considering its entire length from the Santa Monica Mountains to where it goes offshore in the San Diego Bay area. The OZD is not a throughgoing fault, but a zone of discontinuous faults and folds. (Heath, Tr. 1301, 1307)

190. Investigations of the OZD by others have yielded earthquake estimates as high as magnitude 7.5, but they generally have not been for design purposes. There is a big difference between making an estimate for general purposes on the one hand and actually coming up with a design

value for a particular site and a specific facility on the other. (Heath, Tr. 1324-1325). For design of a structure at a particular location, one looks at the site conditions and in great detail at hazards affecting that site. (Heath, Tr. 1325)

191. Studies that are done to arrive at a first approximation of magnitude commonly just measure a fault, divide it by two and then establish the corresponding magnitude from Slemmons' curve, but this is not appropriate for design purposes. (Heath, Tr. 1325)

192. In the case of the Bolsa Island nuclear project, the objective was to arrive at an appropriate ground acceleration, which was established at 0.5g, and magnitude was not the important parameter at that time. From the standpoint of magnitude, the estimate is too conservative because the investigation was made 14 or 15 years ago before much was known about the OZD, which is not the case at this time. (Heath, Tr. 1324-1325, 1327-1329; J. Smith, written testimony, p. 17)

2. <u>Slip-Rate/Magnitude Method</u>

193. The slip-rate/magnitude relationship compares favorably with the half-rupture-length method of Dr. Slemmons using a cross plot of fault-rupture-length and slip-rate. (Heath, written testimony, pp. 20-22; Tr. 1301, 1307, 1308, 1311, 1316-17, 1335, 1388, 1389, 1391, 1398, 1399, 1473-80)

194. The slip-rate/magnitude method was originally presented in December of 1978, and has since been reviewed by consultants for the Applicant, by the NRC staff, by the U. S. Geological Survey, by the California Division of Mines and Geology, and by Dr. Slemmons. (Heath, written testimony, p. 24; Tr. 1276-77, 1410-1412, 1414, 1433-1434, 4044; Exhibit #9,EGH-7; Staff Exhibit #1-DBS)

a. Criteria for selecting data base

195. The long term geologic slip rates of strike-slip faults in southern California, and in other places around the world where tectonic settings are similar, were compiled from the available data in the literature. To establish geologic slip-rate one must have stratigraphic control that is age-dateable, and also a measurement of horizontal or lateral separation of control units across the fault. (Heath, written testimony, p. 23; Figure EGH-I; Exhibit #9,EGH-7)

196. Applicants have attempted to determine a slip-rate on the San Miguel and Vallecitos faults in Baja California, but the data on total slip and the period of time over which it occurred is inadequate to develop a meaningful slip-rate. (Heath, Tr. 1486-1487, 1490-1491) To be included in the Applicants' slip-rate/magnitude data base, it was required that a fault be identified with the amount of displacement, the timing of displacement or a report of slip-rate vs. earthquake magnitude for the fault. The data

base for the slip-rate/magnitude method did not include faults and earthquakes from Baja California because reliable data are absent there. (Heath, written testimony, Tr. 1486-1490)

197. The Applicants' slip-rate/magnitude methodology involved analyzing northwest-trending strike-slip faults from similar tectonic environments worldwide. From displacement estimates of geologic units of various ages, slip-rates were calculated and compared with slip-rates calculated by other investigators. The best estimate of geologic slip-rate was selected and compared with the largest earthquakes known to have occurred on the respective faults. (Heath, Tr. 1436-1437; Figure EGH-J)

198. Seismic reflection profiles offshore of San Onofre provide general information on the stratigraphy and the age of the units, but not good evidence of the actual amount of displacement across the fault. For this reason, a definitive slip-rate for the SCOZD has not been determined. Total displacement along the SCOZD would be less than that for the NIZD because of the lower degree of deformation offshore. (Heath, Tr. 1379 - 1380)

199. Applicants identified approximately 230 low slip-rate, strike-slip faults that were at least 10 kilometers long in the Coast Ranges, Peninsular Ranges, Mohave Desert and Transverse Ranges of California to determine how many low slip-rate faults that might be added

to the slip-rate/magnitude curve. Approximately 180 of those faults do not have direct slip-rate estimates. None of these faults have had significant earthquakes, although it is possible that they may have been associated with events of magnitude 4 or less. Additional research is not likely to identify new faults having slip-rates above about 5 millimeters per year because faults with that slip-rate are very easy to recognize by geologic mapping and should have been identified by now. (Heath, Tr. 1441-1443, 1449-1450, 4037-4038, 4050; Exhibit #34,ECH-10)

200. The absence of data points on the slip-rate magnitude plot for low slip-rate faults is significant in part because it means that such faults have not had earthquakes large enough to be recognized or that would exceed the bounding limit. If there was an equal likelihood of large earthquakes on low and high slip-rate faults, then because there are many more low slip-rate faults one would expect to experience more large earthquakes in the lower slip-rate area. But this is clearly not the case. (Heath, Tr. 1442, 1448)

201. The absence of data below 1.0mm/yr is also significant because we know that there are an additional 180 faults that were tabulated but not included in the analysis because of the lack of specific data on slip-rates and associated earthquakes. (Heath, Tr. 1443, 1450, 1620)

202. There are a large number of faults in California, the majority of which are presumed to be strike-slip, that have not experienced significant earthquakes in historic time. Thus, there really is a large data base, at least in California, of faults in the low-slip range. If any of these have had major earthquakes, there would be evidence of them in the last 100 to 200 years. The absence of large earthquakes on these faults suggests that they are not capable of producing larger events. (Heath, Tr. 1441-1442, 1450, 4049)

203. Applicants' slip-rate/magnitude analysis included all low slip-rate faults where the slip-rate could be determined and where a magnitude 5 or larger earthquake occurred on or near them. The Mammoth Lake earthquakes were not included in the slip-rate/magnitude analysis because they were not associated with a strike-slip fault. Examination of low slip-rate faults where slip-rates were unknown in some cases included analysis of aerial photographs to measure offset of geomorphic features. Combining estimates of the age of the features with measurements of apparent offset, estimates were made of slip-rates in various ranges. (Heath, Tr. 1622, 4052-4054, 4060-4061)

b. Rose Canyon fault slip-rate data excluded

204. Applicants have also identified a number of faults that have some characteristics suggesting low to very low slip-rates but for which specific offsets over a specific

time are unknown. (Heath, Tr. 1615-1616). For example, the RCFZ and the geology of the surrounding region were studied in detail. These studies included a review of all current literature dealing with estimations of slip rate. Slip-rate on the RCFZ proposed by Dr. Kennedy are questionable because he used the term "near shore facies of the San Diego formation" incorrectly, when he should have referred to a most-landward extent of the San Diego formation as a "pinchout". (Ehlig, Tr. 6355-6356)

205. The San Diego formation was deposited about 2 to 3 million years ago in a marine environment. As the sea regressed, the Linda Vista formation was deposited on top of the San Diego formation. Consequently, the pinchout line of the San Diego formation occurs at the most-landward extent of the marine deposits where they are capped in sandwich fashion by the younger Linda Vista formation. This pinchout line does not describe the orientation of a former shoreline nor a structural feature and, therefore, it does not provide a sound basis for estimating displacement across the Rose Canyon fault. (Ehlig, Tr. 6356-6360). An old beach ridge developed on top of the Linda Vista formation during a higher stand of sea level extends across the Rose Canyon fault in the vicinity of Ardath Road and is not offset. (Ehlig, Tr. 6360-6361). The sequence of Eocene rocks on either side of the Rose Canyon fault also indicates no real evidence for major strike-slip displacement. Thus, the displacement of 4

kilometers across the Rose Canyon fault proposed by Dr. Kennedy is incorrect, and consequently any slip-rate derived from it is unreliable and too high. (Ehlig, Tr. 6362)

206. Other evidence of large young displacement on the Rose Canyon fault suggested by Dr. Kennedy, i.e., that the shoreline at La Jolla Cove is offset one kilometer, is incorrect. The proposed offset assumes that the coastline was originally straight and has been subsequently offset solely by lateral displacement on the Rose Canyon fault. However, the evidence that Mount Soledad has been rising as a domal structure during Plio-Pleistocene time suggests that the coastline has probably not been straight. Beach ridges on the Linda Vista formation also indicate that La Jolla Cove had an irregular coastline during the last one million years. Also, the blocking of longshore currents and their transported sand caused accumulation in La Jolla Cove and then erosion out to sea via the La Jolla Submarine Canyon, which was a consequence of the domal uplift of Mount Soledad. Erosion in the La Jolla Cove area would be more readily accomplished east of the fault in the younger and softer Eocene rocks than in the older, harder Cretaceous rocks on the west. Indeed, the juxtaposition of older rocks west of the Rose Canyon fault with younger ones to the east indicates that the area to the west has been uplifted, which would cause the shoreline west of the fault to migrate seaward in response to uplift. Consequently, the coastline

juts out at La Jolla Cove primarily because of differential erosion acting on rocks uplifted west of the Rose Canyon fault. (Ehlig, Tr. 6363-6365)

207. Kennedy also suggests that the 200-meter bathymetric contour offshore of Mount Soledad diverges landward at the projection of the Rose Canyon fault because of fault displacement. However, this is more apparent than real because the shelf is wider off Mount Soledad as a result of older and harder formations existing there than east of the Rose Canyon fault. Examination of other contours, such as the 500-meter contour, indicate they are not similarly divergent across the Rose Canyon fault. Consequently, there is no valid basis for using this bathymetric divergence as a measure of fault offset as proposed by Kennedy. (Ehlig, Tr. 6366-6368)

c. Exclusion of Japanese and dip-slip fault data

208. Fundamental differences in fault behavior appear to exist between different styles of faulting and different tectonic environments. Slip-rate magnitude data for Japanese earthquakes were not plotted because they occurred in a tectonic environment much different than the model used for San Onofre (Heath, Tr. 4044; Reiter, Tr. 5814-5820).

209. Dr. Brune correctly assumed and Dr. Allen confirmed that there are at least two physical reasons that

justify disregarding data from Japan. These include the general tectonic setting, i.e., Japan is characterized as a subduction zone, whereas California is characterized by strike-slip transcurrent faulting. Secondly, Japanese faults are characterized as checkerboard (or block) faulting and California is characterized by branch faulting. (Brune, Tr. 4568; Allen, Tr. 4884-4885)

210. Applicants extensively reviewed data on slip-rate/magnitude relationships in Japan, but excluded them because it was difficult to substantiate the correctness of the slip-rates reported. Also, the faults there involve block faulting related to a deep subduction zone as opposed to the translational plate-edge that exists in southern California. (Heath, Tr. 1407; Slemmons, Staff Exhibit 1-DBS, p. E-4)

211. In evaluating slip-rate versus magnitude relationships, Applicants excluded data for dip-slip faults (normal and reverse) because they represent a different style of faulting than that being considered for the SONGS site. It appears that dip-slip faults behave in a different manner than strike-slip faults associated with plate boundaries. Professional judgment to exclude dip-slip faults is based on a synthesis of all information available concerning the behavior of other faults throughout the world and the occurrence of other earthquakes. (S. Smith, Tr. 1558). Therefore, in estimating the magnitude of potential

earthquakes, care must be taken that the same types of faults within a similar tectonic environment are being compared in order to establish meaningful relationships. Accordingly, the data from Japan and from dip-slip faults were not included in the slip-rate/magnitude method by the Applicants. (Heath, Tr. 1406-1407)

d. Slip-rate magnitude relationships

212. Plotting the geologic slip rate for faults against the magnitudes of the corresponding largest historical earthquakes indicates a trend of increasing maximum earthquakes with increasing geologic slip-rates. (Heath, written testimony, pp. 24-25; Tr. 1438; Exhibit #9,EGH-7)

213. The line bounding the empirical observations of slip-rate versus magnitude suggests that there is a consistent limit to the size of an earthquake associated with the geologic slip-rate of these strike-slip faults. The line that envelopes the largest earthquakes, with the assumption that they are maximum or close to maximum events on some of the strike-slip faults in the world, forms a maximum Historic Earthquake Limit (HEL) related to slip-rate. (Heath, written testimony, p. 25)

214. The bounding line of Figures EGH-K and EGH-M was drawn to envelope all the data; the data base includes all faults with sufficient slip-rate data and large magnitude earthquakes and, thus, includes some faults that have

probably had their maximum or close to maximum earthquakes. No fault in this category has been encountered that would exceed the bounding lines. (Heath, Tr. 1439, 1440)

215. The position of the bounding lines on Figures EGH-K and EGH-M are well controlled by the data points for the higher slip-rate faults. It is significant that the lower slip-rate faults have not produced data points lying to the right of the bounding line when the line is projected downward from the higher slip-rate points. Even though the return periods for large earthquakes on these faults might be long, there is a large number of such faults and, certainly, when considering all of these faults, in the last 200 years significant earthquakes should have occurred on them if that were their characteristic. The bounding line on Figure EGH-K is simply a maximum line of historic observations that indicates this limit has not been exceeded. It doesn't predict that every fault has the capability of reaching that maximum limit. (Heath, Tr. 1443-1444)

216. A major difference between the line of Figure EGH-K and the curves drawn by Dr. Slemmons is that Dr. Slemmons' line represents mean values, so that half of the data falls to the right of the line. The line on Figure EGH-K is a limit line and, therefore, half of the data would not fall to the right of the line. (Heath, Tr. 1447, 1455-56; Exhibit #9,EGH-7)

217. For conservatism, and to account for possible uncertainties in earthquake magnitude values, the Applicants assigned a magnitude range of two-tenths of a unit for each earthquake used in their slip rate versus magnitude relationships. (Heath, written testimony, p. 26; Exhibit #9,EGH-7)

218. To account for variation in slip rate, ranges of slip rate data were used for conservatism. Combining the ranges of slip rates with the magnitude ranges to establish a Maximum Earthquake Limit line (MEL), the MEL was drawn to envelope the lowest slip rate ranges and the maximum magnitude ranges of all the data points. The MEL line represents an outer bound for maximum magnitude that should not be exceeded by future earthquakes on these faults. (Heath, written testimony, pp. 26-27; Exhibit #9,EGH-7; SER, Section 2.5.1.10). Figure EGH-L represents all possibilities of variations in the slip-rate estimates and maximum magnitude estimates for the data points. (SER, Section 2.5.1.10)

e. Slip-rate/magnitude results for SONGS

219. Using the slip-rate/magnitude method and applying the most conservative interpretation of the MEL line, the maximum magnitude for the NIZD associated with the highest slip rate of .68 mm per year results in M_S7.0. Comparing such estimates with the results of the half-fault length rupture for numerous other faults shows results that

are consistent with those predicted from the Historic Earthquake Limit and the Maximum Earthquake Limit. A reasonable maximum earthquake magnitude for the OZD is M_s 6-1/2. The most conservative maximum magnitude for the OZD is M_s 7. A larger earthquake is inconsistent with the geologic and seismologic features of the OZD. (Heath, written testimony, pp. 5-6; Exhibit #3,EGH-1; SER, Section 2.5.1.10).

220. Dr. Allen, in a separate assessment, stated that a maximum magnitude for the Newport-Inglewood fault is in the magnitude range of 7 to 7.5. He made this conclusion, in part, knowing that the 240-kilometer long region of interest for San Onofre does not contain a continuous, single, well-defined fault zone (Allen, Tr. 4730, 4732). He further stated that, based on his inadequate knowlege of detailed investigation along the OZD, he could not offer more enlightened estimates for maximum magnitude along the OZD. (Allen, Tr. 4879, 4881-4882)

221. Finally, after reviewing all of the data and extrapolating the MEL about 1/2 magnitude to the right of all historical data, both the NRC Staff and Applicants are of the opinion that there is confidence in the maximum earthquake limit line as representing an outer limit of earthquake magnitude. (Heath, Tr. 1498; Figure EGH-M; SER, Section 2.5.1.10)

3. <u>Recurrence Interval</u>

222. The recurrence interval for a magnitude 7 earthquake, according to Anderson with slip-rate of 1 mm per year is 1500 years between two magnitude 7 events. (Thus assuming a slip rate of 0.5 mm per year, the recurrence interval is 3,000 years.) (Anderson, Tr. 4633). The recurrence interval for a magnitude 7 earthquake with slip-rate of 0.5 mm per year is greater than 5,000 years. (Intervenors Exhibit #12; Anderson, Tr. 4638). Anderson states that Intervenors Exhibit #12 indicates a recurrence time for earthquakes with magnitude greater than 7, if such earthquake can occur, would occur once every 10,000 years or even less frequently (Anderson, Tr. 4641). However, he stated on cross examination that a magnitude 7 earthquake on the OZD could not possibly occur more than once every 7-8,000 years. (Anderson, Tr. 4927). This is consistent with Dr. Smith's opinion that reasonable periods of time for viewing earthquake phenomena in the context of critical facilities is about 10,000 to 20,000 years. Dr. Smith's assessment of an M_S 7 earthquake on the OZD is that this event is larger than the maximum earthquake that will happen within this time frame. (S. Smith, Tr. 1525, 1532). These numbers are in stark contrast with those of Dr. Brune, who stated that the tectonic characteristics of faults over the last 30 million years should be considered (Brune, Tr. 4210).

F. <u>Conclusions of Maximum Magnitude Evaluations</u>

223. An appropriate representation of the maximum earthquake on the OZD to be used in determining the DBE at San Onofre is M_s =7. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A5) This conclusion rests upon the combined result of the following approaches

1) the evaluation of the historic seismicity:

   (a) largest earthquake in southern coastal California: M_s =6.3, (1933) possible M_s =6.5 (1800, 1812);

   (b) largest earthquake on postulated extension of the OZD into Baja California: M_s =6.8 (1956); (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A5)

2) evaluation of fault parameters (in order of relative importance):

   (a) slip rate: utilizing an estimator which conservatively incorporates uncertainties in both magnitude and slip rate results in a maximum earthquake estimate of M_s =7;

   (b) Fault length: utilizing the range of inferred fault-rupture length results in a maximum earthquake estimate ranging from M_s 6.6 to M_s 7.2; and

(c) Fault area: utilizing the range of inferred fault-rupture length with a fault width of 15 km results in a maximum earthquake estimate ranging from M_S 6.8 to M_S 7.2 (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A5)

224. The maximum magnitude of M_S=7 on the OZD is based upon a reasonable and conservative presentation of all available geologic and seismologic information outlined above. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A5)

225. Four distinct lines of inter-related evidence all lead to the same conclusion regarding the maximum magnitude earthquake on the OZD: (1) the instrumental record of the last half-century, (2) the historic record of several centuries, (3) the geomorphic record of several hundred thousand years and the geologic record of several centures, and (4) the geologic record of several million years. (S. Smith, Tr. 1542)

226. Based on evaluation of the geologic record, and particularly the very important Quaternary record (Allen, Tr. 4868-4869), the nature of the OZD, its features, geologic strain rate, slip-rate, and tectonic setting, a maximum magnitude earthquake of M_S 7 is the largest that might occur along the OZD. A more probable maximum value would be

magnitude 6.5. The time frame for these estimates involves the present stress field and the next 10,000 years, during which time the stress field cannot be perceived to change. (Ehlig, Tr. 993-994, 1042-1043)

227. An estimate of M_S7.5 earthquake on the OZD would be unreasonable and inconsistent with the geologic and seismologic features of the OZD. (Heath, written testimony, pp. 27-28; Tr. 1268, 1284, 1469, 1477-78, 1498; Exhibit #9,EGH-7). It is extremely unlikely for a rupture to proceed along the three segments composing the OZD. There is good geologic evidence that there has not been a throughgoing rupture over the last 4 to 5 million years, thus making it extremely unlikely that it could happen in the near future. (Heath, Tr. 1299)

IX. EMPIRICAL EVALUATION OF STRONG GROUND MOTION

A. Regression for Peak Ground Acceleration (PGA)

228. Applicant's witness, Mr. L. Wight, demonstrated that given the occurrence of a M_S 7 event on the OZD, 0.67g as the anchor for the design response spectrum is conservative. The results of this extensive study of available relevant earthquake acceleration data, and of the effect of structural filtering on soil structure interaction, are contained in Exhibits #11,LHW-1 and #12,LHW-2. (Wight, written testimony, pp. 4-6)

229. The data set for the SONGS studies is well suited for predicting ground motion at the SONGS site because

the 192 peak ground acceleration (PGA) recordings from 22 earthquakes were based on a selection criterion that statistically tested and eliminated data irrelevant to SONGS. Specifically, the data set was limited to recordings within 50 km of the causative fault, at stations where ground motion was statistically consistent with the geology at SONGS, and from instruments located either in the free field or at ground level or in the basement of small buildings. The selected data set was screened to use records whose quality was certain and whose distance to the rupture surface could be adequately defined. (Wight, written testimony, p. 6)

230. The accelerations predicted from the statistical analysis of the data base correspond to a median prediction of .33g and an 84th percentile prediction of 0.52g, which leads to the conclusion that in the event of an M_S 7 earthquake occurring 8 km from the site, the design peak ground acceleration of .67g is conservative. (Wight, written testimony, p. 7; Exhibit #11, LHW-1)

231. One reason the data set can be used confidently to predict near-source ground motion is the fact that the data base has an average distance of about 11 km, which is comparable to the 8 km distance for SONGS. (Wight, written testimony, p. 7). Also, when the effect of fault type is incorporated in the regression analysis, there is a systematic upward bias in the ground motion associated with reverse (thrust) faults. Reverse-fault ground motion is

approximately 23% higher than the corresponding ground motion for strike-slip faults. The ground motion predictions for SONGS include reverse-fault ground-motion data. (Wight, written testimony, p. 11)

