July 6, 1983

APPLICANT'S FINDINGS OF FACT ON
REMEDIAL SOILS ISSUES AND SEISMIC MODELS

A. INTRODUCTION

1. All nuclear power plants, even plants like Midland which are not located in seismically active regions, must be designed and built to protect the public from the hazards of radioactive releases should the plant be subjected to movements in the earth's crust.[1] In 1972, when the construction permits for Midland were issued, the AEC approved two postulated earthquakes for seismic design purposes: an "Operating Basis Earthquake" with a ground acceleration of 0.06g, and a "Maximum Earthquake" or "Design Basis Earthquake" with a ground acceleration of 0.12g, where "g" represents the acceleration at the earth's surface due to gravity.[2]

2. In 1973, 10 C.F.R. Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants" was promulgated.[3] The express purpose of Appendix A is to set forth the principal seismic and geologic considerations which guide the

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1 Pacific Gas & Electric Co. (Diablo Canyon Nuclear Power Plant, Units 1 & 2), ALAB-644, 13 N.R.C. 903, 909 (1981), quoting ALAB-519, 9 N.R.C. 42, 45 (1979); Holt, prepared testimony at p. 14, following Tr. 4539; Holt Ex. 10, p. 8; Kimball, prepared testimony at p. 18, following Tr. 4690.

2 See CPCo Application of Reactor Construction Permit and Operating License, Preliminary Safety Analysis Report ("PSAR") Section 2.7.5 (Amendment No. 5, 11/3/69); AEC Staff Safety Evaluation p. 13 (11/12/70); Consumers Power Company (Midland Plant, Units 1 and 2) LBP 72-34, 5 A.E.C. 214, 219 (December 14, 1972).

3 38 Fed. Reg. 31,281 (November 13, 1973), as amended at 38 Fed. Reg. 32,575 (November 27, 1973) and at 42 Fed. Reg. 2052 (January 10, 1977).

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Commission in its evaluation of proposed sites for nuclear power plants and the suitability of the plant design bases. Two basic decisions are involved in the Appendix A methodology: first, a Safe Shutdown Earthquake ("SSE") is selected based on evaluation of capable faults, tectonic structures, and tectonic provinces,[4] and, second, response spectra[5] representing the vibratory ground motion produced by the postulated SSE are constructed.

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4 A Safe Shutdown Earthquake or SSE "is the seismic event 'which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional.'" Pacific Gas & Electric Co., (Diablo Canyon Nuclear Power Plant, Units 1 & 2), ALAB-644, 13 N.R.C. 903, 910-911 (1981), quoting 10 C.F.R. Part 100, App. A, §III (c). An Operating Basis Earthquake or OBE is also considered in designing nuclear plants. 10 C.F.R. Part 100, App. A, §III (d). An OBE "is the largest earthquake considered likely to occur during a plant's operating lifetime. Nuclear facilities must be designed and built to function through the OBE without creating undue risk to the public health and safety." ALAB-644, 13 N.R.C. at 911. For consideration of plant design "the distinction between the OBE and the more severe SSE is in essence this: the SSE is the seismic design basis for safety-related or 'Category 1' structures and equipment and the OBE the benchmark for the balance of the plant." ALAB-644, 13 N.R.C. at 989.

5 10 C.F.R. Part 100, App. A, §V(a)(1)(iv). Response spectra relate the response of the foundation of the structures to the vibratory ground motion considering such foundations to be single degree of freedom damped oscillators and neglecting soil-structure interaction effects. Holt, prepared testimony at p. 4, following Tr. 4539. The Atomic Safety Licensing Appeal Board has stated that:

> . . . a response spectrum is the result of an analytical procedure whereby a number of one-degree-of-freedom harmonic oscillators, each having the same degree of damping but with different natural frequencies, are driven by the time-dependent motion characteristic of a real or postulated seismic event. For a particular event and degree of damping there will be a time-

(continued on page 3)

3. In 1978 in connection with the operating license review for Midland, the Applicant proposed an SSE, determined in accordance with 10 C.F.R. Part 100, Appendix A, which was consistent with the Design Basis Earthquake approved for Midland at the construction permit stage.[6] The Applicant stated that the Midland site lies in the Michigan Basin tectonic province which is part of the Central Stable Region of North

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(footnote [5] continued from page 2)