232. Sensitivity studies subsequent to the date of Exhibit #11,LHW-1 resulted in the following additional improvements; (1) magnitude scale was improved by using M_S for magnitudes greater than 6 and M_L for magnitudes less than 6. The results are insensitive to the division point between M_S and M_L; (2) the data base for LHW-1 was frozen in January 1980 but increased in August 1980 by adding 37 acceleration components from five earthquakes. The improved data base consists of 229 acceleration components reported from 27 separate earthquakes; (3) refinements were made to certain magnitude and distance values based on further investigation; and (4) the physically derived constraints used in the regression analysis of Exhibit #11,LHW-1 were removed, and the sensitivity of the results were tested by repeating the calculations. The results of these subsequent investigations have thus increased the level of confidence in the earlier predictions. (Wight, written testimony, pp. 10-11). The TERA study represents the best and the most relevant analysis of peak ground acceleration data for large earthquakes at close distances that has yet to be done. (S. Smith, Tr. 3275; Campbell, Tr. 6770)

B. Regression for PGA and Response Spectra

233. The approach to estimating the characteristics of ground motion at SONGS resulting from an M_S 7 earthquake on the OZD involves: (1) developing a site-specific, empirical, attenuation relationship for a magnitude M_S 6.5 earthquake, (2) providing estimates of mean and 84th percentile instrumental acceleration and response spectra at SONGS, (3) scaling the instrumental peak acceleration and response spectra to a M_S 7 and comparing the resulting 84th percentile response spectrum with the SONGS 2 & 3 DBE spectrum, and (4) verifying results with ground motion data recorded in the 1979 Imperial Valley earthquake (IV-79). (Idriss, written testimony, pp. 7-8)

234. M_S 6.5 is a reasonable maximum magnitude earthquake consistent with the geologic and seismologic features of the NIZD. The NIZD was conservatively taken as representative of the seismic potential of the OZD for purposes of evaluating the DBE for SONGS 2 & 3. For additional conservatism, the results of the initial analysis were scaled to M_S 7. (Idriss, written testimony, p. 8; Heath, written testimony, pp. 16-17)

235. The development of a site-specific empirical attenuation relationship was developed from 56 accelerograms obtained during seven earthquakes in the M_L range 6.3 to 6.5 and M_S range 6.3 to 6.7. Visual examination of the data indicates flattening of the attenuation curve at close

distances (saturation). (Idriss, written testimony, pp. 8-11; Exhibits #13,IMI-1, #14,IMI-2, #15,IMI-3, #16,IMI-4, and #17,IMI-5)

236. Accelerograms recorded during the Imperial Valley earthquake of 1979 provided significant data at near-source distances. Examination of the IV-79 earthquake data confirmed the conclusions with regard to the selected form of the attenuation relationship and quantification of parameter C (C=20 for M_S 6.5) which describes the near-field shape of the attenuation curve (Idriss, written testimony, p.14; Exhibit #19,IMI-7; SER, Section 2.5.2.4.1). The normal regression curves for PGA have a distance saturation effect in the near field. (Brune Tr. 4447) (See also Applicants' Findings of Fact, Contention 1, Section III.C)

237. From the site-specific attenuation relationship developed from the regression analysis, the mean and 84th percentile peak accelerations and response spectra at SONGS, resulting from an M_S 6.5 earthquake on the OZD, were .42g and .57g, respectively. The DBE spectrum exceeds the instrumental spectrum at all periods. (Idriss, written testimony, pp. 11-12; Figure 10 of Exhibit #13,IMI-1)

238. Applying a scaling factor to increase the PGA values for M 6.5 to those for M_S 7, the 84th percentile instrumental peak acceleration for M_S 7 is estimated to be .63g compared to .57g for an M 6.5 (Idriss, written testimony, p. 13; Figure IMI-A). The DBE spectrum is

conservative because it exceeds the 84th percentile instrumental spectra for both M_S6.5 and M_S 7 at all periods. (Idriss, written testimony, p. 13; Figure IMI-B; McNeill, written testimony, p. 24)

C. USGS Open-File Report 81-365

239. The following points have been identified as significant criteria for evaluating or comparing regression analysis studies: (1) the data base should include information from earthquakes in the distance and magnitude range of interest; (2) the functional form assumed for the regression should not be biased or constrained; (3) all other things being equal, the regression with the lowest standard error is preferable. (Brune, Tr. 4461-4465). In the regression analyses for SONGS, values of PGA below 2% g are irrelevant. (S. Smith, Tr. 3263)

240. The revised version of Open-File Report 81-365 submitted to the Bulletin of the Seismological Society of America (BSSA) predicts a mean value of PGA for M_S 7 that is 2% lower than the original 81-365. Otherwise, this paper has not been altered from the Open-File Report to any significant extent (Boore, Tr. 4754).

241. Statistical analysis presented in the publication USGS Open-File Report 81-365 has no impact on SONGS 2 & 3 DBE assessment because: (1) TERA analysis used the same available data and showed that values were less than the DBE; (2) TERA-USGS differences arise partly due to

limited near field data where results are strongly influenced by model assumptions, and partly due to the weighting procedures; (3) the USGS assumed that all earthquakes, irrespective of magnitude, have attenuation curves of the same shape, but TERA showed the curves are significantly different for different magnitudes; (4) the USGS weighting system results in data from larger distances dominating the prediction of peak motion at closer distances; (5) the TERA approach fits the data better because it recognizes differences in attenuation curves with magnitude, and it emphasizes close-in data; (6) The use of low accelerations and large distances by the USGS increases scatter and standard deviation without adding useful information; and (7) it is important to insure that no single earthquake dominates the prediction, but it is equally important to make sure that the numerous data available at large distances do not dominate the few but very important data that are available for distances less than 10 km. The USGS procedure fails to provide this important feature. (S. Smith, written testimony, contention 1, pp. 4-6)

242. For statistical analyses, the model should be selected that reflects the known physics of the process and whose results are chiefly controlled by the data rather than assumptions in the model. The model of USGS Open-File Report 81-365 is not appropriate for near-field accelerations of a large earthquake, although it may be satisfactory at

distances greater than 40 km where a point-source model is used. Closer in, however, the dimension of faulting begins to influence the distribution of peak ground motion within the geometric near field of the rupturing fault, which is not suitably represented by a point source. More appropriate models recognize the role played by an extended ruptured surface. In essence, such models share two properties: (1) attenuation of peak ground motion with distance is a function of magnitude, so there is a shape-dependence on source size; and (2) the peak-motion values at different magnitudes approach one another in the near field so that there is a near-field magnitude-saturation effect. (S. Smith, written testimony, Contention 1, pp. 7-8) The decision by Boore and Joyner to exclude magnitude saturation from their analysis is a philosophical point. This constraint simply minimizes the number of parameters that they must deal with in their analysis. Boore expects that as more data become available, PGA will be shown to saturate with magnitude. (Boore, Tr. 6589-6591)

243. The model must be tested with the raw data. The first such test of the USGS Open-File Report 81-365 show that the model fails to predict the data at close distances for magnitudes near 6.5. (S. Smith, Tr. 3271) These inconsistencies prevent application of the results to this proceeding. These inconsistencies include an 84th percentile that essentially envelopes all of the data for magnitudes

near 6.5. With a magnitude 5, the median of the computed attenuation relationship falls below all the data. Hence, extrapolations to larger magnitudes probably overestimate PGA. Therefore, in the near field the predicted PGA values from this report are not useful. (Idriss, Tr. 1738; McNeill, Tr. 4023)

244. The calculated acclerations and velocities used in USGS Open-File Report 81-365 appear to be inappropriate for SONGS based on engineering experience and on the site-specific studies which have been done for SONGS. (McNeill, written testimony, p. 25) The Boore and Joyner BSSA paper is certainly not definitive. The study lacks data close to large earthquakes, and represents their latest iteration. (Boore Tr. 6571)

245. From Boore and Joyner, Equation 1, for a magnitude 7 earthquake at a distance of 8 km the mean PGA is 0.41g and the mean plus one sigma (84th percentile) is 0.73g. These values have been reduced by a factor of 1.13 to be compatible with other studies. (Boore, Tr. 6559). For a magnitude 7.5 earthquake at a distance of 8 km, Boore and Joyner predict a mean and 84th percentile of 0.54 and 0.98g, respectively. (Boore, Tr. 6613). This is less than the instrumental DBE value of 1 to 1.3g. (McNeill, written testimony, p. 25). When Boore and Joyner exclude from their analysis data beyond 50 km (as recommended by S. Smith, Tr.

3263), the mean and 84th percentile values for PGA are 0.31 and 0.57g, respectively. (Boore, Tr. 6609)

246. USGS Open-File Report 365 by Boore and Joyner cannot address the question of magnitude saturation because the functional form adopted by the authors precludes the possibility. (S. Smith, Tr. 3243) In their study the coefficient H2 of Equation 5 controls the magnitude dependence of the attenuation curve for peak ground acceleration. If H2 is greater than zero then peak acceleration is dependent on magnitude and indicates saturation of PGA. (Campbell, Tr. 6755) Simple visual inspection of the data to determine the significance of H2 is very subjective. (Campbell, Tr. 6757) A visual examination of the data shows a tendency for magnitude saturation. Without a direct statistical test, this visual impression cannot be quantified. (Campbell, Tr. 6774)

247. Testing the significance of the parameter H2 by examining the residual error is not a very sensitive test. It is influenced by data in the distance range where the difference between the magnitude-independent and magnitude-dependent effects are not strong. (Boore, Tr. 6597) The reduction of the standard error by inclusion of the parameter H2 is insignificant. This is because the standard error is being controlled by data beyond 20 km. Hence it is not expected that the variance would be

significantly altered or reduced by including H2. (Campbell, Tr. 6776)

248. The significance of the parameter H2 cannot be evaluated by simply examining the behavior of standard error. (Campbell, Tr. 6758) Analysis of a statistical significance of H2 requires a nonlinear analysis technique. (Campbell, Tr. 6757) The nonlinear Monte Carlo procedure described by Gallant (1975) provides a rigorous methodology for evaluating the significance of H2. (Campbell, Tr. 6757). The Monte Carlo analysis revealed that the parameter H2 was significant, i.e., non-zero, at the 95% confidence level. (Campbell, Tr. 6759)

249. Because parameter H2 has been shown to be statistically significant, Equation 5 of Intervenors, Exhibit 28 (Boore and Joyner) should be used in the determination of PGA. (Campbell, Tr. 6759) Equation 5 from Boore and Joyner, which allows a magnitude dependent shape for PGA, predicts a mean and 84th percentile values of 0.33 and 0.60g, respectively. (Boore, Tr. 6607)

250. The predicted value of PGA for large earthquakes within 10 km of the source are more appropriately characterized in the TERA study described by Wight, S. Smith and Campbell than in the Boore and Joyner study. (S. Smith, Tr. 3275; Campbell, Tr. 6770) In conclusion, the USGS Open-File Report 81-365, because of its data set, its assumed model and weighting procedure, is not appropriate for a M_S 7

at 8 km for SONGS. (S. Smith, written testimony, Contention 1, p.9)

X. EARTHQUAKE MODELING

A. Method

251. The great potential of the theoretical models for predicting strong ground motions is that extrapolations to geometric circumstances or site conditions for which little data exist can be made. (Frazier, Tr. 3327-3328, 3538; Brune, written testimony, pp.38, 43). The earthquake model should be viewed as a highly sophisticated method for extrapolating site-specific ground motions from recorded past earthquakes. Because of the degree of sophistication that includes rupture physics and wave mechanics, fewer data are needed to make reliable extrapolations than from conventional methods. (Frazier, Tr. 3327-3328, 3538; Exhibit #22,GAF-2, pp. 1-1, 1-2). The modeling studies performed for SONGS complement empirical studies performed by Mr. Wight and Dr. Idriss (Frazier, Tr. 6395-6396)

252. The basic objective of the modeling studies has been to predict ground motions at the SONGS site that would result from a large earthquake hypothesized to occur along the OZD by modeling the physical process of previous earthquakes. (Frazier, written testimony, p. 4; Tr. 6395)

253. In the initial stage of model development, computer methods were developed for simulating earthquake rupture and wave propagation in order to synthetically

produce ground shaking over the frequency range 0-20 hertz. Next, strong motion recordings of past earthquakes were used in conjunction with earthquake physics to calibrate rupture parameters in the computer model. The calibrated model was then tested for simulating ground motions for additional earthquakes, and the resulting model was then used to predict motions at the SONGS site due to several hypothesized earthquake ruptures along the OZD. (Frazier, written testimony, p.4)

254. The parameters used in the modeling procedure allow characterization of a specific fault slippage along a specific rupture surface in a specific earth structure. This involves characterization of rupture kinematics, rupture extent and orientation relative to the site and geologic structure (Frazier, written testimony, pp. 6-7). All but one of the key parameters are set according to site-specific conditions or robust generic formulae common to all earthquakes (Frazier, Tr. 3316). That one parameter, the initial slip velocity V_o, has been calibrated from near-field recordings of earthquakes. The considerable effort that went into the assignment of values for this parameter has been described in detail (Frazier, written testimony, p. 8; Exhibit #22,GAF-2; Tr. 3328, 3350-3352). A value for V_o of 800 cm/sec (plus or minus 20 percent) was determined independently for all earthquakes modeled to date including the 1940 Imperial Valley, 1966 Parkfield, 1933 Long

Beach, 1971 San Fernando and 1979 Imperial Valley earthquakes. (Frazier, written testimony, pp. 8-9; Tr. 3357, 6419). Dr. Brune concurs that the TERA/DELTA model does, in fact, agree with the recorded events that it has been tested against. (Brune, Tr. 4404-4405)

255. In the earthquake model, the initial slip velocity characterizes the violence or intensity of the fracture process as the rock initially fails (Frazier, Tr. 3354) and therefore controls the high frequency components of strong ground motion such as peak acceleration (Brune, Tr. 4427, Frazier; Tr. 3355). A constant value of V_o from earthquake to earthquake, as obtained in the calibration studies, then leads to the conclusion that the production of high-frequency energy is invariant with earthquakes. (Frazier, written testimony, pp. 8-9; Tr. 3357, 6419;)

B. Parameters

256. The modeling studies of TERA/DELTA have undergone considerable review. (Frazier, Tr. 3361, 3421). The range of scientific phenomena plus the pioneering nature of the study have generated considerable interest and comments (Frazier, Tr. 6402). Dr. Brune provided a critical review of the modeling studies (Brune, written testimony, pp. 38-42). First, he alleges that the values for standard deviations in the TERA/DELTA model do not represent the kind of standard deviations expected from real data (Brune, written testimony, p. 40) Focusing is one of a number of

physical processes that lead to dispersion or scatter in recorded accelerations (S. Smith, Tr. 3258). Because such phenomena are being simulated in the computer model, it is not appropriate to add such scatter to modeling results. If such effects are not treated properly in the model, they should be referred to as inaccuracy, not as statistical scatter. (Frazier, Tr. 6405, 6406). Dr. Frazier notes that a more appropriate way to compare the scatter in modeling results with that for data is by comparing the range of predictions obtained for San Onofre, which varies over about a factor of two. (Frazier, Tr. 6407)

257. Second, Dr. Brune states that the attenuation parameter Q has not been adequately investigated (Brune, written testimony, p. 41). Frazier responded that uncertainties in Q do not significantly influence San Onofre predictions and therefore do not relate to the reliability of model predictions. (Frazier, Tr. 6400, 6408, 3379-3380). Dr. Luco does not contest this fact. (Luco, Tr. 5049). Furthermore, Frazier notes that both Drs. Luco and Brune refer to the modeling studies for their appraisal of this parameter (Frazier, Tr. 6400; Luco, Tr. 5046). Brune notes that he has not completed any independent studies of the parameter Q. (Brune, Tr. 4422). Improving our knowledge of Q is a scientific quest; predictions at SONGS are insignificantly influenced. (Frazier, Tr. 3372, 6399-6401, 3379)

258. Third, Brune states that it is difficult to infer what the effective value is for dynamic stress drop (Brune, written testimony, p. 41). Frazier contends that effective stress drop relates to a theoretical study with some non-physical implications (Frazier, Tr. 6410) and that dynamic stress drop is in fact more relevant to high frequency ground shaking. (Frazier, Tr. 6418, 6421). The parameter "initial slip velocity", V_o , is actually used in the modeling studies, not stress drop; and values for stress drop can only be estimated from the initial slip velocity (Frazier, Tr. 6419, 3553). Values for the initial slip velocity are established empirically using strong motion recordings from five earthquakes in southern California. (Frazier, Tr. 3356-3357, 6419). Considerable evidence attests to fact that PGA's are not directly related to conventional stress drop (see also, Applicants Findings of Fact, Contention 4, Section XII.E; Frazier, Tr. 6418, 3420, 3552-3553)

259. Fourth, Brune, referencing Luco, states that the TERA/DELTA model does not adequately predict the accelerations actually observed in the Imperial Valley 1979 earthquake at stations a few kilometers from the fault, being too low by approximately a factor of two. (Brune, written testimony, p. 42) Brune stated that he did not independently make this assessment and noted that use of the word "few" may be a mistake. (Brune, Tr. 4425) He then stated that the

results presented in Frazier's testimony are not low by a factor of two. (Brune, Tr. 4426)

260. Actual comparisons between computed accelerations and recorded accelerations for the 1979 Imperial Valley earthquake indicate good agreement for distances near 8 km, which are of primary interest for SONGS. (Frazier, written testimony, Contention 1, p. 23; Tr. 3377, 3607, 3370)

261. Regarding uncertainties in the physics of earthquakes, Frazier notes that: The relevant question is -- "has the modeling been done in a consistent manner?". Each time the model has been updated or improved, and new results calculated for San Onofre, the resulting values are all comparable. The reason the values are similar is not because all of the physics in the model is 100% correct; rather, the results are similar because the modeling matches real data at distances appropriate for San Onofre. (Frazier, Tr. 3478; 3451). Comments on the modeling studies are largely of scientific relevance and not relevant to these hearings. (Frazier, Tr. 6399, 6403, 6407, 3378, 3450, 3467, 3476-3478)

C. <u>San Onofre Predictions</u>

262. A suite of postulated earthquakes was examined in the modeling approach to isolate particular rupture configurations that produce the strongest ground shaking at San Onofre. The various conditions that were compared included different fault locations, rupture directions, fault

length, hypocentral depth, depth to the fault bottom, and depth to the fault top. (Frazier, written testimony, pp. 16-17; Exhibit #22,GAF-2, Chapter 6)

263. Site-specific calculations for SONGS and the SONGS DBE predictions based on the studies are complete and reliable because: (1) they have been validated against near-field recordings of southern California earthquakes in the same distance range as for SONGS; (2) the modeling capability provides a rational basis for extrapolating from past earthquakes to hypothesize conditions at SONGS; (3) the results provide a basis for appraising the likelihood of unusual combinations of conditions that would cause large amplitude shaking at SONGS; and (4) instrumental predictions at SONGS are compared with design spectra without accounting for the presence of the SONGS structures. (Frazier, written testimony, pp. 17-18)

264. The mathematical steps for modeling earthquakes were described for predicting ground motions at SONGS. The worst-case fracture represents an M_S 7, with rupture orientation so as to maximize ground motion at SONGS site. The results indicate that the design spectrum for SONGS 2 & 3 is conservative in that it exceeds the predicted instrumental spectrum at all periods of interest using 2% damping. Damping values of 5%, 7% and 10% also revealed a comparable degree of conservatism for the design spectrum.

(Frazier, written testimony, pp. 14-16; Figures GAF-A, GAF-B, GAF-C, GAF-D)

XI. ADDITIONAL CONSERVATISM OF THE SONGS DBE

A. Development of the DBE Spectrum

265. Applicants' witness Dr. R. McNeill's testified regarding the development of the DBE spectrum for SONGS 2 & 3 and its conservatism. (McNeill, written testimony, pp. 5-6)

266. The process of deriving site-specific spectra involves four steps. The first step involves the geologist who studies the area and identifies the various faults, their dimensions, sense of motion, and degree of activity. The second step involves both the geologist and the seismologist in assessing the characteristics of these faults to determine the maximum magnitude that might occur. The third step is by the seismologist in consultation with the earthquake engineer to take these magnitudes and derive the instrumental site-specific response. The fourth step is by the earthquake engineer who takes these instrumental site-specific motions and derives a design spectrum which he furnishes to the designer. (McNeill, Tr. 2648)

267. Ground motion spectra, both in design form and instrumental form, clearly and concisely display certain relevant information about earthquake characteristics better than the raw instrumental recording. Spectra provide information vital to the design of earthquake-resistant structures. (McNeill, written testimony, p. 9). The purpose

of Dr. McNeill's testimony on Contention 4 is to bridge the gap between the seismologist who deals with an instrumental free field response spectrum, and the designer, who needs a design spectrum. (McNeill, Tr. 2748)

268. The shape of the DBE spectrum for SONGS was derived by mathematically propagating virtually all of the strong motion recordings available in 1971-72 through the profile of the San Mateo formation at San Onofre. The resulting instrumental spectra at the site ground surface was calculated by enveloping these instrumental spectra. (McNeill, written testimony, p. 18) The instrumental spectrum shape was anchored to a zero period acceleration (ZPA) of 0.5g, which is a realistic upper limit of the maximum ground motion governing structure response at the site. (McNeill, written testimony, p. 18; Figure RLM-K)

269. In 1972 the maximum magnitude on the OZD had not been determined, but it was recognized that design for a very large nearby earthquake would be conservatively and appropriate. The following modifications were made to the 0.5g site instrumental spectrum to add extra conservatism: (1) the ZPA was increased to 0.67g and the entire instrumental spectrum was scaled up to that value; (2) the acceleration amplification ratio was increased by about 10%; and (3) the short-period turning-point was decreased from 0.05 second to 0.033 second. (McNeill, written testimony, pp. 18-19; Figure RLM-L) The design time-history involved a

record with 3/4g spikes. This level of acceleration is considered to be essentially the same as the .67g DBE value. (S. Smith, Tr. 1514)

270. The fact that the DBE spectrum was used directly for design probably represents the greatest conservatism because no allowances were made for wave passage, incoherence, mass, depth-of-embedment or other effects which cause the ground motion governing structural response to be less than those recorded by free field instruments, and no allowance was made for the extra strength provided for in the structural design. (McNeill, written testimony, p. 19; Figure RLM-L)

271. In summary, Dr. McNeill's testimony demonstrates that substantial conservatism was introduced at each stage of the development of the DBE spectrum.

B. Base Motions vs. Instrumental Free-Field Recordings

272. The factors entering into the consideration of soil-structure interaction and the manner in which structures of various size and situations respond to vibrations were described. (McNeill, written testimony, pp. 13-15; Figures RLM-H, RLM-I)

273. The conservatism of the design spectrum for SONGS 2 & 3 was quantified by comparing its instrumental form to instrumental records calculated from free field recordings of earthquakes at the ground surface. The majority of the

existing free-field instrumental data have been acquired only in the last two decades. (McNeill, written testimony, p. 20)

274. The case histories clearly demonstrate that the PGA and spectral accelerations from instrumental free-field recordings are higher, and in many cases substantially higher, than those from structures with large plan area and/or embedment. (McNeill, written testimony, pp. 21-22; Figures RLM-M, RLM-N)

275. Finite-element calculations show a substantial reduction of PGA by the presence of a building (Wight, Tr. 1662). At 90% confidence level there is a 25% reduction from free field basement recordings made in intermediate-size buildings. (Wight, Tr. 1653). On the average, the peak ground acceleration in very large buildings is approximately 30% less than the corresponding free field acceleration, and is a function of frequency with a reduction factor being roughly constant between 25 hertz and 2 hertz. (Wight, written testimony, p. 13)

276. Reduction of the free field PGA at a steel mill in Guerrero, Mexico, was 40%. (Wight, Tr. 1659). Reduction of the free field PGA at the Humbolt Bay Nuclear Power Plant during the Ferndale earthquake at a distance of approximately 25 km was 54%. (Wight, Tr. 1659; McNeill, written testimony, p. 20; Figure RLM-N)

277. The observed -20% reduction of PGA for the County Services Building, Imperial Valley, was affected by

building failure and possible anomalous free field measurements. (Wight, Tr. 1655). The building was in an active state of failure during most of the recording. This would lead McNeill, as an experienced engineer, to virtually discount that entire recording. (McNeill, Tr. 2667)

278. The County Services Building was constructed with a first floor having columns of a light, breezy nature and with shear walls located in nonsymmetric position. It is quite clear that the building had gone into not only rocking motion but also because of the nonsymmetric nature, had gone into rotation. For this reason, the record should be discounted and analysis should be based on other records which are more reliable. (McNeill, Tr. 2667-2668). However, this exceptional and unreliable recording was included in Mr. Wight's compilation of observed building reductions for completeness. (Wight, Tr. 1656)

279. The systematic low bias at high-frequencies of the free-field response spectrum recorded at the Imperial Valley County Services building, relative to other recordings, suggest something unique about the recording site. (Wight, Tr. 2720-2721). This free-field record may be anomalous because of motion-coupling between the accelerograph pier, the retaining walls of the enclosing planter and the adjacent sidewalks and parking lot. The setting is unusual for a free-field instrument and should be taken into account when trying to interpret the apparent

anomalous character of the response spectrum. (Wight, Tr. 2726)

280. The response spectra shown on Applicants' Exhibit #35, LHW-3, come from a variety of free-field instruments. (Wight, Tr. 2741). An intercomparison of the free-field response spectra records of the Imperial Valley earthquake indicate that the County Services Building free-field record was low by about a factor of two. The shape of the County Services free-field response spectrum, in comparison with other free-field recordings from this earthquake, suggests that frequency filtering affected the short period or high frequency response. (Wight, Tr. 2720)

281. In summary, the above fact support Applicants' conclusion that at the 90% confidence level, intermediate size buildings reduce the free-field recording by 25%. This conclusion is not altered by the experience with the Imperial Valley County Services Building because both the free-field and ground level recordings are contaminated to an unknown extent by building failure and unusual site conditions.

C. Evaluation of the SONGS DBE

1. Construction Practices

282. There are three elements that add conservatism to the earthquake resistance of a structure. First, the design engineer selects the next larger structural member that is commercially available instead of asking for a special size made up for a particular use. Second, strength

of concrete is based on a small fraction of the total, or final, strength of the material. Third, nonlinear strengths of the material are not considered. (McNeill, Tr. 2658)

2. Instrumental vs. Design Spectra

283. The design spectra, starting with the instrumental spectra, would in general be different for different structures at the same site. (McNeill, Tr. 1655)

284. In present-day design methodology the design spectrum should be reduced from the instrumental free field recordings (Idriss, Tr. 1757), whereas, SONGS 2 & 3 are conservatively designed directly from the instrumental spectrum, with no credit taken for the effects of size of the structure nor embedment beneath the ground surface. (McNeill, written testimony p. 15; Figure RLM-J) The 0.67g modified instrumental spectrum was used directly as the design spectrum. (McNeill, written testimony, p. 19; Figure RLM-L)

285. The instrumental form of the SONGS design spectrum is approximately a factor of 1.5 to 2.0 above the DBE. (McNeill, Tr. 2658) The instrumental form of the DBE spectrum has zero period response of 1 to 1.3g (McNeill, Tr. 2669; Figure RLM-O)

3. Annual Probability of Exceedence

286. The annual probability of exceedence of a free-field PGA of 0.67g at SONGS is less than 10^{-4}. The annual probability of exceedence of the instrumental form of

the SONGS DBE is estimated to be less than 10^{-5} and more likely 10^{-6}. (Idriss, written testimony, pp. 15-16). This risk exposure assessment is not linearly dependent upon the recurrence interval for the maximum magnitude earthquake or the slip rate on the OZD. (Idriss, Tr. 1755)

4. Exceedence of the 84th Percentile

287. There is no significance for design in a single observation that exceeds the 84th percentile. There is intrinsic scatter in the data that must be taken into account by looking at the dispersion. The 84th percentile is one sigma from the mean and does not envelop all data. (Idriss, Tr. 1747). Values of PGA will exceed the 84th percentile instrumental response spectrum. (Brune, Tr. 4230)

5. Brune's Evaluation of the DBE

288. The board should not draw any conclusions or inferences from Dr. Brune's testimony with respect to the significance of a PGA exceeding an instrumental response spectrum for SONGS. (Brune, Tr. 4224-4225). Dr. Brune limits his testimony to seismological aspects of PGA. He is not testifying to the significance of values of PGA that exceed certain values. (Brune, Tr. 4228-4229)

289. Dr. Brune's testimony should not be interpreted as saying that the acceleration anchor point of .67g and the design response spectrum for San Onofre 2 and 3 are unacceptable. (Brune, Tr. 4238). The significance of a comparison between instrumental and design response spectrum,

or the relationship between them, is beyond the area of Dr. Brune's expertise. (Brune, Tr. 4224, 4231)

XII. RELEVANT ASPECTS OF STRONG GROUND MOTION

A. Saturation of Peak Ground Acceleration

1. Overview

290. There is general agreement between all parties that saturation is a real, frequency dependent physical process effecting peak measurements in seismology (M_S, M_L, PGA). The main area of contention has been the point beyond which PGA is effectively independent of increasing magnitude. Intervenors contend that there is not enough near-field strong ground motion data to conclusively prove saturation of PGA. Applicants have provided three independent arguments -- (1) Trend of M_S, M_L, PGA; (2) Near-field data; and (3) Theory -- that each strongly suggest saturation of PGA occurs at about $M_W \backsim 6.5$.

2. Saturation of M_S, M_L, and PGA

291. A parameter moment magnitude, M_W, is a measure of a static offset of the earthquake. This parameter does not saturate. The parameter M_S measures seismic energy in the period range of about 20 seconds. This parameter saturates at about magnitude 7.5-8.0. In the 1960 Chilean earthquake saturation had a big effect on M_S. The parameter M_L measures energy in the frequency range 0.5 to 4 hertz. The parameter M_L saturates, or is bounded, at values of M_W of about 7.25. The parameter PGA is controlled by

frequencies in the range 2 to 10 hertz. Measured against M_S, there is definitely a statistical flattening of peak-ground acceleration at some high magnitude. (Brune, Tr. 4472-4482; Boore, Tr. 6585-6588)

292. The amplitude of five hertz waves (about the frequency of PGA in the near field) would be expected to saturate, becoming insensitive to differences in earthquake size for magnitude greater than about 6.5. Consequently, the ground motion criteria for SONGS is dependent on the postulated nearby earthquake, and the precise magnitude assignment for this event is not critical. (Frazier, written testimony, p. 19; Tr. 6433)

293. The following table summarizes these findings:

SATURATION OF PEAK PARAMETERS WITH M_W

Parameter	Period Range	M_W
M_S	20 sec.	7.5-8.0
M_L	2-0.25 sec.	7.25
PGA	0.5-0.1 sec.	6.5

294. Dr. Brune generally supports these data with the exception of the saturation magnitude for PGA (6.5), which was provided by Applicants' witnesses. Furthermore, he emphasized the approximate nature of these data. (Brune, Tr. 4495-4500)

3. <u>Near Field Data</u>

295. The concept of saturation of PGA is not new. It has been around ever since it was noted that small earthquakes could have large accelerations. Factors which control PGA are somewhat independent of those which control magnitude. (S. Smith, Tr. 3245)

296. Saturation is supported by the fact that with earthquakes in the magnitude range 7, there is not a significant variation in ground motion. (S. Smith, Tr. 3240) These data clearly show that above magnitude 6.5 peak ground acceleration is essentailly independent of magnitude and there is a tendency at 7 or at some point for the peak ground acceleration not to get any greater. (S. Smith, Tr. 3240, 3285). The concept of saturation of PGA above magnitude 6.5 is supported by the recent paper by Hanks and McGuire who state that peak ground acceleration above magnitude 6.5 need not increase significantly above 0.5g. (S. Smith, Tr. 3243)

297. The sensitivity of PGA on earthquake magnitude diminishes with increasing magnitude and with decreasing distance. The earthquake conditons hypothesized for SONGS are sufficiently severe as to be insensitive to small changes in the assigned magnitude. (Frazier, written testimony, p. 18) The physical processes that control peak ground acceleration are well illustrated by earthquakes in the magnitude range 6.5. Conclusions regarding saturations of

PGA and data of magnitude 6.5 to 7.5 are conclusive and do not require substantiation from larger earthquakes. (S. Smith, Tr. 3250)

298. An analogy of the saturation of PGA with magnitude can be made to the saturation of height with age. It does not require height data from a 150 year old person to conclude that height saturates with increasing age. (S. Smith, Tr. 3270)

4. <u>Theory</u>

299. Because the SONGS site is within 10 km of the OZD, its precise proximity to the zone of rupture is not significant because of saturation of peak ground accelerations in the near field with increasing magnitude of earthquake. For distances of less than 10 km, the PGA is controlled by the nearest 10-20 km zone of rupture. Therefore, additional rupture length on the OZD would be inconsequential for influencing the high frequency waves in the near field. (Frazier, written testimony, p. 20; Reiter, Tr. 5843)

300. The saturation of PGA on the fault surface is physically related to the forces required to break rock. Studies indicate that the dependence of peak acceleration on magnitude decreases with decreasing source distance, that dependence of peak acceleration on magnitude at close distances decreases as the magnitude increases, and that the dependence on magnitude to spectral ordinates at different

periods increases with increasing period. The closer an observer moves to the fault the more saturation is seen and the less proportional the increase of PGA. On the fault surface accelerations are essentially independent of magnitude. Studies indicate that the source of high frequency waves along the rupture surface is both independent of earthquake magnitude and fault offset (static stress drop). Ground accelerations increase with increasing magnitude to a point where additional extension of an earthquake rupture serves only to increase the duration of shaking. Theory and data indicate that this point of saturation occurs at about magnitudes 6.5 for high frequency ground motions within 10 km of the causative rupture. (Frazier, written testimony, p. 20-21; Idriss, written testimony, pp. 12-15; Exhibit #18,IMI-6; Wight, Tr. 1694-1695)

B. Basis for Predicting Strong-Ground Motion

(See also Applicants' Findings of Fact, Contention 1, Section III.A.)

301. The current strong-ground motion data from several well-recorded earthquakes provides a basis for examining the likelihood of an event occurring on the OZD with unusual or extreme source characteristics that would significantly bias PGA. Peak accelerations from one earthquake are about as consistent with those reported for other earthquakes, of comparable magnitude and distance, as they are self-consistent. (Frazier, Tr. 3623)

302. The statistical study done in the TERA Report (Exhibits #11,LHW-1 and #12,LHW-2) indicates that the principal scatter in PGA is not due to unusual source properties but rather from whatever causes scatter for a single earthquake. This scatter may be characterized in a rather loose sense as being station correction factors. This conclusion is significant in that it directly addresses the probability of surprises in terms of something unusual happening in the future. Such a happening is improbable. (Frazier, Tr. 3623-3625)

C. <u>Exceptional Recordings of Strong-Ground Motion</u>

(See also Applicants' Findings of Fact, Contention 1, Section III.B.)

303. Large earthquakes with exceptional near-field recordings (one component exceeds the 84th percentile predicted by the TERA PGA model) were evaluated by McNeill (written testimony, Contention 1, pp. 1-3; Table RLM-1; Tr. 4028). After scaling these values of PGA for distances and magnitude (M_S 7, distance 8 km), McNeill concluded that none of the scaled values exceed the Zero Period Acceleration (ZPA) of the SONGS 2 & 3 DBE. The average value was about 40% - 50% of the ZPA, thus demonstrating the conservatism of the SONGS DBE in comparison with significant recent earthquakes (McNeil, written testimony, Contention 1, p. 4; Table RLM-1).

D. Focusing/Directivity Effects

304. Recorded ground motions tend to be higher in the direction of spreading rupture than in other directions due to focusing of seismic waves. Earthquake focusing results from time compression of signals. Actual earthquake ruptures spread in a somewhat irregular manner, lurching and altering directions in response to stress aberrations and material asperities. The consequence is that the bias toward large amplitude motions in the path of focusing is subdued for frequencies greater than about 3 hertz with significant biases confined to peak velocity and lower frequencies. (Frazier, written testimony, pp. 10-11)

305. Recordings of the 1979 Imperial Valley earthquake provide evidence on the limited effects that rupture focusing has on increasing peak accelerations. There is apparently no significant increase in peak accelerations as a result of focusing in the IV-79 earthquake data. (Frazier, written testimony, p. 13; Brune, written testimony, p. 33) These data indicate that the effects of focusing on peak acceleration are much less important than that expected on the basis of simple, coherent fracture theory. (Frazier, written testimony, Contention 1, pp. 12-13)

306. In the paper "Peak Acceleration from Strong Motion Records", Intervenors Exhibit 17, Boore and Porcella discuss the amplitude of focusing as derived from data colle[illegible] from the Livermore earthquakes. Figure 2, from

Invervenors Exhibit 17, suggests that the variation in PGA is about an order of magnitiude (factor of 10). However, if these data indicate focusing, the variation represents the ratio of two earthquakes and not focusing from a single event. (Boore, Tr. 4750). Therefore the range for a single event should be estimated by taking the square root of 10, i.e. about 3.2. (Boore, Tr. 4751). The range from the mean to the focussed value for PGA can be estimated from the square root of the range of the focussed to the defocussed values. (S. Smith, Tr. 3257). Applying this to the factor of 3.2, the variation from the mean PGA is then a factor of 1.8 (square root of 3.2). The raw data from Livermore was examined and discussed by Frazier (Tr. 3557) who noted that the largest recorded value of PGA was less than 0.3g. In addition, in all cases the peak accelerations from one earthquake are equal to or exceed the peak accelerations for the other earthquake. The ratios of the raw values of PGA never exceed a value of about 2. (Frazier, Tr. 3557)

307. The Livermore data are consistent with observations from other earthquakes. The variation from this median value is about a factor of 1.5 (square root of 2). (S. Smith, Tr. 3255-3257)

308. The ratio of the focused to defocused values of PGA for the Coyote Lake earthquake was approximately 2. (S. Smith, Tr. 3258; Frazier, written testimony, p. 12). Focusing for the Santa Barbara earthquake is comparable with

that observed for the Coyote Lake earthquake and the Livermore earthquakes, i.e., about a factor of 2. (S. Smith, Tr. 3259) Dr. Brune would not disagree with the testimony of Dr. Stewart Smith regarding the observed effects of focusing. (Brune, Tr. 4367)

309. Focusing is just one of a number of physical processes that lead to dispersion or scatter in PGA. (S. Smith, Tr 3258)

E. Bias of PGA By High Stress Drop

310. The statement that peak-ground acceleration should, in a general way, increase with increasing stress drop is only an inference and is not founded in data. (Brune, Tr. 4358)

311. Peak acceleration is controlled by fracture mechanics of the rock and not by conventional (or static) stress drop. (Frazier, Tr. 3420, 3552-3553, 6418). It is not surprising that the initial behavior of earthquakes is common from one earthquake to the next. There is apparently some fracture property in the earth for faults that have fractured many hundreds of times in the past that is fairly common from one earthquake to the next. (Frazier, Tr. 3424)

312. Hanks and McGuire have found that high frequency stress drop is roughly constant for approximately 300 strong ground motion recordings that they examined. This is in contrast to a variability of approximately a factor of 50 for conventional stress drop for the same data set.

(Frazier, Tr. 3420) Dr. Hanks has found that the high frequency stress drop does not correlate with conventional stress drop. (Frazier, Tr. 3421)

313. Both Hanks and McGuire and Frazier conclude that conventional stress drop has little significance in the evaluation of peak-ground acceleration. This conclusion is based on the examination of accelerograms for many earthquakes. The conclusion does not agree with Brune's statement that peak-ground acceleration scales linearly with stress drop. (Brune, Tr. 4359-4364; Frazier, Tr. 6423)

314. An example of contradiction is found in the well recorded San Fernando earthquake of 1971 where a region of high localized stress drop on the fault did not control peak ground acceleration. (Brune, Tr. 4344-4345)

315. Intervenors suggest that studies of regional data, recorded at distances of several hundred kilometers, indicate that Baja California events systematically have higher stress-drop than events in the Salton Trough, such as the 1979 Imperial Valley earthquake. (Brune, written testimony, pp. 66-69) However, some of the largest stress-drops quoted by Brune come from Salton Trough earthquakes: El Centro, 350 bars; Brawley, 600 bars; Victoria, 500 bars. (Brune, written testimony, p. 30) There is uncertainty in the determination of these values for stress drop, and confidence in the accuracy of the determination is low. (Brune, Tr. 4346). An uncertainty of

a factor of 2 in the source dimensions translates into a factor of 8 uncertainty in stress drop. (Brune, Tr. 4356)

316. As further support for bias between Baja California and the Salton Trough, Intervenors suggested that the Northern Baja-El Alamo, 1956, earthquake was more energetic, for the same M , than the 1979 Imperial Valley earthquake. (Brune, written testimony, p. 70) This conclusion was based on intensity maps of the two events. However, in the comparison of the areas of intensity VI between the El Alamo earthquake and the Imperial Valley earthquakes, approximately 90% of the area for the El Alamo earthquake has simply been inferred and is not constrained by observations. (Brune, Tr. 4550-4551) All other things being equal, the presence of a deep sedimentary basin would tend to constrict the intensity contours. This adds additional uncertainty to the validity of the comparison of the El Alamo and Imperial Valley earthquake intensity maps. (Brune, Tr. 4552-4553)

317. The areal extent of the felt region is comparable for both the El Alamo and the Imperial Valley 1979 earthquakes. In view of the complications introduced by the deep sedimentary basin associated with the Imperial Valley, the felt region may be a better measure of the energy content of an earthquake for purposes of comparison. (Brune, Tr. 4553)

318. Intervenors presented no evidence regarding near-field strong-ground motion data to support the

speculation advanced by Brune that for a given M , the measured values of PGA in Northern Baja California will be systematically higher than values recorded in the Salton Trough. (Brune, Tr. 4531-4532, 4537-4540). Further, these speculations have been largely premised on the basis of inferred regional bias in static stress drop. Intervenors also have not presented data that establish a relationship between PGA and stress drop; whereas Hanks and McGuire and Frazier, working with real data, conclude that static stess drop does not correlate with PGA.

319. Applicants' conclusion, based on the foregoing facts is that conventional, or static, stress drop does not correlate with peak acceleration and has little significance in the evaluation of the conservatism of the high frequency portion of the DBE spectrum.

F. Imperial Valley Vertical Acceleration

(See also Applicants' Findings of Facts, Contention 1, Section III.C.)

320. The high vertical acceleration recorded within the Imperial Valley during the 1979 earthquake did not correlate with damage. The high-frequency vertical spikes, which did not occur at the same time as the maximum horizontal motions, seem to be of relatively little significance. (Reiter, Tr. 5881)

321. The two-thirds vertical to horizontal ratio adopted for design was based on data from many earthquakes.

On the basis of this statistical analysis it was felt by Dr. Newmark and many others that the two-thirds ratio is a conservative estimate. (Reiter, Tr. 5860)

322. As the data is increased, reliance on ratios becomes irrelevant for determining vertical acceleration for purposes of design. It is much more important to consider the absolute value of the numbers relative to the design. The absolute values for the vertical PGA are well within the value being used for design and analysis. (Idriss, Tr. 3636)

323. The 84th percentile values of vertical accelerations from the distance range of interest for IV-79 all lie below the instrumental form of SONGS DBE. (McNeill, written testimony, pp. 24-25, Figure RLM-R; Idriss, written testimony, Contention 1, p. 3)

XIII. CONCLUSION REGARDING ADEQUACY OF DBE

324. The design ground motion approved at the Construction Permit stage was defined by a response spectrum shape derived from a study of real earthquakes anchored at 0.67g for horizontal motion and 0.44g for vertical motion. The review of this response spectrum has been based on examination of empirical and theoretical estimates of ground motion along with a comparison to an unprecedented set of recently acquired near field data. Several witnesses testified regarding the conservatism of the DBE with respect to the controlling earthquake, M_S 7 at a distance of 8 km.