> dependent response which varies for oscillators of the different frequencies. The maximum values of the response of the oscillators in terms of acceleration, velocity and displacement, may be plotted as a function of the frequency of the oscillators being excited. Such a plot can be produced for any one of the three parameters taken individually. Because of the relationship among acceleration, velocity and displacement under harmonic motion, a tripartite plot showing the maximum responses in acceleration, velocity and displacement as a function of oscillator frequency may also be prepared.
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> Response spectra tend to have jagged peaks and valleys. For engineering analysis and design purposes these can be evened out either (1) by drawing a smooth curve enveloping the peaks (or by averaging the peaks and valleys), or (2) by statistically combining individual spectra derived from similar earthquakes. When so smoothed they are sometimes called "design response spectra."

Pacific Gas & Electric (Diablo Canyon Nuclear Power Plant, Units 1 & 2) ALAB-644, 13 N.R.C. 903, 924 n. 40 (1981). See also paragraphs 31-44, 55-58, infra.

6 Because this proposed earthquake was submitted to the NRC Staff for their review in Applicant's Final Safety Analysis Report, it is hereinafter referred to as the "FSAR SSE."

America. By using the Michigan Basin, instead of the entire Central Stable Region, to determine the historical seismicity the Applicant determined the SSE for Midland to be one with a Modified Mercalli Intensity ("MMI") of VI.[7] The ground motion which would be produced by the occurrence of the FSAR SSE at the site was characterized by modified Hausner Response Spectra anchored at 0.12g.[8]

4. During the course of its Operating License review the NRC Staff initially found insufficient support that the Central

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7 An earthquake's size is defined either in terms of intensity or magnitude. Intensity is based on the effects felt as reported by persons witnessing the earthquake. Modified Mercalli Intensity or MMI is the standard scale used to measure intensity. Holt. Ex. 4.

An earthquake's magnitude is defined on the basis of instrumental recordings. Thus magnitude is a more accurate measure of earthquake size than intensity, but instrumental recordings are not available for many historical earthquakes. Holt, prepared testimony at p. 4 n.1, following Tr. 4539. There are several accepted magnitude scales used in different areas of the world, and this caused some confusion in the record. See note 108, infra. However, unless otherwise indicated in this Partial Initial Decision, "magnitude" refers to body wave magnitude, M_{blg}.

8 The Hausner Response Spectra were modified by increasing the 0.2 to 0.6 seconds period response by fifty percent. "Anchored" refers to the "g" value at the high frequency end of the spectrum:

> In an earthquake, a hypothetical very rigid structure (i.e., one with very high natural frequencies) would shake in phase with the motion of the ground itself -- and the ground motion would not be amplified in the building. For this reason, the high frequency or "zero period" portion of the response spectrum provides a convenient point from which to scale the standard spectrum; hence the high frequency end of the spectrum is called the anchor point.

Pacific Gas & Electric (Diablo Canyon Nuclear Power Plants, Units 1 & 2), ALAB-644, 13 N.R.C. 903, 925 n. 43 (1981); see also Holt, prepared testimony at p. 5, following Tr. 4539.

Stable Region could be subdivided into separate tectonic provinces such as the Michigan Basin. The significance of this position was that it led to the conclusion that a larger earthquake than the 0.12g Design Basis Earthquake approved at the construction permit stage was required to represent the seismic hazard at Midland. The Staff's concerns were expressed in a letter dated October 14, 1980 from Robert L. Tedesco, Assistant Director for Licensing, Nuclear Regulatory Commission to J. W. Cook, Vice President, Consumers Power Company entitled "Seismological Input for the Midland Site," along with two alternative proposals for establishing an SSE acceptable to the NRC Staff, based on the assumption that the Central Stable Region was the appropriate tectonic province.[9] Mr. Tedesco's letter informed the Applicant that it was the Staff's position that establishment of acceptable seismological input parameters would be necessary not only for its Operating License review but also for the Staff's approval of the remedial actions associated with the soil settlement matters.