325. The empirical results demonstrate that, for the controlling earthquake, the predicted 84th percentile spectrum is less than the DBE at all frequencies. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A6; SER, Sections 2.5.2.4, 2.5.2.4.1)

326. The instrumental one standard deviation free field acceleration for the San Onofre site is .52 g for M_s 7 at 8 km. This should be reduced for the strike-slip environment and by consideration of structural effects. The corresponding one standard deviation design acceleration is then even less, perhaps one half of the acceleration, to which structures at the San Onofre site have been designed. (Wight, written testimony, p. 13:19-14:1). Accordingly, the seismic design criteria for SONGS 2 & 3 are extremely conservative. (Wight, written testimony, p. 14)

327. Because the DBE spectrum is a design spectrum, the equivalent instrumental spectrum would be significantly higher. Therefore, the instrumental spectrum, equivalent to the design DBE spectrum, is significantly higher than the 84th percentile instrumental spectra for M_s6.5 and M_s7 at all periods. (Idriss, written testimony, pp. 13-14; Figure IMI-B);

328. Following the guidelines of NUREG/CR-0098 and using the mean values for peak acceleration and velocity from Boore and Joyner a response spectrum for the site can be estimated. This new response spectra, consistent with

previous procedures by the NRC staff, is exceeded by the design basis earthquake response spectra. (Reiter, Tr. 5918, 5920)

329. For a M_S 7 earthquake at the distance of 8 km Brune has no conclusions regarding the mean or the 84th percentile for PGA. (Brune, Tr. 4331)

330. The conservatism associated with empirical regression analysis is supported by comparison with estimates of response spectra computed using theoretical models developed for review of San Onofre Unit 1. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A6; SER, Section 2.5.2.4.2). Dr. Frazier's earthquake modeling studies provide great confidence in the adequacy of the DBE to withstand a magnitude 7 earthquake along the OZD. (Frazier, written testimony, p. 21, Tr. 6433)

331. The conservatism associated with the empirical estimates is also supported by comparison with recent data collected from the well recorded M_S =6.9, 1979, Imperial Valley earthquake. The 84th percentile for this earthquake, recorded in the distance range of interest, is less than the empirically estimated (by Dr. Idriss) 84th percentile at all frequencies. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A6; SER, Sections 2.5.2.4.3, 2.5.2.4.4)

332. Dr. Brune noted that the horizontal accelerations recorded from the 1979 Imperial Valley

earthquake are about as high as has been recorded in other earthquakes. (Brune, Tr. 4387)

333. The design spectrum for vertical motion is considered to be appropriately conservative. The 84th percentile vertical spectrum, in the distance range of interest from the Imperial Valley earthquake, is less than the vertical design spectrum, except for some slight exceedances at periods less than 0.13 seconds. Exceedance of the vertical DBE at some stations in the Imperial Valley is not considered to be significant due to the short duration of the high acceleration and the lack of correlation between horizontal and vertical peak motions. In addition, the local site conditions which are believed to have caused anomalous high vertical ground motion in the Imperial Valley are not present at San Onofre. (Reiter, supplemental testimony, ff. Tr. 5566, Question and Answer A6; SER, Section 2.5.2.4.6). [See also, Applicants' Findings of Fact, Contention 1, Section III.C.(3).];

334. Intervenors witness Dr. Brune contends that the state of our scientific knowlege is too limited to allow us to predict with confidence the maximum magnitude and consequent maximum ground acceleration to which the San Onofre Nuclear Power Plant may be exposed during its lifetime (Brune, written testimony, p. 3) Dr. Brune references the National Academy of Sciences' report on Problems Relating to the Siting of Critical Facilities to illustrate limitations

in the scientific basis for establishing seismic criteria (Brune, written testimony, p. 7-10). He concludes that, given our present lack of knowledge, the burden of proof to show that the DBE could not be exceeded could not be scientifically held. (Brune, written testimony, p. 11)

335. The term "possible" and the phrase "isn't it possible that" occurred a great deal in this proceeding. In matters relating to physical happenings in nature essentially anything is possible. It is necessary to temper estimates of maximums by characterising them as being realizable during conceivable periods of time. (S. Smith, Tr. 1518). Reasonable periods of time for viewing earthquake phenomena in the context of critical facilities is judged by Dr. Smith to be about 10,000 to 20,000 years. (S. Smith, Tr. 1525).

336. Dr. Allen, one of the authors of the National Academy of Science's "Report On Problems Relating to the Siting of Critical Facilities," pointed out that although the report states that we may not have optimal information for purposes of design, it does not say that we do not have <u>adequate</u> information. (Allen, Tr. 4665) As a result, some structures with a deficient resistance have undoubtedly been built, although probably more often critical structures have been built using <u>excessive</u> <u>conservatism</u> to compensate for our acknowledged ignorance. (Allen, Tr. 4668; Brune, Tr. 4272)

337. While Dr. Brune recognizes that critical structures have been built using excessive conservatism more

often than not to compensate for acknowledged ignorance (Brune, Tr. 4272), he could not offer an opinion as to whether SONGS facilities are overdesigned. (Brune, Tr. 4582) However, in Dr. McNeill's opinion, if the DBE time history were to be constructed today with so many more records available, the DBE spectrum would be much less severe. (McNeill, Tr. 4017).

338. Conclusive evidence of the conservatism of the SONGS DBE was presented by the NRC Staff witness Dr. Leon Reiter. Dr. Reiter tesitifed that he has been involved in a review of at least 30 nuclear power plants, (Reiter, Tr. 5585) and in his opinion San Onofre is probably the most conservatively designed power plant that he is aware of. (Reiter, Tr. 5597)

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CONTENTION 3

> Whether the seismic design basis for SONGS 2 & 3 is inadequate to protect the public health and safety as a result of discovery subsequent to issuance of the construction permit of the following geologic features: (1) ABCD features at the site; (2) Features located at Trail 6, Target Canyon, Dead Dog Canyon, Horno Canyon, and "Onshore Faults E & F"; (3) Such other features as the parties may agree are relevant to the seismology of the SONGS site or with respect to which intervenor Friends of the Earth makes a threshold showing of relevance.

I. INTRODUCTION

339. Mr. J. L. Smith and Dr. P. L. Ehlig testified for the Applicants, regarding the following geologic features discovered and investigated subsequent to issuance of the construction permit: (a) ABCD features at the site; (b) Trail 6 landslide; (c) Target Canyon offsets; (d) Horno Canyon landslide; and (e) Faults E and F. Mr. A. Thomas Cardone testified for the NRC Staff regarding these geologic features and Mr. M. Legg testified for FOE regarding the ABCD features at the site. (J. Smith, written testimony, p. 1-19; Ehlig, written testimony, p. 1-4; Exhibits #25,JLS-1, #26,JLS-2, and #27,JLS-3; SER Sections 2.5.1.3, 2.5.1.4, 2.5.1.6, 2.5.1.8; Legg, written testimony, pp 8-10).

340. No other geologic features beside the ABCD features, features located at Target Canyon, Dead Dog Canyon, Horno Canyon, and onshore faults E & F were agreed upon by the parties to be relevent to the seismology of SONGS.

Intervenor FOE did not even attempt to make a threshold showing of relevance for any feature other than those listed above. Thus, the parties presented evidence only on the above referenced features.

II. POST-CONSTRUCTION PERMIT GEOLOGIC INVESTIGATIONS

A. Description and Extent of Investigations

341. Investigations of these features were detailed and extensive, and included the following:

1. Geologic mapping of the SONGS site and vicinity;
2. Review of geologic literature on the site and its region;
3. Analysis of aerial photographs;
4. Excavation of exploratory trenches;
5. Drilling of borings;
6. Detailed logging of all exploratory and construction excavations;
7. Microscopic and petrographic laboratory examinations; and
8. Theoretical analyses (Exhibit #25,JLS-1, p. 5-6, Appendix B; Exhibit #26,JLS-2, p. 6; Exhibit #27,JLS-3, pp. 3-4; Ehlig, written testimony, p. 2; Tr. 2906, 2924, 2925).

342. The objectives of the investigations were to analyze in detail the characteristics of the features, determine their age and origin, interpret their structural relationships, and evaluate their significance to SONGS. (Exhibit #25,JLS-1, p. 1; Exhibit #26,JLS-2, p.1; J. Smith, written testimony, pp. 3, 12, 15, 16, 19; Ehlig, written testimony, pp. 3-4; Staff Exhibit #9, p. 1)

343. Investigations of the geologic features took place during the period May, 1974, to February, 1978, and

involved hundreds of man-days by several investigators. (J. Smith, written testimony, pp. 2, 3, 13, 16; Ehlig, written testimony, p. 2; Exhibit #25,JLS-1, p. 1, C-1; Exhibit #26,JLS-2, pp. 1-2; Exhibit #27,JLS-3, p. 1-3; Ehlig, Tr. 2906, 2924, 2925, 2782; Staff Exhibit #9, p. 1)

344. During construction of SONGS 2 & 3, Edison geologists made routine field inspections to identify and evaluate geologic features revealed by excavation. (Exhibit #25,JLS-1, p. 1)

B. Investigation of ABCD Features

1. On-site Investigation

345. Planar joints (called features A, B, C and D) with small amounts of offset in the San Mateo formation were discovered at the SONGS site during excavation, and were investigated there and in the site vicinity. (Exhibit #25,JLS-1, p. 1; #26,JLS-2, pp. 1-2; J. Smith, written testimony, p. 2-5; J. Smith, Tr. 2672-2674; Staff Exhibit #9, p.1-3)

346. No structural features besides the ABCD features and bedding in the San Mateo formation were observed in the construction excavations at the SONGS site. (Exhibit #27,JLS-3, p. 23; Staff Exhibit #9, pp.7-8)

347. The planar features called Type A and Type B were discovered by Edison geologists in May, 1974. They were preserved until an investigation could be made and they could be observed by representatives of the Nuclear Regulatory

Commission (NRC), United States Geological Survey (USGS), and Advisory Committee on Reactor Safeguards (ACRS). (Exhibit #25,JLS-1, p. 1-2; SER, Section 2.5.1.3)

348. After initial evaluation of the A and B features, investigations were continued on a daily basis so that all geologic relationships and structural features could be documented as grading progressed. (Exhibit #25,JLS-1, p. 1; #27,JLS-3, p. 2)

349. C and D type features in the San Mateo formation at the SONGS 2 and 3 sites were discovered after the A and B features were noted. They were recognized and evaluated as part of continuing monitoring of grading of the site by Applicant's consultants. (Exhibit #26,JLS-2, p. 1; #27,JLS-3, pp. 2-3; SER, Section 2.5.1.3)

350. The investigations of the A, B, C, and D features at the site were extensive and detailed. They included review of pertinent geologic literature, review of aerial photographs, geologic mapping at Units 1, 2 and 3 of SONGS, excavation of 19 backhoe trenches, drilling of seven borings to a depth of 25 feet, detailed logging of all backhoe trenches and pertinent excavations, microscopic and petrographic studies, theoretical analysis regarding the mechanics of their origin, detailed mapping at two areas outside the SONGS site and inspection of two other localities. The investigations involved approximately 215 man-days, and were reviewed on several occasions by

representatives of the NRC, USGS, and ACRS. (J. Smith, Tr. 2672-76, 2690-91; Exhibit #27,JLS-3, pp. 3-4; Staff Exhibit #9, pp. 2-3)

351. Trenches excavated at the site to investigate the ABCD features were on the order of 5 to 10 feet deep into the San Mateo formation. Borings for that purpose were on the order of 15 to 25 feet or more deep. Maps in Exhibits #25,JLS-1, #26,JLS-2, and #27,JLS-3, show their location at various stages of the investigation. In addition, any accessible sumps and construction pits in the site were exhumed for inspection, and the San Mateo formation over the entire site was scraped clean to provide surfaces for observation and mapping. (J. Smith, Tr. 2692; Exhibits #27,JLS-3, p. 3; #25,JLS-1, Drawings 3 to 25)

352. Investigations and searches for all existing A and B features included complete inspections of all available cuts and exposures within the site boundary, cleaning and detailed inspection of areas being graded, and continued monitoring of the grading. (Exhibit #25,JLS-1, p. 19)

353. Detailed petrographic and microscopic analysis were made of the A, B, and D features at the SONGS site. (Exhibits #25,JLS-1, p. A-1, A-2; #26,JLS-2, p. A-1 to A-4)

354. The occurrence of AB features at various elevations in the site region suggests they extend to depths of a few hundred feet within the San Mateo formation. Because of their very good exposure in both plan and vertical

views at the site and in the vicinity, it was not necessary to investigate them to great depths. (J. Smith, Tr. 2693-2694)

355. The C and D features were investigated by geologic mapping of the graded surface at the Units 2 and 3 sites, which was accommodated by scraping of covered surfaces in the San Mateo formation, exhuming sumps and construction pits, and excavation of five backhoe trenches. All trenches and exposures were documented by maps and photographs. Microscopic and petrographic studies were made of the C and D features, and theoretical analysis of their origin was performed. Additionally, a search was made for other C and D type features outside the SONGS 2 and 3 site. The investigation involved approximately 115 man-days. (Exhibit #26,JLS-2, p. 6)

2. Off-Site Investigations

356.Studies of the Type A and B features have also been made outside the site area, and they indicate that the features exist in the San Mateo formation at many areas and are not unique to the site. (Exhibit #25,JLS-1, p.4; Staff Exhibit #9, p. 29)

357. Of the several areas away from the site where the San Mateo formation contained AB features, two were selected for detailed study. Area 1 was an abandoned quarry along Basilone Road about 1.7 miles northwest of the site. Area 2 is in the seacliff near San Onofre beach, on the west

bank of San Onofre Creek, also about 1.7 miles northwest of the site. Two other specific areas where AB features were found but not investigated in detail are along the transmission line crossing the ridge between San Mateo and San Onofre Creeks (Area 3), and in a gully cutting the seacliff southeast of SONGS (Area 4). AB features found in these and other areas are similar to those exposed at the SONGS site. (J. Smith, Tr. 2672-2674, 2772, 2783-85; Exhibit #25,JLS-1, p. 23, p. C-1; Staff Exhibit #9, p.9)

358. The AB features were excellently exposed in Areas 1, 2, 3, and 4 because of excavations for a quarry, access roads, as well as natural surfaces produced by erosion. Accordingly, trenches were not necessary for their investigation there. However, a number of trenches and drill holes were used to investigate the features at the site. (J. Smith, Tr. 2684-2685; Exhibits #25,JLS-1, pp. C1-C5; #27,JLS-3, pp. 3-4)

359. A complete search of all available exposures of San Mateo formation outside the site revealed no C features other than the one in the site. (Exhibit #26,JLS-2, p. 8)

360. Several D type features were observed in the Unit 1 excavation, but a search conducted outside the site disclosed no D type features. (Exhibit #26,JLS-2, p. 13)

3. Documentation of ABCD Features

361. The ABCD features observed in the Units 2 and 3 excavations, have been thoroughly evaluated and documented in detail. (Exhibit #26,JLS-2, Drawings 2-19; #27,JLS-3, Drawings 1 to 4, Drawings A1 to A5)

362. Prior to the construction permit review, very detailed log of the seacliff was carefully made from the Cristianitos fault to the SONGS site, and no ABCD features were recorded. (J. Smith, Tr. 2686)

C. Investigation of Features at Trail 6, Horno and Dead Dog Canyons, Target Canyon

363. The offsets at Trail 6, Dead Dog/Horno Canyons, and Target Canyon were investigated in 1977 to evaluate their extent, nature and origin. The scope of investigation included detailed geologic mapping, analysis of aerial photographs, logging of natural exposures in the seacliff and transecting gullies, excavation of trenches. (J. Smith, written testimony p. 13, 16, 17; SER, Section 2.5.1.6)

D. Investigation of Faults E and F

364. Geologic mapping of the San Onofre region in 1977 by Dr. Perry Ehlig disclosed the presence of Faults E and F. Additional study of Fault E was made during 1977-78 and included excavation of two trenches across it. (Ehlig, written testimony, p. 2; SER, Section 2.5.1.5)

365. Twenty-two days each were spent in the field by Dr. Perry Ehlig and Tom Farley in mapping the geology of the San Onofre area in 1977. The area extended 7 miles downcoast from the site and northward across San Mateo Creek. (Ehlig, Tr. 2925)

E. Adequacy of Investigations

366. Investigations performed by the Applicants since the construction permit review have been detailed, and they adequately represent those aspects of the geology pertinent to the safety of SONGS. The new information is adequate to support the earlier conclusion reached in the Safety Evaluation Report approving an DBE of .67g for SONGS 2 and 3. (SER, Section 2.5.1.1., last paragraph; SER, Section 2.5.1.3, second paragraph; SER, Section 2.5.1.5, last paragraph; SER, Section 2.5.1.6, last paragraph; Staff Exhibit #9, Section 3.0, first and second paragraphs)

III. DESCRIPTION AND EVALUATION OF ABCD FEATURES

A. Description of ABCD Features

367. The ABCD features are narrow, linear, light gray or white streaks that were discovered in the San Mateo formation during site grading operations in 1974. The features were carefully investigated by mapping, trenching, and drilling to locate all the features, determine their physical and structural characteristics, to evaluate the evidence for their age, and to interpret their mode of formation. (J. Smith, written testimony, pp. 2-3)

1. Location On-Site and Offsite

368. The AB features in the SONGS site form an "X" pattern in the San Mateo formation at the Unit 2 area. They are the most abundant, prominent and most continuous of the four types of features. (J. Smith, written testimony, p. 5; Exhibit #26,JLS-2, Drawing 2)

369. The AB features have been observed along Basilone Road which lies along the north side of San Onofre Creek, and at the mouth of San Onofre Creek just north of the Santa Fe railroad tracks. They have also been observed on the ridge lying between San Mateo Creek to the northwest and San Onofre Creek to the southeast, along access roads to the power transmission lines crossing the ridge. They have also been found in one or two of the minor gullies just southeast of the SONGS site within a few hundred feet of the site. (J. Smith, Tr. 2673-2674)

370. Area 1, identified on Drawing 25 of the Applicant's Exhibit #25, is a sand quarry about 1.7 miles northwest of SONGS and 1.1 miles west of the Cristianitos fault, where AB features have been investigated. (J. Smith, Tr. 2678-2679; Exhibit #25,JLS-1, p. C-1)

371. The exposure of San Mateo formation at Area 1 is excellent and is about 1,000 feet by 500 feet in size, 7xtending from elevation 100 to 250 feet above sea level. (Exhibit #25,JLS-1, p. C-2)

372. The A and B features at Area 1 are similar in appearance to those at the SONGS site, and have identical orientation, dimension, and sense and amount of displacement. (Exhibit #25,JLS-1, pp. C-2 to C-4)

373. Area 2 is a cliff immediately south of Basilone Road and along the northwest bank of San Onofre creek. The San Mateo formation at Area 2 is well exposed along the seacliff and bluff along San Mateo creek between Basilone Road and the Santa Fe railroad near San Onofre beach. Area 2 is about 1.7 miles northwest of SONGS and 1.6 miles west of the Cristianitos Fault. (Exhibit #25,JLS-1, p. C-4)

374. At the mouth of San Onofre Creek (Area 2) only A features having a nearly north-south strike and overlain by unbroken terrace deposits were found. Under the transmision line (Area 3) the AB features have the same orientation as the AB features at the site. (J. Smith, Tr. 2682; Exhibit #25,JLS-1, pp. C-4 to C-5)

375. The AB features found in Area 3 would be about one mile southwesterly from the Cristianitos fault. In Area 4, they are about .4 of a mile almost due west of the fault. (J. Smith, Tr. 2688)

376. In the seacliff and adjacent gully southeast of the SONGS site (Area 4), one A feature and one B feature were observed. The seacliff and gully wall at this location hundreds of feet from the site provided exposures that were

excellent and comparable to, if not better than a trench. (J. Smith, Tr. 2684)

377. The C and D features are relatively rare and have not been found outside the site. The C feature is limited to a 60-foot long area in the northeastern part of the site. It is similar in appearance and character to the A feature but is less straight and does not clearly exhibit displacement. (J. Smith, written testimony, p. 7)

378. Feature C is exposed only in the northeast corner of the SONGS 3 site, where it extends approximately 30 feet across the northern cut slope and about 30 feet across the level graded pad area. (Exhibit #26,JLS-2, p. 7, Drawing 2)

379. Feature D extends from the east corner of the Unit 3 site from the cut slope below the haul road westerly across the Unit 2 and Unit 3 reactor area, dying out on the west side of Unit 2. (Exhibit #26,JLS-2, p. 8, Drawing 2)

2. Appearance and Dimensions

380. The A and B features at the SONGS site are light gray or white, slightly resistant ridges in the tan San Mateo formation. The ridges are a fraction of an inch wide and collectively comprise a zone 1-6 inches wide, averaging about 2-4 inches. (Exhibit #25,JLS-1, p. 15)

381. The A and B features are discontinuous joint-like shears that intersect in a conjugate relationship. They are nearly vertical, and linear or

broadly curvilinear in plan. Type B features decrease in width and eventually disappear in the eastern half of the site, and the Type A features decrease in width or disappear in the southern part of the site. (Exhibit #25,JLS-1, p. 3)

382. The individual elements of the A and B features present a stepping or intertwined appearance that consistently indicates right- or left-lateral displacement. The absence of the intertwining and stepping arrangement of the elements where the features are observed in vertical excavations indicates that slip on the features occurred horizontally rather than vertically. (Exhibit #25,JLS-1, pp. 15-16)

383. The San Mateo formation is excellently and continuously exposed in slopes throughout Units 1, 2, and 3 of the SONGS site, thus providing excellent opportunity for identification of structural features in the formation. (Exhibit #25,JLS-1, Drawing 3)

384. Some clay layers within the San Mateo formation are extensive, on the order of 50-80 feet wide and 120 feet long, and provide easily-traceable horizons for identifying A and B features or for demonstrating their absence. (Exhibit #25,JLS-1, pp. 21-22)

385. The A and B features are straight in plan and section and they are resistant to brushing in the more easily eroded sardstone because of the slight amount of crushing and

compression that occurred along them during their formation. (J. Smith, written testimony, p. 5)

386. Under the microscope, the A and B features can best be described as a crush-breccia with a very closed framework. The cementing agent is not clay or calcite, but a weak binding of fine sand or silt-size grains. (Exhibit #25,JLS-1, p. A-2)

387. Feature C consists of a sinuous zone of thin (1/8 to 1/4 inch) white resistant ribs that are very similar to the A and B features. (Exhibit #25,JLS-1, p. 7)

388. The D feature consists of a sinuous pattern of hairline planar fractures containing little or no evidence of crushed grains and no evidence of compaction. It is quite different from the ABC features because of its lack of linearity and its lack of resistance to erosion by brushing. The orientation of the D feature is very similar to that of bedding in the San Mateo formation. Displacement on the D feature is in a reverse sense, with the northern part being up. Displacement ranges from as low as 1/8 inch to a maximum of 2-3/4 inches. The direction of slip is south, parallel with or along the line of the A features. (J. Smith, written testimony, p. 7-8; Exhibit #26,JLS-2, pp. 8-9)

389. In contrast to the A, B, and C features, the D feature is usually apparent after light brushing of the sandstone because the planar surface erodes slightly more than the surrounding formation, leaving a thin line in the

sandstone. While feature D has a distinct surface, that surface contains no evidence of gouge, cementation, crushing, or extensional separation. (Exhibit #26,JLS-2, p. 8)

390. Features A, B, and D are plainly shears, but A and B are more highly anastomosed and have a greater total displacement across them than the D features. In addition, grain crushing is more evident on A and B so that in brushing, these features appear in relief, whereas feature D exhibits lesser resistance to abrasion than the adjacent material. The resistance to brush erosion of features A and B is related to the greater cohesion of the fine grain sheared debris that exists there than along feature D. (Exhibit #26,JLS-2, p. 14)

391. Petrographic examination of samples of the D feature disclosed an abundance of voids and empty fractures which suggest that deformation did not take place repeatedly or was not intense enough to cause filling of the void spaces. (Exhibit #26,JLS-2, p. A-3)

392. AB features, viewed in a vertical exposure rather than in plan, are very innocuous looking. They represent essentially a single white line within a tan sandstone, and very little note was taken of them during the early mapping. (J. Smith, Tr. 2687)

3. <u>Attitude, Sense of Slip, Displacement</u>

393. The AB features in the San Mateo formation at the site have consistent attitudes: Type A features strike

north-south to north 10° east, and Type B features strike approximately north 50° west. (Exhibit #25,JLS-1, p. 3)

394. The sense of slip and amount of displacement is also consistent. The AB features exhibit strike-slip displacement ranging from 1/2 to 4 inches with no indication of any vertical slip or pull apart due to tension. The sense of displacement is consistently left lateral for Type A features and right lateral for Type B. (Exhibits #25,JLS-1, p. 3, B-1, Drawings 17-18; #27,JLS-3, p. 21)

395. Careful examination of claystone clasts offset by the A and B features have repeatedly demonstrated a consistent amount and sense of movement along the features. The amount of displacement ranges from 1/2 inch on a single surface to 4 inches of cumulative slip across a thin zone. (Exhibit #25,JLS-1, pp. 16-17)

396. The B features are discontinuous laterally and die out completely to the east and west within the site. Where A and B features intersect one another they mutually offset each other at nearly equal intervals so that neither on dominates. (J. Smith, written testimony, p. 6; Exhibit #25,JLS-1, p. 18-19, 25, Drawings 3, 10)

397. The A features at the site are not parallel to the strike of the Cristianitos fault. The Cristianitos fault has an overall strike of about north 15° west, while the A features strike nearly north-south to north 10° east. The Cristianitos fault has a variable strike from place to place,

and the extent to which it appears to bend depends on where it is examined and on the nature of the map being inspected. (J. Smith, Tr. 2656)

398. The vertical extent of the AB features is on the order of the vertical relief in the topography, that is, in the range of somewhere from 55 to 300 feet. It is not known whether they extend the full depth of the San Mateo formation at the site (approximately 900 feet), but they could. It is speculation whether they extend to the base of the San Mateo formation, but if they do, they would not be expected to continue beyond the base and extend into the Monterey formation. There is, therefore, a bottom limit on the vertical extent of the AB features at the site. (J. Smith, Tr. 2700-2701; Exhibit #25,JLS-1, p. 8)

399. The A features can be traced across the site for about 800 feet. However, there is no single A feature that is 800 feet long because the A features are everywhere offset and interrupted by the B features. The greatest dimension of any A feature would be approximately the dimension between any two B features. The A features collectively and singularly are widest in the central part of the site, narrowing perceptibly to the north and to the south, suggesting they are dying out near the northern and southern margins of the site. (J. Smith, written testimony, p. 5; J. Smith, Tr. 2702-4; Exhibits #25,JLS-1, Drawings 7-12; #27,JLS-3, p. 21)

400. Type B features at the site strike between north 45 degrees west and north 56 degrees west, roughly parallel to the coastline. The Type B features are very similar to the Type A features, but all of them are more discontinuous and completely terminate to the southeast and northwest within the site. (J. Smith, Tr. 2703; Exhibit #25,JLS-1, pp. 16-17, 25)

401. Trenches excavated beyond the ends of A and B features where they are visible on the ground surface indicate that the features do not extend at depth beyond the ends of their exposure at the ground surface. (Exhibit #25,JLS-1, p. 17)

402. The beach sand does not contain AB features but rather prevents the features from being observed south of the site. (J. Smith, Tr. 2703, 2707)

403. The abrupt contact between marine terrace deposits and San Mateo formation in an exposure along a construction haul road at the Unit 2 site coincides with the existence of an A feature, suggesting the possibility of vertical offset of the two formations along the A feature. Detailed mapping of this exposure, however, clearly shows that the contact is an erosional one developed along an A feature, with positive evidence existing of no displacement of the marine terrace deposits across the A feature. (Exhibit #25,JLS-1, p. 4, Drawings 5 and 6; Staff Exhibit #9, pp. 12-13)

404. Referring to the ABCD features as shear zones, rather than joints, could be misleading if not qualified. In a general context, a shear would be a surface along which there has been displacement parallel to the surface. Using the term shear or shear zone is a matter of scale. If one can identify a discrete planar surface, something that is a millimeter or a fraction of an inch wide and appears to be a single plane, there would be a tendency to call it a shear. If it had a greater dimension in terms of width, or contained a collection of shears sub-parallel to each other over a few inches wide, one would refer to that as a shear zone. However, in a mass of rock like the San Mateo formation that is jointed, especially with a conjugate, intersecting set of joints, there are many different ways to define a zone. Thus, the distribution of A features in the site appear to be as a zone, but this is only apparent because of additional A features forming, rather than the width of existing A features increasing. Consequently, it would be misleading to call them a shear zone. (J. Smith, Tr. 2680-2705)

405. Although the A features might be characterized as having a distribution that could be called a zone, the features themselves do not widen. In contrast the features themselves become narrower and what is seen southward is the addition of A features lying sub-parallel to other A features. In defining a zone for some purpose, one has to look at the area as well as the scale at which one is

talking. With regard to the A features, a "series" might have a less prejudicial implication than the term "zone". Therefore, the increasing number of A features in the southern part of the site does not indicate a greater magnitude of shearing there, because individually the features do not indicate increased displacement. (J. Smith, Tr. 2706-08)

406. The AB features in the site and in offsite areas are joint-like rather than fault-like because of their orientation, planar nature, and their relationship to each other. Although they do exhibit some displacement parallel to the surface, the amount of displacement is small. (J. Smith, Tr. 2680)

407. The one C feature exposed at the site is short, diffuse, and, with the exception of its attitude, has similar physical characteristics to Type A and B features. (Exhibit #26,JLS-2, p. 18)

408. Feature C strikes north 50 to 60° east and dips 5° to 19° northwest, an attitude grossly similar to bedding in the San Mateo formation. (Exhibit #26,JLS-2, p. 7)

409. No clear evidence of displacement has been recognized on Feature C, but a questionable offset of a thin clay seam suggests about 2-1/2 inches of apparent right-lateral displacement. (Exhibit #26,JLS-2, pp. 7-8)

410. Feature D generally coincides with bedding planes in the San Mateo formation, although it tends to dip

slightly more steeply in deeper excavations and has a shallower dip near the ground surface. (Exhibit #26,JLS-2, p. 10)

411. The sense of displacement along the D feature is reversed with amounts ranging from 1/4 inch or less to about 2-3/4 inches. The direction of displacement is south to south 10° west, parallel with the direction of the A features. (Exhibit #26,JLS-2 at pp. 8-11)

4. Structural Relationships

412. The mutual displacement of the A and B features by one another indicate that the features formed simultaneously with no particular orientation being dominant. (Exhibit #25,JLS-1, pp. 25-26)

413. Detailed examination of the intersections of A and B features at the SONGS site indicate that the features mutually displace one another and nearby clasts of clay or sand in lateral directions, with no direction of offset being dominant. At a large number of intersections, however, the last movement is indicated to have occurred on the B features, resulting in offset and termination of the A features. (Exhibit #25,JLS-1, Drawing 7, 8, 10, 11)

414. The angles formed between the Type A and B features are consistent with the angle that would be expected between planes of failure in a moderately dense sand under compression. This observation, along with the presence of the features over a broad area, suggests that the compressive

stresses were widespread and the features do not represent a single zone. (Exhibit #25,JLS-1, p. 27)

415. The A and B features are consistent with the application of a compressive strain or stress in a direction about north 20° west. The presence of a generally compressive stress state implies that the San Mateo formation probably was subject to an overburden pressure of several hundred feet at the time when shearing occurred. (Exhibit #25,JLS-1, p. B-2; Staff Exhibit #9, p. 29)

416. Feature C does not intersect A and B features or the D feature, so their mutual structural relationships cannot be evaluated. (Exhibit #25,JLS-1, p. 8)

417. The structural relationship between features A, B, and D indicate that feature D was the last to form. Feature D is overlain by unbroken terrace deposits of the stage 5e platform, which have been established to be on the order of 125,000 years old. (Exhibit #26,JLS-2, p. 11)

418. The degree of grain crushing which occurs in the shearing of granular material is related to the composition of the grains and to the hydrostatic component of stress of which shearing is carried out. Shears A and B developed at a mean of hydrostatic stresses in the order of 20 to 30 kg/cm or greater, which indicates an overburden height above the present level of the shear features in the order of 300 feet or more at the time of their formation. (Exhibit #26,JLS-2, pp. 14-15; Staff Exhibit #9, p. 11)

419. The D feature developed at a mean of hydrostatic stresses in the order of 10 kg/cm static stresses indicating an overburden height in the order of 60 feet. (Exhibit #26,JLS-2, pp. 15-16)

420. The D feature was generated under generally north-south compression when the upper level of the San Mateo formation was not much different from its prevent elevation, but before deposition of the overlying terrace gravels. (Exhibit #26,JLS-2, p. 17)

421. The ABCD features are joints displaying small amounts of mutual shear displacement, and they are not capable faults. They are of such a small scale as to go unnoticed in general mapping of the region. Such small breaks in rocks of this region are ubiquitous, and they may be due to nontectonic deformation. The ABC features formed in response to small amounts of horizontal regional compression acting on relatively homogeneous sandstone over an area many times larger than the site. The D features formed during a time of reduced overburden pressures and when a regional compression was generally north-south. The D features are related to stress release that resulted from removal of several hundred feet of overburden during Late Pleistocene time. (J. Smith, written testimony, pp. 10-11; Ehlig, Tr. 2934)

422. The AB features have no characteristics that would permit associating them with seismicity or to known

faults or other types of shears in the vicinity. They are not parallel to the Cristianitos fault or to other known faults, their gross distribution is not zonal, and they do not maintain a constant proximity to the Cristianitos or any other fault in the area. Also, they have senses of motion along them that are not compatable with motion on the Cristianitos fault or other faults in the immediate area, including offshore faults. (J. Smith, written testimony, pp. 6-7; Tr. 2697-2698; Exhibit #25,JLS-1, p. 28, C-6)

423. The A and B features are not surface expressions of a deep-seated shear zone. They exist within the San Mateo formation because of the characteristics of the formation itself, and they do not have any zonal distribution that would relate them to some master shear zone, or any shear zone, at depth. (J. Smith, Tr. 2697)

424. If there is a fault or zone of deformation within or beneath the San Mateo formation, the A and B features are not its surface manifestation. (J. Smith, Tr. 2698)

425. Theoretical analysis of the mechanics of the A and B features indicates that the shear movements are consistent with the application of compression in a north 20° west-south 20° east direction. This is in contrast with modern motion on the large fault systems in southern California (the San Andreas, San Jacinto, and Elsinore) which are considered to be moving in response to a generally

north-south compressive stress field on a very large scale. (Exhibit #25, JLS-1, pp. 25, B-3 to B-4; Staff Exhibit #9, p. 10)

426. The B features are unrelated to the OZD. They are parallel to the trend of the OZD only where elements of the OZD trend northwest. However, there are places where the trend of the OZD deviates from northwest. (J. Smith, Tr. 2662)

427. All of the features formed under stress conditions quite different or somewhat different from those of the modern tectonic regime, and certainly different from those that produced the Cristianitos fault. (J. Smith, written testimony, pp. 9-10)

428. The evidence from investigations of A and B features indicates they must have been the result of compressional stresses, which contrasts with the extensional forces necessary to produce the Cristianitos fault. (Exhibit #25, JLS-1, p. C-7)

429. While it may be logical to associate the A and B features with deformations on a smaller scale, for example stress relief inland of the coastal bluffs, it would be reasonable to expect that the features, particularly the Type B features, would exhibit tensional characteristics in that case. These clearly do not exist on either the A or B features. (Exhibit #25, JLS-1, pp. B-4 - B-5)

430. The distribution of A and B features in the site region indicates that the features are independent of the effects of either the Cristianitos fault or stress release due to erosion along the seacliffs. (Exhibit #25,JLS-1, p. 26; Staff Exhibit #9, p. 10)

5. Origin and Age

431. The A and B features developed in the San Mateo formation after it had obtained a partially cemented stage in its development, because the formation of the features requires a brittle parent material. Although it is possible for shear planes to develop when a dense sand is stressed, the details of the A and B features (such as narrow width, intertwining elements, crushing of grains) indicate that the San Mateo formation must have been cemented at the time shearing occurred. Thus, the features were formed sometime during the 4 million years following the formation's deposition. (Exhibit #25,JLS-1, p. B-2)

432. Significant overburden pressure would be required in the San Mateo formation to permit shearing to occur, and the height of overlying San Mateo formation must have been on the order of several hundred feet. This implies that shearing occurred much longer than 125,000 years ago (possibly more than 800,000 years ago), long enough to account for erosion of several hundred feet of San Mateo formation prior to development of the marine terrace platform

at the site. (Exhibit #25,JLS-1, p.27; Staff Exhibit #9, pp. 10-11)

433. Since the San Mateo formation was deposited 4-10 million years ago, the stresses producing the A and B features could have developed several million years ago when the regional stress pattern may have been different then what exists today. (Exhibit #25,JLS-1, p. B-3)

434. Where A and B features at the SONGS 2 and 3 site are overlain by marine and nonmarine terrace deposits, the deposits lie unbroken across the features. (Exhibit #25,JLS-1, Drawing 3)

435. The stage 5e (125,000 years old) marine terrace platform overlying the ABCD features at the SONGS 2 and 3 site lies at about elevation 55 feet above sea level where it is exposed in the north cut slope. The erosional platform in the Unit 1 area farther to the north lies at about elevation 45 where exposed in the seacliff and in cut slopes surrounding the Unit 1 site. The platform and AB features in the Unit 1 area are overlain by nonmarine deposits of a younger age than that of the stage 5e platform. (Exhibit #25,JLS-1, pp. 9 11, Drawing 3)

436. Several excellent exposures in the seacliff and in cut slopes at the Unit 3 site disclose A type features clearly overlain by undisturbed marine terrace deposits, and these exposures have been documented. (Exhibit #25,JLS-1, Drawings 4, 6, 16)

437. Because the ABCD features are overlain by unbroken marine and nonmarine terrace deposits of the stage 5e platform, whose age is approximately 125,000 years, the minimum age of last movement on the A and B features is older than this age range. (J. Smith, written testimony, pp. 8-9; Exhibit #25,JLS-1, pp. 3-4; Tr. 2707, 2710; Staff Exhibit #9, p. 9)

438. Although feature D displaces types A and B by minor amounts, and is therefore younger, it does not displace the marine platform or the overlying terrace deposits that are in the order of 125,000 years old. (Exhibit #26,JLS-2, p. 18, Drawing 14; Staff Exhibit #9, p. 15)

439. The D feature probably formed when the land surface was within a few hundred feet of its present elevation, but prior to 125,000 years ago. (J. Smith, written testimony, p. 9; Staff Exhibit 9, p. 16)

B. <u>Non-significance of ABCD Features to SONGS</u>

440. All available evidence indicates the AB features are small, discontinuous, widespread, display consistent patterns, and are clearly older than 130,000 years. They resemble conjugate joint-sets with small amounts of offset, rather than faults. (Exhibit #25,JLS-1, p. 28)

441. These features are not unique to the SONGS site, but they are unique to the San Mateo formation, which is a massive homogeneous sandstone that is somewhat brittle and with high strength, but with relatively little tenacity.

Their distribution and discontinuous short lengths, particularly their small displacements and great age, indicate that the ABCD features are joints and, thus, are very minor elements of the San Mateo formation having no significance for the SONGS site. (J. Smith, written testimony, p. 11)

442. The ABCD features have been demonstrated to not be capable faults as defined by 10 C.F.R. Part 100, Appendix A, and are not significant to the safety of SONGS. (Exhibits #25,JLS-1, p. 4, 28; #27,JLS-3, p. 23; SER, Section 2.5.1.3, 3rd paragraph; Staff Exhibit #9, pp. 17-18, 31)

IV. DESCRIPTION AND EVALUATION OF FEATURES AT TRAIL 6

A. Location and Investigation

443. The features at Trail 6 are small vertical offsets of the contact between the bedrock and the marine terrace deposits of the stage 5e platform exposed in the seacliff approximately 3 miles south of SONGS. They were noted during 1977 by a geologist for the California Energy Commission. (J. Smith, written testimony p. 12-13)

B. Description

444. Geologic units in the vicinity of Trail 6 are sandstone of the Monterey formation, overlying marine and nonmarine terrace deposits, landslide deposits, and colluvium. The contact between the marine terrace deposits and the Monterey formation represents the 125,000-year old

stage 5e marine erosional platform. (J. Smith, written testimony p. 13-14)

445. Large landslides are common along the San Onofre coast where the Monterey formation is exposed to wave erosion. The offsets at Trail 6 exist within the southeastern boundary of a large (6 acres) landslide displaying many of the features common to massive movement in response to gravity. (J. Smith, written testimony p. 14)

446. The general strike of planar fractures associated with the offsets at Trail 6 is north northwest to north 60° west. The fractures can be traced about 80 feet northwest from the seacliff to intersect the back scarp of the main landslide. At this projection, the bedrock/marine terrace deposit contact is not exposed, but a nearly complete section of nonmarine terrace deposits can be observed and these are not offset. Projections of the fractures farther inland do not coincide with any mapped faults, nor are similar fractures or offsets found in the seacliff outside the landslide boundaries. (J. Smith, written testimony, p. 14-15)

C. <u>Non-significance of Trail 6 Offsets to SONGS</u>

447. The investigation of the Trail 6 offsets indicates that they are of landslide origin, and are not faults. Consequently, they are of no significance to the SONGS site. (J. Smith, written testimony, p. 15; SER, Section 2.5.1.6, fourth paragraph)

V. DESCRIPTION AND EVALUATION OF FEATURES AT HORNO AND DEAD DOG CANYONS

A. Location and Investigation

448. Offsets of the 125,000 year-old bedrock/marine terrace contact were discovered near the mouth of Horno and Dead Dog Canyons approximately 5 miles southeast of SONGS. (J. Smith, written testimony, p. 15)

B. Description

449. The investigation of the Horno and Dead Dog Canyon offsets disclosed abundant evidence of seacliff failure and seaward landsliding that extends 200-300 feet up the canyons. The location, orientation, sense of slip and the nature of the offsets indicate they are the result of landsliding. (J. Smith, written testimony, p. 16)

C. Non-Significance of Horno and Dead Dog Canyon Features to SONGS

450. The offsets at Horno and Dead Dog Canyons are of no significance to the SONGS site. (J. Smith, written testimony p. 16)

VI. DESCRIPTION AND EVALUATION OF FEATURES IN TARGET CANYON

A. Location

451. The stage 5e marine platform and overlying deposits are offset a small amount by narrow shears in Target Canyon, approximately 6-1/2 miles southeast of SONGS. (J. Smith, written testimony p. 16-17)

B. Description

452. Offsets of the stage 5e platform were observed at seven localities within an area measuring 2,000 feet by 1,000 feet in Target Canyon. Bedrock shears coincident with the offsets strike between north-south and north 15° east, and dip in the range 26° to 90°. Displacements of the marine platform are no more than 14 inches vertically, and are generally less than 12 inches. The displacements are chiefly normal dip-slip, with minor apparent horizontal and reverse slip on some shears. (J. Smith, written testimony p. 17)

453. Displacements in Target Canyon die out about 17 feet below the adjacent ground surface, ending in nonmarine deposits several tens of thousands of years old that overlie marine terrace deposits 125,000 years old. (J. Smith, written testimony pp. 17-18)

454. The offsets in Target Canyon have no association or alignment with any faults landward or seaward, and their zonal distribution is poorly developed. Assuming they represent a shear zone, projection toward the north along their strike would take them toward distinct and continuous strata in the San Onofre Breccia formation that are not faulted. (J. Smith, written testimony p. 18)

455. The association of the offsets and their shears with conjugate sets of fractures adjacent to a buried ridge of San Onofre Breccia suggests an origin related to differential compaction of the overlying softer sediments.