5. The Applicant opted to use the second alternative approach of the Tedesco letter and to develop Site Specific Response Spectra ("SSRS"). The SSRS submitted by the Applicant

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[9] Holt Ex. 3. Both of the alternative approaches proposed in the Tedesco letter used as a controlling earthquake the 1937 Anna, Ohio event which, the Staff stated, had a body wave magnitude of 5.3 M_{blg} and a MMI of VII-VIII. The first approach was to use the MMI of VII-VIII and the standardized response spectrum of Regulatory Guide 1.60 anchored at 0.19g. The second approach was to develop Site Specific Response Spectra ("SSRS") by collecting representative real time histories for magnitude 5.3 $\pm$ 0.5 M_{blg} earthquakes, epicentral distances less than 25 kilometers at soil sites, represented at the 84th percentile. Holt, prepared testimony at pp. 5-7, following Tr. 4539. <u>See also</u> paragraphs 11-13, <u>infra</u>.

is to be used as the design basis for the remedial underpinning work. It is not practicable to substitute a new design basis for the old design basis for structures which have already been built. However, the adequacy of completed structures may be assessed by a seismic margin review which uses the SSRS.[10] The Staff has used such an approach in other operating license reviews.[11] Hereinafter, the earthquake corresponding to the SSRS ground motion will be referred to as the "Seismic Margin Earthquake" or "SME" to distinguish it from the FSAR SSE; the latter is the earthquake that has been used as the design basis for structures and equipment (other than remedial underpinning work) at Midland.

6. At a prehearing conference on January 29, 1981 the Staff proposed to the Atomic Safety and Licensing Board that the hearings on the soil settlement matters include seismic issues.[12] The Applicant objected to the Staff's proposal. On March 18, 1981 the Applicant filed a "Motion to Defer Consideration of Seismic Issues Until the Operating Licensing Proceeding". In their responses of April 6, 1981 and April 7, 1981, respectively, Intervenor Barbara Stamiris and the NRC Staff opposed the Applicant's motion. A prehearing conference was held on April 27, 1981 at which the Applicant's motion was considered and argued.[13]

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10 Applicant's Brief on Compatibility of Site Specific Response Spectra Approach with 10 C.F.R. Part 100, Appendix A, September 27, 1981 (hereinafter "Applicant's Brief").

11 See NRC Staff Brief in Support of the Use of the Site Specific Response Spectrum to Comply with the Requirements of 10 C.F.R. Part 100, Appendix A, September 29, 1981 (hereinafter "Staff's Brief"); Kimball, Tr. 4701.

12 Tr. 775-792.

13 Tr. 832-943.

7. On May 5, 1981, the Atomic Safety and Licensing Board issued a Prehearing Conference Order "Ruling Upon Applicant's Motion to Defer Consideration of Seismic Issues Until the Operating Licensing Proceeding and upon other matters" that, inter alia, resolved the issues raised by the Applicant's Motion to Defer Consideration of Seismic Issues in accordance with a compromise reached by the Applicant and the Staff. The order divided the seismic issues into three parts. Establishment of seismic criteria, including a determination of ground motion and associated response spectra, would be considered in connection with the soils hearings. The new seismic criteria so established would be used as the design basis for the soils-related remedial underpinning work. The mathematical models to be used for dynamic analyses of structures as modified by the remedial soil settlement measures, including the bases for the derivations of the spring constants, also would be considered in the soils hearings. Consideration of whether in fact existing structures as modified by the soils remedial work and other seismic Category I structures at the plant conform to the new seismic criteria was postponed until subsequent stages of the OL proceedings. Notwithstanding the foregoing, the Board has sought and heard preliminary conclusions from the Applicant and Staff with respect to the ability of structures modified by remedial measures to withstand the SSRS ultimately agreed upon by the NRC Staff and Applicant.[14]

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14 See paragraphs 59-78, infra.

B. THE CONFORMANCE OF THE SITE SPECIFIC RESPONSE APPROACH WITH 10 C.F.R. PART 100, APPENDIX A.

8. In a Memorandum dated August 18, 1981 the Licensing Board noted that one of the two alternatives proposed by the NRC Staff in the October 14, 1980 Tedesco letter for selection of the Seismic Margin Earthquake and associated ground motion involved site specific response spectra. Because this appeared to be a probabilistic approach we requested that the Applicant and the Staff file briefs discussing the compatibility of the SSRS with the requirements of 10 C.F.R. Part 100, Appendix A. The Licensing Board was particularly concerned about the compatibility of the SSRS approach with paragraphs V(a)(1)(ii) and (iv) of Appendix A which require, inter alia, that the SSE, at a minimum, equal the maximum historical earthquake experienced in the site's tectonic province and that the SSE be assumed to occur at the site.[15] In addition, the Licensing Board requested that the Staff provide information regarding the NRC's approval of, or other actions with respect to, the SSRS approach. The Applicant and Staff filed their briefs, both of which are dated September 29, 1981.[16]

9. The SSRS submitted by the Applicant were developed by an approach which is primarily deterministic and which conforms with 10 C.F.R. Part 100, Appendix A. Appendix A provides that a SSE be defined on the basis of a capable fault, a tectonic

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15 10 C.F.R. Part 100, Appendix A, §§V(a)(1)(ii) and (iv).