The gradual dying-out upward of the displacements tends to support this possibility, rather than that of a fault origin. Offsets of fault origin would be more likely to have displacements indicating abrupt episodic movements. (J. Smith, written testimony p. 18)

C. Non-significance of Target Canyon Offsets to SONGS

456. The weight of the evidence from investigations of offsets in Target Canyon favors a nontectonic origin for them. In any case, the offsets are small, tens of thousands of years old, and have a different orientation from most faults in the region. Furthermore, they are more than five miles from SONGS, and even their projection beyond known locations would be tangent to a five-mile radius drawn around SONGS. Accordingly, they are not significant to the site. (J. Smith, written testimony pp. 18-19)

VII. DESCRIPTION AND EVALUATION OF FAULTS E AND F

A. Location

457. Fault E lies from about 500 to 5,000 feet east of the Cristianitos Fault on the south flank of the San Onofre mountains. Fault F lies about 2,000 feet east of fault E. (Ehlig, written testimony, p. 1)

B. Description

458. Faults E and F strike about north 15 degrees west, nearly parallel to the Cristianitos fault. (Ehlig, Tr. 2899-2900)

459. Faults E and F have subparallel trends striking nearly north-south, but they dip steeply toward each other. Their displacement is small (300-400 feet for Fault E and about 25 feet for Fault F) and chiefly normal dip-slip. (Ehlig, written testimony, pp. 2-3)

460. Although Fault E might appear to join the Cristianitos fault if projected in planview, it dips in the opposite direction from the Cristianitos, so the two faults diverge at depth. Therefore, Fault E is not a branch of the Cristianitos fault. (Ehlig, Tr. 2904-2905)

461. The term "fault zone" refers to a zone of intensely deformed or sheared rock along the fault, and includes material that was involved in the faulting in the past but has been largely abandoned by more modern movement. (Ehlig, Tr. 2901) Faults E and F are not part of what would be characterized as a fault zone. (Ehlig, Tr. 2920)

462. Faults E and F are secondary features probably associated with early deformation at the start of the Cristianitos fault development. However, they do not join the Cristianitos on the surface or at depth. (Ehlig, Tr. 2903-2904)

463. Throughout the area of Faults E and F there is no topographic expression of faults. Where marine terrace platforms with or without terrace deposits exist there is no evidence that they are offset by faulting. These platforms

are very old, probably a few hundred thousand years. (Ehlig, written testimony, p.3; Tr. 2940-2941)

464. The age of the E and F faults is imprecisely known, but displacement is younger than about 14 to 15 million years old, the age of the Monterey Formation adjacent to the fault. Both faults lack physiographic expression and show no evidence of cutting the coastal terrace. Fault E passes beneath the remnant of a wave cut terrace bench at an elevation of about 350 feet without displacing the bench or an overlying soil unit. The bench is probably a few hundred thousand years old, thus suggesting that fault movement ceased by Late Pleistocene time. (Ehlig, written testimony, p.3)

C. <u>Non-significance of Faults E and F to SONGS</u>

465. Faults E and F were most likely formed in an east-west extensional tectonic regime 4 to 10 million years ago, and they thus do not fit the present north-south compressional regime. They have had no movement in the past several hundred thousand years. They are not capable faults and, thus, are not significant to SONGS. (Ehlig, written testimony, p. 4)

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CONTENTION 2

Whether characterization of certain offshore geologic features as a zone of deformation, referred to as the Cristianitos Zone of Deformation (CZD), or whether any additional information about the CZD which became available subsequent to issuance of the construction permit render the seismic design basis for SONGS 2 & 3 inadequate to protect the public health and safety.

I. OVERVIEW

466. Eight witnesses testified regarding various aspects of the so-called Cristianitos Zone of Deformation (CZD) including the extent of research, geologic characterization, comparison with older interpretations and age. Drs. D. Moore, M. Kennedy and G. Greene discussed the extent of the research; Messrs. M. Legg, T. Cardone, J. Devine and R. Morris, and Drs. D. Moore, G. Greene and M. Kennedy discussed the geologic characterization; Dr. D. Moore compared the current interpretations with older ones; and Drs. Shlemon, and Moore and Mr. Cardone discussed the age of the CZD based on the stratigraphy and both offshore and onshore marine terraces and platforms. (Moore, written testimony, pp. 37-50; Kennedy & Green, and Kennedy, SER, Section 2.5.1.12; Legg, written testimony pp. 10-12; Cardone, SER, Section 2.5.1.12; Devine and Morris, SER, Appendix G; Shlemon, written testimony, pp. 7-10)

467. The principles of seismic reflection profiling, the manner in which marine surveys are made, the

variations in penetration beneath the sea floor, and the degree of resolution obtained by using surveying systems of various frequencies and firing rates were described by Applicants' witness Dr. D. Moore. These systems and techniques provided the data on which Dr. Moore based his interpretations and conclusions of the geology offshore of SONGS. (Moore, written testimony, pp.22-28; Figures DGM-J, DGM-K)

468. Various techniques for graphically representing interpretation of offshore structure were utilized in the preparation of geological maps and structural cross-sections. Dr. Moore testifed that some methods can produce misleading characterization of folds and faults. This is particularly the case when maps display all faults at the same datum regardless of the depth below the sea floor at which they have expression and, therefore, the age of the folding and/or faulting. Because faults are indeed the critical structural features offshore of the SONGS region, Dr. Moore differentiated between faults that cut through rocks of all ages and extend to or near the sea floor from older faults that occur only at depth within the rock sequence. (Moore, written testimony, pp.34-37; Figures DGM-C, DGM-E, DGM-F)

469. Dr. Moore also described the importance of distinguishing between real data and spurious marks produced on the graphic record. The spurious marks can be caused by a

number of things unrelated to geology, but they can complicate or confuse the record and be misinterpreted as being of structural significance. Dr. Moore described how geologic structures should be interpreted, emphasizing the importance of arriving at interpretations through a broad understanding of the geologic processes and the regional and local patterns of structure both onshore and offshore. (Moore, written testimony, pp.30-34)

II. HISTORY OF OFFSHORE INVESTIGATIONS

470. Since the late 1960's, more than 2500 km of seismic reflection transects have been utilized by the Applicants to investigate the offshore geology of SONGS. About 1500 km of deep-penetration common-depth-point (CDP) seismic reflection data were used in regional studies, along with several hundred kilometers of higher resolution Sparker data. Most of the remaining transects have been concentrated on or near the San Onofre Shelf and upper Continental slope. Altogether, the geophysical studies of the geologic structures offshore of SONGS have extended for more than 100 km to the northwest and southeast of the plant site, and seaward across the shelf to the deep basins of the southern California Continental Borderland. The most detailed of the geophysical investigations were conducted close to SONGS, with most transects confined to a 15 km by 30 km area on the continental shelf which parallels the coastline between San

Mateo Point and Oceanside, hereinafter referred to as the San Onofre Shelf. (Moore, written testimony, p.7; Figure DGM-C)

471.The submarine topography [illegible] southern California comprises an irregular terrain of basins and submarine ridges bordered along the coastline by a narrow continental shelf that varies from less than a kilometer to a few tens of kilometers wide. The San Onofre Shelf is oval in shape and varies in width from 6 km in its northern end, to more than 9 km in the central area, narrowing again to about 6 km in the southern end near Oceanside. The narrow shelf here has a very gentle slope of about 10 meters per kilometer from the shoreline out to the 100 meter contour, near the shelf edge. The steep basin slope beyond the shelf edge has a declivity of over 260 meters per kilometer and extends down to the basin floor at a depth of about 800 meters. The greatest concentration of geophysical data is largly confined to the shelf area because of the adjacent topography and the nature of the strata underlying the shelf. The shelf edge is a natural barrier to the collection of useful geophysical data because of its steepness and the numerous sea gullies that have incised it to form a highly irregular topography. All of the geological structures important for SONGS 2 & 3 lie landward of this steeply sloping terrain and on the San Onofre Shelf. (Moore, written testimony, pp.4-6; Figures DGM-A, DGM-B)

472. Detailed examination and interpretation of a very large amount of relatively close spaced seismic reflection profiling data have provided information to construct a tectonic map of the San Onofre Shelf and have allowed interpretation of the structures in that area with a high degree of confidence. The greatest number of seismic transects and those having the closest spacing were concentrated in the shelf area south and southeast of SONGS where the data are of good quality, and they reveal a relatively complicated structural situation with well determined stratigraphic units. Collectively, more than 1000 km of seismic profile transects are contained within the San Onofre Shelf area with a line density of about 2.5 km per sq. km and an average line spacing of about 400 meters. (Moore, written testimony, p.7; p.9; p. 49; Figure DGM-C)

473. Because of the extraordinary line density of the seismic profile transects, Staff witness, Dr. G. Greene, (USGS) stated "[There was] no lack of general [offshore] data" (Greene; Tr. 2286). He went on to conclude that the track line spacing in this investigation is ". . . the greatest density of track lines that I've ever dealt with . . . ." (Greene; Tr. 2282).

474. Several different surveys were run during the last 10-15 years. Exhibit 36, DGM-L shows that the major structural features of the region were detected in a very rough way by the earliest reconnaissance survey done by

Marine Advisers in 1970. Dart core and bore hole samples of the sea floor were also taken to provide ages for the seismic stratigraphy seen in the recorded sections. The position of the survey track lines and bottom samples are shown in Figure DGM-C. The most recent surveys, the Woodward-Clyde (1978) and Nekton Survey (1980), data are important to the offshore investigations because of their high quality, resolution, and close spacing of transects which show major structural elements of the San Onofre Shelf in considerable detail. They also provide a high degree of confidence in correlating geological structures from one line to the next. The Nekton survey lines were specifically positioned, and data were collected in 1980 to cover the area south of the Woodward-Clyde survey where an offshore projection of the Cristianitos fault had been postulated to intercept the South Coast Offshore Fault within the South Coast Offshore Zone of Deformation. (Moore, written testimony, pp.8-9, 35; Tr. 2982)

III. GENERAL GEOLOGY

A. Offshore Geology

475. As shown by these surveys, a great thickness of rock strata underlies the near surface erosional and depositional features of the San Onofre Shelf. All of these strata were originally deposited horizontally or gently sloping, and they have subsequently been variously warped in places into folds or broken by faults as the region has been subjected to compressional, tensional, or shear forces. When

mapped and age dated, these rocks and their structural features indicate the tectonic history of the region. The most conspicuous and consistent features of the offshore shelf are those associated with the South Coast Offshore Zone of Deformation (SCOZD), on the western and southwestern edge of the Shelf. The SCOZD has been assumed to be one of the zone of folds and faults referred to as the Offshore Zone of Deformation (OZD) that includes the Newport-Inglewood Zone of Deformation (NIZD)to the north and the Rose Canyon Fault Zone (RCFZ) to the south. (Moore, written testimony, pp.10-13; Figure DGM-E)

476. The most important element of the SCOZD is the South Coast Offshore Fault (SCOF) which occurs as a single trace in the southernmost part of the area and as a double trace in the central part, extending to the northwestern part of the shelf as a less well-defined single trace. Over most of this length, the SCOF is associated with the crest or near the crest of a large anticline or anticlinorium designated the San Onofre Shelf Anticline (SOSA). Only in the southernmost part of the shelf where the SOSA dies out, does the SCOF continue as a single trace unassociated with folding. The SOSA and its eastward flanking syncline are much larger features than the very gentle folds to the east. (Moore, written testimony, pp. 13, 39)

477. Flanking the SOSA on the northeast is the San Onofre Shelf Syncline (SOSS), a very broad and conspicuous

asymmetrical fold on all seismic profiles that cross it. SOSA and SOSS show remarkable continuity along the central part of the outer San Onofre Shelf, where they are continuous for more than 9 km, or over 30,000 feet. Other fold pairs occur to the northwest and are similarly oriented to the SCOF, but they do not have the continuity of those to the south. (Moore, written testimony, pp.13-14)

478. The principal structural features of strata beneath the San Onofre Shelf are shown on Figure DGM-E. This structural map (DGM-E) is designed to display the amplitude or magnitude of folding as well as continuity of the major features and to contrast the age of faulting in the different parts of the area. (Moore, written testimony, pp.11-12)

479. In summary, the principal structural features on the San Onofre Shelf are the SCOF and the intimately associated SOSA and the SOSS. The folds in this zone are very long and continuous, whereas the principal features to the east are much smaller, shorter and discontinuous. The longest fold east of the SCOZD is only about 1/5 the size of the SOSA of the SCOZD. (Moore, written testimony, pp.14-15)

B. Onshore Geology and Relationship of the CZD and Cristianitos Fault

480. In addition to the extensive geologic mapping performed offshore, geologic mapping onshore has been performed for the Applicants to provide a comprehensive analysis of the Capistrano Embayment, its tectonic evolution

and stratigraphy and the tectonic settings of the Cristianitos fault (see Contention 4, Findings of Fact). In general, the analysis shows that the Cristianitos fault is a north-trending, west-dipping, listric-normal fault along the eastern margin of the Capistrano Embayment. The west side of the fault was downthrown during development and opening of the embayment between about 10 and 4 million years ago. Both the Cristianitos fault and the embayment were caused by east-west crustal extension. In Mid-Pliocene time the tectonic setting changed from east-west extension to north-south crustal shortening or compression, probably as result of plate convergence near the bend in the San Andreas fault. The Cristianitos fault does not have the proper orientation to be involved in the uplift and compression and appears to have been inactive since Late Pliocene time. The fault is known to have not moved during at least the last 125,000 years as demonstrated by the uniform terrace deposits of that age (stage 5e) overlying it in the sea cliff at San Onofre State Beach. The timing of displacement on the Cristianitos fault has been established by its relationship with sedimentary formations, which indicate that the fault was not present during deposition of the Middle Miocene Monterey and older formations. Displacement on the Cristianitos fault in Late Miocene time created a west-facing submarine scarp and caused a change in depositional environment, marked by the contact between the Monterey formation and overlying Capistrano formation. Onshore the Capistrano and the San Mateo formations occur only west of the Cristianitos fault. (Moore, written testimony, pp.15-17, Tr. 2977; Ehlig, written testimony, Contention 4, pp.16-20; J. Smith, written testimony, pp.37-38)

481. The use of the term Cristianitos Zone Of Deformation (CZD) implies that offshore structures within that zone are somehow related to the Cristianitos fault, an implication not supported by the seismic data. The Cristianitos fault is a discrete, single, normal fault resulting from east-west extension and, thus, is by nature a tensional feature. On the other hand, the faults and folds of the CZD are typical compressional features. Also, the faults of the CZD are shallow and generally do not extend downward to any great depth in the section as would be expected of an extensional feature such as the Cristianitos fault. (Moore, written testimony, p.45, Tr. 2997; J. Smitn, Tr. 867-868)

482. Much detailed profiling has been done along a projected seaward extension of the Cristianitos fault to test its postulated connection with the SCOF. Careful examination of seismic lines closest to the Cristianitos fault and across its offshore projection do not reveal any feature which could be interpreted as an extension of the Cristianitos fault beyond about 6,000 feet (2,000 meters) from the shoreline. Faults occurring farther seaward along a projection of the

Cristianitos fault have displacements that are opposite to that of the Cristianitos fault, and which are much too deep and old to be associated with the fault. The faults nearest such a projected offshore trend have been inactive for a period greatly predating the opening of the Capistrano Embayment and activity on the Cristianitos fault (Moore, written testimony, pp.44-45, 48; J. Smith, written testimony, Contention 4, pp.21-32, 37; Tr. 840-846, 870-873).

483. Additionally, the northerly trending zone of gentle folds and associated faults east of the SCOZD and west of the Cristianitos fault, i.e. the CZD, does not form a connection between the SCOZD and the onshore trace of the Cristianitos fault. (Moore, written testimony, p.37). Instead, faulting along the SCOZD contrasts strongly in terms of amount and continuity as well as age of faulting with that along the so-called CZD (Moore, written testimony, p.37). The CZD is largely associated with the Miocene Monterey formation. Southeast of this zone and inshore are a number of relatively minor folds and associated faults, which are associated with deeply buried older formations. (Moore, written testimony, p.14)

C. Stratigraphy of Offshore Area

484. The stratigraphy of the offshore area in the vicinity of SONGS, which is a very important aspect of Applicants' studies, has been interpreted in the context of the evolution of the Capistrano Embayment and the

Cristianitos fault, and has been based on extensive detailed geologic mapping done for the Applicants and extending inland several miles. Offshore stratigraphic units have been identified by correlating data from borings and dart cores with seismic reflection profile data. (Moore, written testimony, p.15; Tr. 2965-2967)

1. San Onofre Breccia

485. The oldest unit recorded offshore, and the unit that serves as effective acoustic basement, is believed to be the San Onofre Breccia which, because of its poor bedding, and lack of coherent internal reflectors produces a fuzzy appearance in the profiling records. It also underlies the sea floor off Dana Point at the northern boundary of the region. Consequently, data quality in this area is reduced significantly. South from Dana Point and approaching San Onofre, the relatively simple and nearly-horizontal bedded nature of the San Mateo and Capistrano formations make close spacing of seismic reflection profile lines unnecessary because, in areas of very simple structure, close-spaced traverses do not yield significantly greater information than wide-spaced lines. Early reconnaissance lines supplied ample data for identifying major structures in that area. (Moore, written testimony, pp. 6, 15, 18; Figure DGM-F; Tr. 3008-3012)

486. Farther southeast of the northerly-trending structures east of the SCOZD there are deeply buried faults

in the San Onofre Breccia overlain by undisturbed Monterey formation. (Moore, written testimony, p.43)

2. Monterey Formation

487. Overlying the San Onofre Breccia is the Monterey formation which has a very characteristic seismic signature of many strong, continuous, repetitive reflectors with very little scattering or defraction. Seismic profiles of the Monterey formation almost anywhere along the California coast show the characteristically well-developed bedding and its typical response to tectonic compression by formation of well-developed anticlines and synclines. Offshore San Onofre, older and younger units of the Monterey formation rocks have been mapped with an angular unconformity being clearly expressed between the two. The most pronounced folding has taken place at depth beneath the youngest Monterey unit. (Moore, written testimony, pp.18-19; Figures DGM-C, DGM-G, DGM-H, DGM-I)

3. Capistrano Formation

488. The Capistrano formation overlies the younger Monterey unit and is less well bedded than the Monterey formation. Several borings in the vicinity of the plant were also used to identify the Capistrano formation. The age of the Capistrano formation was determined to be about four to ten million years old showing a Delmontian Late Miocene age. (Moore, written testimony, p.20) The pinching-out in places of the Capistrano formation against the Monterey formation

indicates that some degree of folding took place in the SCOZD during the time the Capistrano formation was being deposited. In the northern part of the San Onofre Shelf, the Capistrano formation is relatively undeformed by faulting and folding except in the immediate vicinity of the SOCZD. The Capistrano formation and the younger unnamed Plio-Pleistocene unit overlying it disappear southward on the San Onofre Shelf. Onshore the Capistrano formation is sharply terminated on the east by the Cristianitos fault. On the San Onofre Shelf, however, the seismic stratigraphic unit identified with the Capistrano formation is less-sharply limited on the east and south. This is supportive of the lack of evidence for the Cristianitos fault on the San Onofre Shelf, and, hence, a less sharply defined easterly termination of the Capistrano formation. In summary, it is apparent that the SOSA and SOSS are by far the most prominent features on the shelf and that the area of gentle broad folding to the east is, with a few exceptions, of a much lesser amplitude and a different character. (Moore, written testimony, pp. 20, 39-40; Figures DGM-F, DGM-G, DGM-H, DGM-I)

4. <u>Plio-Pleistocene Rocks</u>

489. Offshore, a relatively-thick stratigraphic unit of Plio-Pleistocene age underlies younger Pleistocene terrace deposits. The unit is acoustically transparent and generally without good internal reflectors, suggesting it is soft and poorly stratified. This younger stratigraphic unit

can be clearly differentiated from the older bedrock formations by correlation and by the presence of intervening well-defined unconformity that appears on the seismic profile records. The intensification of the folding as indicated by the configuration of this and lower unconformities between the formations increases with depth and is most striking beneath the youngest Monterey formation unit. Folding in the Capistrano and younger units is relatively mild and, in fact, disappears in the northern part of the offshore area, north of Woodward Clyde line 841. (Moore, written testimony, pp. 20, 37-39; Figure DGM-H).

D. <u>Structure of Offshore Area</u>

1. <u>Previous Studies of CZD</u>

490. The features now characterized as the CZD have been known to people associated with the site for some period of time, were discussed back in the construction permit days, and were identified quite some time ago, before the Greene and Kennedy study (Devine, Tr. 6115) Much of the data on the structure of the offshore area in the vicinity of SONGS were generated several years ago by Marine Advisers and Western Geophysical. In 1970, Marine Advisers mapped several minor folds and faults in the vicinity of the CZD, but gave these features another name. (Moore, Tr. 4065-4070; Exhibit #36, DGM-L) In addition, in 1978, Woodward Clyde Consultants mapped a zone of minor folds and faults in the same general vicinity as the features mapped by Greene and Kennedy who, in

1980, assigned the name "Cristianitos Zone of Deformation." These features, mapped several years ago by the Applicants in the area of the CZD, have been shown to be several discontinuous faults of unknown strike on the shorter sections. (J. Smith, Tr. 829, 830, 864; Moore, Tr. 2982, 4069, 4084)

2. Relationship of South Coast Offshore Fault to the CZD

491. The youngest and most continuous faulting on the San Onofre Shelf is confined to the SCOF of the SCOZD. There is a striking difference in continuity and intensity of faulting between that of the SCOF and the relatively small and discontinuous faults associated with the folding to the east. The SCOF at some locations extends to the sea floor and through the Plio-Pleistocene sedimentary unit, thereby confirming the relatively recent activity or this fault. Throughout much of its length the SCOF is a dual-trace fault or a broad fault zone. In the northwestern part of the shelf, the SCOF appears to be dying out or becoming less distinct, and the SOSA and SOSS are becoming discontinuous. Toward the southeastern end of the shelf the SCOZD clearly changes its expression from that of a very large, complexly-faulted anticline to a single fault across which well-bedded Monterey Formation reflectors are juxtaposed against a zone of incoherent or fuzzy reflectors suggestive of San Onofre Breccia. (Moore, written testimony, pp.40-42)

492. The SCOF is best developed along the outer edge of the central part of the San Onofre Shelf where there is a change in trend of the fault from northerly to northwesterly. Along this change in trend, the fault is closely associated with the SOSA, and it is probable that the folding is a direct result of strike-slip faulting resulting from compression accompanying the change in direction. The faulting in the anticline is well developed and extends from the sea floor or near the sea floor to depths as great as surveying equipment is able to penetrate. In contrast, the north-trending folds of the CZD east of the SCOF are associated with largely intraformational faulting within the flexures. This is explained by recognizing that a thick sedimentary section of Monterey-type lithology can develop very high pore pressures and consequently low shear strength if bent even slightly. When gently or broadly folded this type of sediment typically develops many small folds or flexures along the crests of larger anticlines. The flexures are of a scale difficult to detect with seismic profiling equipment and, thus, often produce a record resembling a zone of disturbance or deformation, but which is not clearly related to faulting. Intraformational faulting has limited upward and downward extent, and commonly develops in association with this minor folding superimposed on larger broad folds as illustrated in Woodward Clyde profiles 836, 839 and 841 of Figure DGM-H. (Moore, written testimony, pp.42-43)

493. Greene and Kennedy's postulated connection of the CZD and the SCOF relies on the existence of a narrow band of fault-bounded deformation trending southeast at an angle to the main body of folding in the CZD. Dr. Moore interprets this deformation instead to be a deeply buried small anticline, and a nearby adjacent "fault" to be a misinterpretation of seismic-signal crossovers on a relatively steep-sided flank of the asymmetric SOSS. (Moore, Tr. 3074). Even if this fault and a connection with the SCOF existed, the area of the postulated connection is overlain by clearly unfaulted strata of probable Late Miocene age, requiring the conclusion that there has been no movement on the faults for at least 5-6 million years. Therefore, these questionable faults and their purported connection with the OZD have no real significance. (Moore, written testimony, pp.46-47; Tr. 3075)

494. Regarding a postulated connection between the SCOF and the CZD, it is also important to distinguish between connections of faults rather than of so-called zones of deformation. The orientation and continuity of faults is the key issue, inasmuch as only movement on faults can cause earthquakes. Folds are of great geologic interest in determining tectonic history, but are not associated with earthquake generation. Faulting in the CZD is the result of compressional forces related to folding. Faults of the CZD do not displace the Pleistocene erosional surface and,

therefore have not moved for thousands of years according to data based on the ages of the terraces. (Shlemon, written testimony, pp. 9-10) Therefore, Greene and Kennedy's postulated near connection of the CZD and the SCOF relies on questionable and difficult interpretation of deep faults in the records. However, unfaulted probable late Miocene strata overlying this area make it clear that movement on these questionable features has not occurred since Miocene time. (Moore, written testimony, pp.45-46, 48-49; Tr. 3074-3075, 3079)

495. The closest approach of faults of the CZD to the SCOF is approximately 10,000 feet (or 3.6 km) when measured along a projection of the onshore Cristianitos fault. This interpretation cannot support a postulated connection between the SCOF and the faults of the central shelf area. (Moore, written testimony, p.46)

3. <u>Data Voids</u>

496. In addition to the naming of some features as the CZD, Greene and Kennedy, in their analysis, noted areas as "data voids". (SER Appendix F, Plate 1, p.F-24) However, some areas noted as "data voids" by Greene and Kennedy are flanked by several seismic profiles or are transected by them (Moore, Tr. 2076; Exhibit #42, DGM-1).

497. In one instance involving a postulated connection between the OZD and CZD a line did not go through a specific point, where Greene and Kennedy believed data were

necessary and that area was called a "data void" (Greene, Tr. 2286). Since the need for data at a point is a subjective opinion, the designation of such a data void is also subjective.

498. Greene and Kennedy also testified that they are not complaining of a lack of geophysical profiles in certain other areas marked "data voids." These areas were marked "data voids" because Greene and Kennedy felt there were some problems with profile lines that they could not use to identify what they were looking for. (Greene, Tr 2283 - 2284) If a major fault, e.g., the Cristianitos fault, were to project through these data voids towards SONGS, these studies would almost certainly have shown it (Moore, Tr. 3082). Therefore, the designation of many data voids (in the SONGS offshore area) has little significance.

IV AGE OF THE CZD

A. Quaternary Studies

499. Once the regional and local stratigraphy and structure have been determined, it is necessary to evaluate and assign the ages to the various features. From the regional studies it is clear that broad tectonic uplift has been occurring for hundreds of thousands of years in the western United States, including the California coastline and the SONGS region, as indicated by elevated wave-cut platforms. While this uplift may indicate the existence of tectonic stress, it does so on a broad continental scale

rather than a local scale, and would include the 25 to 40 mile region surrounding San Onofre. (Shlemon, Tr. 3177-3180; SER, Section 2.5.1.8)

500. Applicants have investigated the broad chronological framework of the entire San Onofre region, on land and offshore, in order to extrapolate and determine the age of features offshore. The results of these investigations are contained in Exhibits #28,RJS-1, #29,RJS-2, and #30,RJS-3. These investigations showed the Quaternary stratigraphy in the San Onofre area to be rather remarkable and perhaps the best exposed on the entire west coast of the United States. (Shlemon, Tr. 3168)

501. Dr. Shlemon's investigations for the Applicants involved collecting and interpreting all relevant literature dealing with the Quaternary geology of the area. He also mapped marine and fluvial terraces and collected samples as appropriate to determine the age, continuity and deformation of marine platforms and their overlying sediments. Investigative procedures included measuring and describing soil profiles; collecting and interpreting water-well logs; obtaining and interpreting uranium-series, amino-acid, and radiocarbon dates; and associating terrace ages with the Quaternary marine isotope stage chronology. (Shlemon, written testimony, p.6) In support of both Dr. Shlemon and Dr. Moore, dart core and bore hole samples of the sea floor were also taken to provide ages for the seismic

stratigraphy seen in the recorded sections. (Moore, written testimony, p.8,

B. <u>General Results of Studies</u>

502. The gently sloping surface of the San Onofre Shelf is interrupted by several erosional wave cut platforms that mark former sea levels which fluctuated in response to glaciations during the Pleistocene epoch. These wave cut platforms truncate underlying strata of Miocene age and are covered by younger sediments laid down as the sea fluctuated to new levels (Shlemon, Tr 3189-3194; Exhibit #28,RJS-1, p. 32; Figures 6, 7). These platforms and the younger covering sediments are not displaced and their ages therefore provide a minimum date for any faulting that may have occurred in the vicinity of the San Onofre Shelf. (Moore, written testimony, pp. 9-10; SER, Section 2.5 1.12).

503. An analysis of the worldwide marine isotope chronology shows that there has been some 17 to 20 major fluctuations of sea level within about the last 700,000 years, caused mainly by glacial (low stand) and interglacial (high stand) alternations (Shlemon, Tr. 3190-3194; Exhibit #28,RJS-1, p. 32). A well documented high stand of sea level, referred to as substage 5e, took place about 125,000 years ago and is recorded onshore by the almost continuous, unbroken platform exposed in the seacliffs. Previous high stands of sea level are also recorded by other elevated marine platforms found throughout the Camp Pendleton area.

Younger fluctuations of sea level are recorded by submerged platforms offshore San Onofre. (Shlemon, written testimony, p. 10; Tr. 3135; SER, Section 2.5.1.12).

C. Age of Offshore Terraces

504. Several submerged platforms exist on the San Onofre Shelf. The ages of these platforms range from about 5,000 years to at least 40,000 years and possibly as much as 80,000 years old. (Shlemon, written testimony, pp.9-10, Figures RJS-A, RJS-B; SER, Section 2.5.1.12). Seismic profiles in this area show that no faults displace these platforms and that there is no deformation or faulting within the overlying covering sediments with the possible exception of an area at the northern part of the SCOF of the SCOZD. Confidence in the absence of faulting of the offshore platforms and overlying deposits is provided by the strong contrast of seismic reflectors between the younger sedimentary cover and the underlying Miocene-age rock. Nowhere east of the SCOF does displacement on the San Onofre Shelf extend upward into the Pleistocene erosional unconformity (Moore, written testimony, pp.21-22; SER, Section 2.5.1.12).

505. The terrace platforms offshore San Onofre are dated by radiocarbon of organic matter from younger covering sediments and by association with the worldwide marine isotope stage chronology. One of the platforms was probably cut during isotope stage 3 about 35,000 - 40,000 years ago,

and another during a preceding high stand, possibly isotope stage 5a, about 80,000 years ago or during a minor intermediate age level (Shlemon, written testimony, pp. 9-10, Figures RJS-A, RJS-B; Exhibit #28,RJS-1, Figures 6, 7). The older sediments covering the platforms are in the order of 20,000 to 40,000 years old. The younger sediments probably range in age from about 20,000 to 2,000 or 3,000 years old. The contact between these covering sediments is well defined on the seismic profiles. (Shlemon, Tr. 3170-3177). There is high confidence in the radiocarbon dates of 8,500 to 13,000 years for the youngest sediments covering the offshore terraces, because the dates are stratigraphically consistent and are not likely to be contaminated by younger organic matter. Although there are always some uncertainties in isotopic dating techniques, in most cases errors in the San Onofre samples favor a younger age, so that the dates obtained are minimal. (Shlemon, Tr. 3195-3197)

506. Radiocarbon dates and world wide sea level fluctuations (Flandrian transgression) indicate that the youngest offshore cover was deposited since the last 17,000 or 20,000 years. The underlying older cover was deposited prior to about 20,000 years ago. Conservative extrapolation suggests that the entire sequence of sediments covering the marine platforms offshore San Onofre are at least 35,000 to 40,000 years old. (Shlemon, Tr. 3183-3187)

507. The folds and faults of the so-called CZD have not had movement since Miocene time (Moore, written testimony, pp. 48-49). In addition, it is known that without exception the wave-cut platforms are not displaced. (Kennedy, Tr. 2455; SER, Section 2.5.1.12). Therefore, faults of the CZD have had no movement for at least about the last 80,000 years and possibly not for several million years.

D. Age of Onshore Terraces

508. Nine marine terraces were identified onshore in the San Onofre area. The Terrace 1 platform, investigated for at least 10 kilometers south to the Target Canyon area and 17 kilometers north to Dana Point, is the lowermost platform in the San Onofre onshore region and is traced almost continuously in the sea cliffs from about 10 km south of San Onofre to Target Canyon. It can be discontinuously traced northerly some 17 km to Dana Point. (Shlemon, written testimony, p.7; Exhibit #29,RJS-2) Although there are places where streams have eroded the platform or have covered it, the platform is almost continuously exposed over this distance, and the SONGS sea cliff area is one of the best exposures on the west coast. (Shlemon, Tr. 3134-3137) Excellent exposures of the sea cliff and the Stage 5e platform and 125,000 year old terrace deposits are observed unbroken from the northern end of the San Mateo flood plain north of SONGS, to south of SONGS (Shlemon, Tr. 3181).

509. Assurance of no displacement of the fluvial and marine terrace deposits is obtained either through direct observation or by projection of surfaces across unexposed areas. In the case of San Onofre and San Mateo Creeks, the exposures are sufficiently continuous such that resolution of vertical displacement by these methods is in the order of three to four feet. (Shlemon, Tr. 3203-3204) However, Terrace 1 is not exposed for approximately 7,200 feet north of the SONGS site where it is covered by younger fluvial materials or has been removed by erosion (Shlemon, Tr. 3137-3142). There are, however, other dateable geomorphic markers and stratigraphic units, including the San Mateo formation, to cover these minor gaps. (Shlemon, Tr. 3146; Exhibit #25,JLS-1, Drawing 2)

510. River terrace deposits laid down by ancestral San Mateo and San Onofre Creeks, dated at about 60,000 to 70,000 years old, have been observed in valley walls and found to be undisplaced where exposed from the coast upstream some 2 or 3 miles (Shlemon, Tr. 3152-3153). In addition, interpretation of water well logs from the lower San Mateo Creek area discloses a general continuity of buried gravels, indicating no displacement in the vicinity of the projected CZD (Shlemon, Tr. 3149). These logs show that the buried gravels of part of an ancient (glacial) channel of San Mateo Creek (QC-2), about 17,000 to 20,000 years old, preserved some 100 feet below sea level at the present coast line

(Shlemon, Tr. 3149). The modern floodplain deposits of San Mateo and San Onofre Creeks are flanked by fluvial terrace deposits (Q 4) and related soils in the 40,000 - 60,000 year-old range, and are undisplaced (Shlemon, Tr. 3200-3202, 3204, 3162). Additionally, these deposits are well exposed in other localities adjacent to SONGS including sea cliffs, and road and railroad cuts (Shlemon, Tr. 3156-3158).

511. In addition to dates based on terrace development and the worldwide isotope chronology, absolute dates on sediments in the San Onofre area were derived from radiocarbon analysis, uranium-series methods, and amino-acid techniques. The age ranges for these techniques overlap sufficiently to provide confirmation of the various dates obtained. In essence, Quaternary sediments at San Onofre, both onshore and offshore, have been dated by multiple methods including geomorphic and isotopic techniques. All methods yielded generally consistent results (Shlemon, written testimony, pp.8-10; Exhibits #28,RJS-1; #29,RJS-2; Tr. 3199-3200).

512. At San Onofre, Terrace 1 is overlain by about 60 feet of nonmarine deposits containing several buried paleosols, excellent stratigraphic markers to determine the age of the deposits and the last movement of any fault in the area. (Shlemon, Exhibit #28,RJS-1) Several age dating techniques demonstrated that Terrace 1 is about 125,000 years old. Terrace 1 clearly passes unbroken over the Cristianitos

fault as exposed in the seacliffs (Ehlig, Tr. 1103; Shlemon, written testimony, pp.8; Shlemon Tr. 3190-3194, 3212; Exhibit #28,RJS-1, pp.57-109; SER, Sections 2.5.1.8, 2.5.1.12) The absolute ages of the older and higher marine terraces at San Onofre are unknown; but, based on the marine isotope stage chronology, range from about 250,000 to almost a million years old, and these terraces are also not displaced. (Shlemon, Tr. 3190-3194, 3212)

513. No evidence for the postulated CZD has been found onshore at San Onofre. Examination of the sea cliffs between San Mateo and San Onofre creeks and between San Onofre Creek on the north and the Cristianitos fault on the south show no faults in either the Tertiary San Mateo formation nor in overlying 125,000 year old marine terrace and approximately 60,000 year old fluvial deposits (Shlemon, written testimony, pp.10; Exhibit #30,RJS-3, Figures 5, 5a, 6).

514. The sea cliffs and river valleys bordering San Mateo and San Onofre Creeks have also been inspected to determine if there may have been displacement of various geomorphic features and formations along any conceivable projection of the CZD. There is no deformation or displacement of the 4-10 million years old San Mateo formation nor of the younger marine and fluvial terrace deposits (Shlemon, Tr. 3204-3205). Therefore, from geomorphic expression and continuity, there is no evidence

for faults or folds of the CZD extending onshore at San Onofre (Shlemon, Tr. 3208-3209).

V. SU MARY

515. All seismic profiles examined show that faults associated with the CZD end at or below the surface of an apparent wave-cut platform that is overlain by acoustically transparent sediment. Nowhere within the CZD is there evidence of seafloor displacement. The CZD dies out to the north and has essentially disappeared within the area of the close-spaced Woodward-Clyde lines. Marine Advisers line S-26 farther north also shows no evidence of CZD folds, but homoclinally seaward-dipping beds. No faults of consequence extend onshore from the CZD offshore recording to analysis of the offshore data. (SER p. F-8; Moore, Tr. 2969-70, 3082-83)

516. The only capable fault within five miles of the SONGS site is t F which is an element of the SCOZD. (Moore, written testimony, p.49)

517. The onshore Cristianitos fault does not extend seaward for more than about 2,000 meters, and it does not have a connection or other structural relationship with the SCOZD. (Moore, written testimony, p.49)

518. Faults on the San Onofre Shelf that nearly coincide with the onshore trend of the Cristianitos fault are confined to horizons deep within the section and do not extend into the younger Monterey formation. They cannot be

related to the much younger movement on the Cristianitos fault. (Moore, written testimony, p.49; Tr. 3079-80)

519. Other faults east of the SCOZD in the CZD are associated with gentle folding and are largely intraformational. Most of them do not extend deep into the section or upward to the sea floor, and they do not have the intensity or continuity of deformation comparable to the SCOF. (Moore, written testimony, p.50)

520. Last displacement on faults of the CZD offshore SONGS occurred in Miocene time, about 5-6 million years ago (Moore written testimony, pp. 45-49).

521. Wave-cut platforms offshore San Onofre range in age from about 5,000 to possibly 80,000 years old, based on association with the marine isotope stage chronology and on stratigraphic relationship to overlying marine sediments dated by radiocarbon. Neither the offshore platforms nor overlying sediments are displaced by the CZD (Moore, written testimony, pp.46-47; Shlemon, written testimony, pp. 8-10; SER, Section 2.5.1.12).

522. The first marine terrace onshore, Terrace 1, is dated by uranium-series, amino-acid, faunal association and soil-stratigraphic techniques as about 125,000 years old (substage 5e). This terrace (platform) is an almost continuous stratigraphic marker in the San Onofre area crossing unbroken over the Cristianitos fault as exposed in

sea cliffs (Shlemon, written testimony p. 8; Tr. 3182; SER, Sections 2.5.1.8, 2.5.1.12).

523. Nine older terraces onshore at San Onofre are dated by association with the marine isotope chronology, and range in age from about 250,000 to almost a million years. None of these are known to be offset. (Shlemon, Figures RJS-A, RJS-B; Exhibit #28,RJS-1, Figures 5, 6)

524. Fluvial terraces bordering San Onofre and San Mateo Creeks, in the order of 60,000 years old, are traceable from the coastline some 2 or 3 miles upstream. Within the resolution of field measurements these terraces are not displaced by any onshore projections of the CZD (Shlemon, Tr. 3180; Exhibit #30,RJS-3, Figures 5, 5A, 6).

525. No evidence has been observed for displacement of the 125,000 year old marine platform, the 60,000 year old fluvial terraces, or the underlying Tertiary bedrock (San Mateo formation), in areas adjacent to SONGS where the CZD might be projected onshore (Shlemon, written testimony, p. 10; Exhibit #30,RJS-3, Figures 5, 5A, 6).

526. Certain offshore features characterized as a zone of deformation and referred to as the CZD are not structurally related to either the Cristianitos fault onshore or to the SCOF offshore. (Moore, written testimony, p. 50.) Furthermore, the so-called CZD fulfills the role of a non-capable fault (SER, Section 2.5.1.12). Therefore, neither characterization of the offshore features as a zone

of deformation or any additional information about this zone of deformation which became available subsequent to the issuance of the construction permit renders the seismic design basis for SONGS 2 & 3 inadequate to protect the public health and safety.

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CONTENTION 1

> Whether as the result of ground motion analysis techniques developed subsequent to issuance of the construction permit or data gathered from earthquakes which occurred subsequent to issuance of the construction permit, the seismic design basis for SONGS 2 & 3 is inadequate to protect the public health and safety.

I. COMPREHENSIVE REVIEW OF CURRENT THEORY AND DATA

527. Comprehensive investigations of earthquake effects have been conducted using current earthquake theory and earthquake recordings. The number of recordings close to potentially damaging earthquakes has approximately doubled during the eight years since the construction permit was issued in 1973. (Frazier, written testimony, pp. 9-10) Special studies have been undertaken to investigate strong-motion recordings of earthquakes throughout the world for relevance to ground motion predictions at SONGS (Hadley, Tr. 6379, 6380; McNeill, written testimony, pp. 1-3, Tr. 4020; SER, Sections 2.5.2.2 and 2.5.2.4.1; Idriss, Tr. 1739; Wight, written testimony, Contention 4, p. 5). Empirical studies of earthquake recordings performed by Applicant's consultants are unsurpassed for purposes of evaluating the adequacy of seismic criteria used for SONGS (Wight, Tr. 1668, 1669; Idriss, Tr. 1736-1738) The TERA Report (Exhibits #11,LHW-1 and #12,LHW-2) represents the best and most relevant analysis of peak ground acceleration data for large earthquakes at close distances that has yet been

done. (S. Smith, Tr. 3275) Even Intervenor's witness, Dr. Boore, of the United States Geological Survey (USGS) stated that he considers his study as appropriate but not more appropriate as that sponsored by the Applicants. (Boore, Tr. 6541, 6542)

528. Similarly, the TERA/DELTA theoretical studies of earthquake motions (Exhibits #21,GAF-1 through #24,GAF-4) are the most extensive yet achieved for modeling broad-band earthquake motions. (Reiter, Tr. 3546 (response to Board request for Staff opinion); Frazier, written testimony, p. 8) Thus, the evidence is clear and uncontroverted that the Applicants have thoroughly examined both earthquake theory and data for appraising the adequacy of the seismic design basis for SONGS 2 and 3.

II. RECENT THEORETICAL ADVANCEMENTS

529. The principal theoretical advances in earthquake ground motions have been made possible by implementation of digital computer techniques to appraise effects of various geophysical processes: (1) the fracture producing the earthquake and (2) propagation of seismic waves from fracture to site. (Frazier, written testimony, p. 2)

530. Forward method models are highly idealized, but provide useful information on speed of fracture spreading, the abrupt onset of slip at leading edge of a crack, and fault-offset/stress-change relationship for various fracture sizes. The uncertainties in this approach

are large, and the reliability for modeling actual earthquake fracture has not yet been established. Consequently, the forward method is best used as a guide to the gross characterization of earthquake fractures. (Frazier, written testimony, pp. 3-5)

531. The most reliable characterization of earthquake fracture is obtained by combining the forward and inverse methods by adjusting results from simulations of idealized cracks so that they are consistent with actual recorded motions. This was done for SONGS to provide the least complicated characterization of the fracture process consistent with recorded data. However, this simplest characterization yields more high frequency waves in the expansion direction of rupture than has been recorded for past earthquakes. To compensate for this, irregularities were introduced into the fracture process, thus subduing the excess focusing of high frequency waves in accordance with observations. (Frazier, written testimony, pp. 6-7; Exhibits #21,GAF-1, #22,GAF-2, #23,GAF-3, #24,GAF-4)

532. The key to improved theoretical understanding has been the capability to calculate wave propagation effects through realistic earth models, which in turn has permitted a better isolation of the actual source effects on ground motion. Two important results that have emerged are: (1) that the rupture propagation phenomenon is incoherent at high frequency; and (2) that focusing has proved to be

of limited importance for peak ground accelerations. (S. Smith, written testimony, p. 3)

533. Propagation characteristics of seismic waves vary with different geologic environments, and are influenced by transmission velocities of rocks, depth, and trajectory. The computer method (PROSE) used for SONGS is the best available method for modeling ground motions near large earthquakes. (Frazier, written testimony, pp. 8-9.)

534. The great potential of the theoretical models for predicting strong ground motion is that extrapolations can be made to geometric circumstances or site conditions where little data exists. (Frazier, Tr. 3327-3328; Brune, written testimony, p. 38, 43)

535. Current state of the art is such that with considerable effort detailed modeling studies can be performed to estimate site-specific ground motions for postulated future earthquakes. (Frazier, Tr. 3621-3622) The Staff concluded in its review, that the modeling procedure utilized by Applicants demonstrates the conservatism of the empirically derived spectra and particularly the SSE. (SER, Section 2.5.2.4.2)

536. Earthquake theory and earthquake recordings support the conclusion that the SONGS 2 & 3 DBE high frequency acceleration anchor point (0.67g) and design spectrum are acceptable, i.e., the DBE used for SONGS is conservative with respect to the largest postulated

earthquake on the OZD. (Frazier, written testimony, pp. 23-24; SER, Section 2.5.2.5)

III. EARTHQUAKE DATA SINCE 1973

A. Overview

537. In 1972 the maximum magnitude earthquake for the OZD had not been established. (S. Smith, written testimony, Contention 4, pp. 12-13) However, it was well recognized that the design was for a very large nearby earthquake. The best data available indicated that a Peak Ground Acceleration (PGA) anchor point of 0.5g, with a spectral shape defined by propagating strong ground motion data through the San Mateo formation, would define an adequate free-field spectrum. Additional conservatism was added by increasing the zero period response to 0.67g, by modifying upwards the shape of the response spectra and finally by using the so-modified free-field response spectrum directly for design (McNeill, written testimony, Contention 4, pp. 18-19; see also Applicants Findings of Fact, Contention 4, Section XII.B)

538. Since 1972 the data base of strong-ground motion accelerograms has approximately doubled (Frazier, written testimony, pp. 9-10; S. Smith, written testimony, p. 1). Experience has shown that as new data is obtained from earthquakes, it confirms and tightens the projections that have been made in the past. (S. Smith, Tr. 3251). For example, comparisons between the SONGS DBE and our enhanced

data base confirms the conclusion that the seismic design is a conservative representation of a very large, nearby earthquake. (McNeill, written testimony, pp. 4-5; written testimony, Contention 4, pp. 24-25). Indeed, Dr. McNeill testified that if he were to alter the current DBE, he would reduce the severity of the existing spectrum. (Tr. 4017) This state of affairs is also echoed in the National Academy of Sciences statement that many critical structures are overdesigned, at significant cost to society. (Allen, Tr. 4668-4669)

539. The current strong-ground motion from several well-recorded earthquakes provides a basis for examining the likelihood of an event occurring on the OZD with unusual or extreme source characteristics that would significantly bias PGA. Peak accelerations from one earthquake are about as consistent with those reported for other earthquakes, of comparable magnitude and distance, as they are self-consistent. (Frazier, written testimony, pp. 11, 14; Tr. 3623)

540. The statistical study done in the TERA Report (Exhibit #11,LHW-1 and #12,LHW-2) indicates that the principal scatter in PGA is not due to unusual source properties but rather from whatever causes scatter for a single earthquake. This scatter may be characterized in a rather loose sense as being station correction factors. This conclusion is significant in that it directly addresses the

probability of surprises in terms of something unusual happening in the future. Such a happening is improbable. (Frazier, Tr. 3623-3625)

B. Exceptional Data

541. The most relevant comparison to the DBE at SONGS would be from several heavily instrumented, strike-slip earthquakes of approximately magnitude 7. Such ideal earthquakes are not available, so data from other similar earthquakes must be used. Six earthquakes selected as most appropriate occurred in Imperial Valley, California, Iran, Russia, Baja California, Italy and Mammoth Lakes, California. The characteristics of these earthquakes differ from those assumed for the SONGS 2 & 3 DBE, particularly in their mechanism of fault slip. However, they were all more than M 6, their source-site distance was less than 20 km, the instruments stations were free field or in small buildings on level ground, and they occurred after 1973. Also, for each of these event records, at least one component exceeds the 84th percentile value (16% of the data from a given population should exceed this value of PGA, (McNeill, Tr. 4028) predicted by the TERA attenuation relationships for the magnitude and source-site distance of that particular earthquake. These recordings were scaled appropriately to the conditions assumed for SONGS 2 & 3 (M 7, source-site distance 8 km) and values were calculated for PGA. These values were then compared to the Zero Period Acceleration

(ZPA) of the SONGS 2 & 3 DBE (McNeill, written testimony, pp. 1-3; Table RLM-1; Tr. 4028). Dr. McNeill noted that his compilation of earthquake recordings excluded no relevant data. (McNeill, written testimony, p. 1; Tr. 4020)

542. None of the scaled values exceed the ZPA of the SONGS 2 & 3 DBE, and their average was about 40%-50% of the SONGS ZPA, thus demonstrating the conservatism of the SONGS DBE in comparision with exceptionally strong motions recorded in significant recent earthquakes. (McNeill, written testimony, p. 4; Table RLM-1)

C. Imperial Valley 1979 Earthquake

1. General Findings

543. Although all parties do not agree on the precise magnitude of the 1979 Imperial Valley earthquake (moment magnitude = 6.5 by Kanamori and Regen (1981), Brune written testimony, p. 48; M_S = 6.9, McNeill written testimony, p. 2), the U. S. Geological Survey has determined a value of M_S = 6.9 (Brune, Tr. 4378). This magnitude is derived from an average of world-wide stations according to the procedure commonly used by the U. S. Geological Survey. (Brune, Tr. 4380)

544. The Imperial Valley, California, earthquake of October 15, 1979, is important to SONGS 2 & 3 for several reasons: (1) the mechanism (strike-slip) and magnitude (M_S6.9) are essentially the same as postulated for the source of the DBE offshore of SONGS 2 & 3; (2) the tectonic setting,

(southern California) is comparable; and (3) the instrumentation was extensive enough to derive important properties of fracture propagation, characterizations of strong ground shaking close to a large fault, and the attenuation of shaking with distance away from the fault. (Frazier, written testimony, pp. 11-14; Figures GAF-E, GAF-F, GAF-G, GAF-H; SER, Section 2.5.2.4.3)

545. The 1979 Imperial Valley earthquake (IV-79) has invalidated some earthquake hypotheses while others have been confirmed. The concepts that have found added support include: (1) Peak accelerations close to earthquakes of large magnitude depend only weakly on value of the earthquake magnitude; (2) The effects of focusing on acceleration peaks are much less important than those obtained from simple coherent fracture theory. The average horizontal acceleration close to the surface exposure of fracture is less than 0.5g regardless of whether averaged over the nearest 1 km, 2 km, or any other distance; (3) Peak horizontal accelerations saturate with decreasing distance to the earthquake fracture; (4) The scatter in recorded acceleration peaks from one recording site to another is comparable to the scatter in acceleration peaks recorded for several different earthquakes when properly scaled for magnitude and distance effects. This indicates that dissimilarities in earthquake fractures are not the major source of uncertainties in predicting ground motion. The

major uncertainty results from whatever mechanism causes dissimilarities in the recording for a single earthquake (principally station-correction factors). (Frazier, written testimony, pp. 12-13; Figure GAF-H)

546. IV-79 is dissimilar and less applicable to SONGS 2 & 3 with regard to near-surface geology, in which the thickness and seismic velocity of sediments overlying crystalline basement are significantly different. Consequently, velocity peaks and vertical acceleration peaks would be expected to be higher in Imperial Valley because of the deep soft sediments there and that expectation is supported by the data from IV-79. The SONGS area can be chacterized by a shallow basement overlain by consoldiated higher-velocity sedimentary rocks. (Frazier, written testimony, pp. 14-15; Figure GAF-I)

547. Considering the composite of these differences in geology between Imperial Valley and SONGS, it is concluded that horizontal motions for IV-79 are representative of what to expect for a comparable large earthquake on the OZD while vertical accelerations would be about 30% lower at 8 km from the OZD than those for IV-79 at a comparable distance. (Frazier, written testimony, p. 21; Tr. 3416)

2. Horizontal Accelerations - Imperial Valley Earthquake, 1979

548. The horizontal accelerations recorded from the IV-79 earthquake are about as high as have been recorded in other earthquakes. (Brune, Tr. 4387)

549. The mean and 84th percentile peak horizontal accelerations for IV-79 at 8 km are significantly below the M_s7 regression values derived for SONGS, and they are significantly below the .67g acceleration used as the horizontal design basis for SONGS 2 & 3. (Idriss, written testimony, Contention 4, pp. 14-15; Figure IMI-C; Exhibit #19, IMI-7, Figure 361.55-5; Exhibit #20, IMI-8; Tr. 1745-46; McNeill, written testimony, Contention 4, p. 24; SER, Section 2.5.2.4.4)

3. Vertical Accelerations - Imperial Valley Earthquake, 1979

550. Unexpectedly high vertical accelerations at some recording stations for IV-79 were the result of P-waves radiating horizontally outward from the fracture and, because of the gradual increase in material velocity with increasing depth, refracting sharply towards the earth's surface. Consequently, higher amplitude P-waves emerged close (10 km) to the earthquake fracture. These conditions are not similar to those at SONGS, and unusually high vertical accelerations are not likely. (Frazier, written testimony, pp. 15-18; Figures GAF-I, GAF-J, GAF-K; Idriss, written testimony, p. 2; Tr. 3636; McNeill, written testimony, Contention 4, pp. 24-25; Figure RLM-R; SER, Section 2.5.2.4.6)

551. The vertical components in the IV-79 earthquake are typically very rich in high frequencies. As the damping is increased in the calculation of the response

spectrum these high frequencies are rapidly suppressed relative to longer periods. Although the acceleration peaks for the IV-79 vertical data exceed the vertical DBE of SONGS, this occurs only in the narrow period range of 0.05 to 0.12 seconds. The exceedance is less than about 20% and is not significant for design. (Idriss, written testimony, p. 1; Tr. 3645; SER, Section 2.4.2.4.6)

552. The high vertical accelerations recorded within the Imperial Valley did not correlate with damage. These very high-frequency vertical spikes are not occurring at the same time as the maximum horizontal motions, seem to be of relatively little significance. (Reiter, Tr. 5881)

553. The two-thirds vertical-to-horizontal ratio adopted for design of SONGS was based on data from many earthquakes. On the basis of this statistical analysis it is felt that the two-thirds ratio is a conservative estimate. (Reiter, Tr. 5857-5858, 5860)

554. As the data base is increased, reliance on ratios for determining vertical acceleration for purposes of design has become less meaningful. It is much more important to consider the absolute value of the numbers relative to the design. The absolute values for the vertical PGA are well within the values being used for design and analysis (Idriss, Tr. 3636) and all lie below the instrumental form of the SONGS DBE. (McNeill, written testimony, Contention 4, pp. 24-25)

555. None of the vertical accelerations from the exceptional events analyzed by McNeill exceed the vertical instrumental form of the DBE. The average value for these events is a little over one half of the zero period acceleration for the DBE. (McNeill, Tr. 4025)

556. The vertical DBE spectrum as used for the design of SONGS 2 & 3 is a conservative representation of the motions of structures at the site due to a very large nearby earthquake. (McNeill, written testimony, Contention 4, pp. 24-25)

D. Mammoth Lake Earthquakes, 1980

557. Four earthquakes, magnitude range 6.0 to 6.7, occurred in the Mammoth Lake region of California in May, 1980. The region was instrumented with strong-ground motion recorders deployed by the California Division of Mines and Geology. Dr. Anderson installed additional stations that recorded the last large event (Hadley, Tr. 6386; Anderson, Tr. 4624). In total, 37 values of peak acceleration were recorded during these earthquakes. These new data provide independent information for evaluating the appropriateness of Applicants' regression curves for PGA and also have been included in McNeill's study of exceptional recordings (McNeill, written testimony, Table RLM-1). Had these data been available when Idriss carried out the PGA study described in Applicants' Exhibit #14,IMI-2, they would have been included in the data base (Hadley, Tr. 6390-6391). Out

of the 37 measurements, 67.6% of the data are below the mean, 18.9% are between the mean and the 84th percentile, and 13.5% are above the 84th percentile. Therefore, the regression study for PGA described by Idriss is conservative in that it overestimates the mean and 84th percentile of the more recent data (Hadley, Tr. 6391).

E. Historical Perspective of Estimated Values of Peak Ground Accelerations

558. Experience has shown that as new data are obtained, they confirm and tighten the projections that have been made in the past (S. Smith, Tr. 3251; Frazier, written testimony, p. 10). As further evidence of this fact, Intervenor's witness Dr. Boore testified on cross examination that, since 1972, U.S.G.S. personnel have released at least four documents describing the behavior of peak acceleration. U.S.G.S. Circular 672 (1972) predicts a mean of 0.9g for magnitude 6.5 at distances of 3-5 km. Circular 795 (1978) predicts a mean of 0.8g for magnitude 6.5 at 3-4 km. Open-File Report 81-365 (1981) predicts a mean of 0.48 for magnitude 7 at 8 km. The fourth, a revision of Open-File Report 81-365 document, is in press. (See Applicants Findings of Fact, Convention 4, Section IX. C) The U.S.G.S. predictions of PGA values for large earthquakes at small distances have systematically decreased over the years. (Boore, Tr. 4754, 6563-6584)

F. Trabuco Canyon Earthquakes: 1975 Events and 1977 Microseismic Events

559. The average level of micro-seismic activity in the region of the Cristianitos fault is about a factor of four or five lower than the average for the entire state. Compared with other areas of southern California, the seismic activity in this area is very low. However, the region is not aseismic and small earthquakes are located randomly throughout the region. (Biehler, Tr. 3982-83, 3999; SER, Section 2.5.2.2)

560. The two largest recent earthquakes located within the region since the construction permit occurred within about seven minutes of each other on the morning of January 3, 1975, several kilometers west of the Cristianitos fault. Their local magnitudes were 3.8 and 3.3; and although they were felt in nearby communities, they did not trigger strong motion instruments having a lower threshold of 0.01g at SONGS, approximately 20 km away. A field survey in the epicentral region and along the Cristianitos fault did not locate any ground surface rupture. (Biehler, written testimony, pp. 4-5)

561. Because the crustal velocity model used to locate earthquakes in southern California is a regional average, it was necessary to develop a refined crustal velocity model for a more limited region in order to locate the epicenters more accurately and to fix limits on the

hypocentral depths. Data for the new model were developed from two calibration blasts that were located slightly east of the two epicenters. Although the blasts were fairly small, clear compressional wave arrivals were obtained at seismic stations located at considerable distances from the blast. The eleven seismic stations in southern California that recorded this calibration shot and the earthquakes of January 1975 provide sufficient data to obtain accurate earthquake location. This location, based on calibrated data, is more accurate than could be obtained with the 30 uncalibrated stations that recorded the earthquakes. A computer program developed by the U. S. Geological Survey, HYPO71, was used to locate these events. Accordingly, a horizontal uncertainty of 0.7 km and 1.2 km was obtained. Depth estimates for both events range from 2.0 km to 4.0 km, with depth error estimates in the range of 1.3 to 2.6 km. (Biehler, written testimony, pp. 5-6; Exhibit #31,SB-1, Figure 16; Tr. 3958)

562. The consistency of the earthquake locations under various changes in model assumptions suggest that the true errors are less than the statistical errors indicated by the program HYPO71. (Biehler, Tr. 3964)

563. There is no evidence suggesting that these events have a style of faulting similar to that of the Cristianitos fault. First motion readings from 30 stations surrounding the two events have been used to compute focal

mechanisms. The focal mechanisms indicate that the two events were characterized by strike-slips with a significant thrust component. This motion is oblique to the trend of the Cristianitos fault. Furthermore, the relative orientation of the two earthquakes, their closeness in time and space, and the identical focal mechanisms strongly suggest that the actual fault plane of the earthquake strikes northeast and dips 53°NW. This is approximately parallel to the trend of Trabuco Canyon. Motion on this plane is thrust, left-lateral, oblique-slip. The focal mechanism, therefore, indicates that the motion is not the same as would be expected from the Cristianitos fault which is dip-slip toward the west-southwest. The spatial separation of these two events from the Cristianitos fault and the different sense of motion strongly support the conclusion that these events were not associated with the Cristianitos fault. (Biehler, written testimony, pp. 7-8; Exhibit #31,SB-1, Figures A6, A7)

564. If the Cristianitos fault is a listric-normal fault as described by Dr. Ehlig, then the flattening of the fault plane occurs at the top of the basement rocks. The depth to the point where the dip of the fault plane significantly flattens is approximately 2-3 km below the hypocentral locations discussed by Biehler. (Biehler, Tr. 3969, 3970)

565. Assuming the shallowest possible planar dip on the Cristianitos fault, the January 1975 earthquakes cannot

be associated with this structure. If, however, the fault is allowed to have some arbitrary orientation at depth, then the hypocenters could be placed on or near the fault. The important constraint is that the orientation of the fault planes for these two earthquakes and the sense of motion is completly opposite to what would be expected for the Cristianitos fault. The assessment of motion on an old fault plane by a small earthquake is only valid if the earthquake both occurred on the fault surface and if shearing was in the same direction as the fault. (Biehler, Tr. 3933-35, 3988; Allen, Tr. 4736; Reiter, Tr. 5746; SER, Section 2.5.1.7)

566. Five small earthquakes the largest of which was magnitude 2.8, occurred between June 29 and July 1 of 1977. These events were located very close together, essentially within a volume of rock having dimensions of only a few hundred meters. Using the velocity model developed for this region, the location of these events is about 2.5 km north of the 1975 events and within Trabuco Canyon. (Biehler, written testimony, p. 8)

567. There is insufficent first motion data to reliably constrain the focal mechanism for these events. Although the strike of the focal planes in unknown, the data are consistent with a thrust mechanism similar to that of the 1975 events. (Biehler, written testimony, pp. 8-9)

568. In conclusion, the 1977 cluster and the 1975 events were associated with each other and with the alignment

of the northeasterly trending Trabuco Canyon. They were not associated with the Cristianitos fault. (Biehler, written testimony, p. 9; SER, Section 2.5.1.7)

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CONCLUSIONS OF LAW

569. Any finding of fact which is more properly a conclusion of law is hereby incorporated in these conclusions of law.

570. Upon consideration of the record of the proceeding and in light of the foregoing findings and discussion, the Board concludes that, with respect to the requirements of the Atomic Energy Act of 1954, as amended, and the rules and regulations of the Commission relating to radiological health and safety and the common defense and security:

(1) The geologic, seismic, and engineering characteristics of the SONGS site and its environs have been investigated in sufficient scope and detail to provide reasonable assurance that they are sufficiently well understood to permit an adequate evaluation of the proposed site, and to provide sufficient information to support the determinations required by these criteria and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the plant site [10 CFR Part 100, Appendix A, IV]; and

(2) In designing SONGS 2 & 3, Applicants have taken into account the potential effects of vibrating ground motion caused by earthquakes. The design basis for the maximum vibratory ground motion and the expected

vibrating ground motion have been determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and the surrounding region. Applicants have identified the most severe earthquakes associated with tectonic structures or tectonic provinces in the region surrounding the site. Applicants have determined the most severe earthquake that could be associated with the controlling feature at the SONGS site -- the Offshore Zone of Deformation-- by considering its geologic history. Applicants then have determined the vibratory ground motion at the site and have designated the earthquake which could cause the maximum vibratory ground motion -- the Safe Shutdown Earthquake. [10 CFR, Part 100, Appendix A, V]; and

(3) Applicants have thoroughly conducted all investigations required to obtain the geologic and seismic data necessary to determine site suitability and provide reasonable assurance that SONGS 2 & 3 can be constructed and operated at the proposed site without undue risk to the health and safety of the public. [10 CFR, Part 100, Appendix A, II]; and

(4) Construction of the facility has been substantially completed in conformity with the construction permit and the application as amended, the provisions of the Atomic Energy Act of 1954, as amended,

and the rules and regulations of the Commission [10 CFR § 50.57(a)(1)]; and

(5) The facility will operate in conformity with the application, as amended, the provisions of the Atomic Energy Act of 1954, as amended, and the rules and regulations of the Commission [10 CFR § 50.57(a)(2)]; and

(6) There is reasonable assurance (i) that the activities authorized by the fuel load and full power operating license can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations. [10 CFR, § 50.57(a)(3)]; and

(7) Southern California Edison, et al, are technically and financially qualified to engage in the activities authorized by the fuel load and full power operating license in accordance with the Commission's regulations [10 CFR § 50.57(a)(4)]; and

(8) The applicable provisions of 10 CFR Part 140 will be satisfied prior to fuel load [10 CFR § 50.57(a)(5)]; and

(9) The issuance of a fuel load and full power testing license will not be inimical to the common defense and security or to the health and safety of the public.

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ORDER

IT IS HEREBY ORDERED, pursuant to the Atomic Energy Act of 1954, as amended and U.S. Nuclear Regulatory Commission regulations, and based on the findings and conclusions set forth herein, that the Director of Nuclear Reactor Regulation is authorized to issue to Applicants Southern California Edison Company, San Diego Gas & Electric Company, City of Anaheim, California and City of Riverside, California a license to authorize fuel load and full power operation for Units 2 and 3 of San Onofre Nuclear Generating Station, for a term of not more than forty (40) years, at state power levels not exceed 1100 megawatts thermal per Unit.

IT IS FURTHER ORDERED, in accordance with Sections 2.760, 2.762, 2.764, 2.785 and 2.786 of the Commission's Rules of Practice, that this Initial Decision shall be effective within thirty (30) days from the date this Initial Decision is transmitted to the Commission and shall constitute the final action of the Commission subject to any review thereof pursuant to the above cited rules.

ATOMIC SAFETY AND LICENSING BOARD

James L. Kelley, Esq., Chairman

Dr. Cadet Hand, Jr.

Mrs. Elizabeth B. Johnson

Dated at
this day of , 1981