16 Applicant's Brief; Staff's Brief.

structure, or, as in the case of Midland, a tectonic province.[17] Appendix A requires that the SSE intensity be, at a minimum, equal to the maximum historical earthquake intensity within the tectonic province in which the site is located. This maximum

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[17] 10 C.F.R. Part 100, Appendix A, §V(a). "Capable fault," "tectonic province," and "tectonic structure" are defined in 10 C.F.R. Part 100, Appendix A, §§II(g), (h), and (i):

> (g) A "capable fault" is a fault which has exhibited one or more of the following characteristics:
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> > (1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
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> > (2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
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> > (3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.
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> (h) A "tectonic province" is a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein.
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> (i) A "tectonic structure" is a large scale dislocation or distortion within the earth's crust. Its extent is measured in miles.

Extensive investigations have established that there are no capable faults or tectonic structures in the vicinity of the Midland site. Holt, prepared testimony at p. 7, following Tr. 4539; Tr. 4571-4572, 4611-4614; Kimball, Tr. 4729.

intensity is assumed to occur at the site.[18] Because this procedure does not formally take into account uncertainties, e.g., it does not account for the probability that an earthquake of maximum historical intensity will be experienced at the site, it is often described as "deterministic" as opposed to "probabilistic."

10. While 10 C.F.R. Part 100, Appendix A is often referred to as a deterministic approach, probabilistic considerations may be taken into account in determining the SSE under Appendix A. Seismicity, the relative frequency of earthquakes in a particular region, is a probabilistic consideration and yet, is explicitly a proper determinant of the SSE under paragraph V(a) of Appendix A.[19] Furthermore, the Commission has held that the proposed use of a particular probabilistic methodology in determining a SSE was not barred by Appendix A.[20] Both the NRC Staff and the Applicant agree that while Appendix A contemplates a deterministic or "cookbook" approach to estab-

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18 10 C.F.R. Part 100, Appendix A, §§V(a)(1)(ii) and (iv). Maximum earthquakes occuring in other tectonic provinces than the tectonic province of the site are assumed to occur at the closest point to the site on the boundary of the tectonic province. 10 C.F.R. Part 100, Appendix A §V(a)(1)(iii); see also paragraph 29, infra.

19 10 C.F.R. Part 100, Appendix A, §V(a) states:

> The design basis for the maximum vibratory ground motion . . . should be determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and the surrounding region. (Emphasis added).

20 Public Service Company of New Hampshire (Seabrook Station, Units 1 and 2), CLI-80-33, 12 N.R.C. 295 (1980).

lish the SSE which involves defining tectonic provinces and maximum potential earthquakes, it does not bar the use of any seismological information, including seismicity and other probabilistic considerations, in making the judgments about tectonic province boundaries and maximum potential earthquakes within such tectonic provinces.[21] Indeed, because empirical methods for ascertaining geologic structure at depths are not well developed, historic seismicity affords one of the most accurate means available for inferring information about the geologic structural features of a site.[22]

11. Following the selection of an SSE, the second decision required by 10 C.F.R. Part 100, Appendix A is the determination of a response spectrum that represents ground motion resulting from the occurrence of the postulated SSE at the site. The construction of a response spectrum is itself a two-step process: first, a series of representative earthquakes are collected,[23] and, second, these records are combined in some way into a smoothed design spectrum.[24] One accepted method, but one which certainly is not required by Appendix A, for representing vibratory ground motion at the site due to the SSE is the use of the spectral shape in Regulatory Guide 1.60, scaled to an appropriate assumed zero period acceleration

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[21] Holt Ex. 3.

[22] Holt, Tr. 4559-4561; Kimball, Tr. 4811, 4826-4827.

[23] 10 C.F.R. Part 100, Appendix A, §V(a)(5).

[24] 10 C.F.R. Part 100, Appendix A, §V(a)(1). See also, note 5, supra.

value -- reflecting the intensity of the postulated SSE. This was the first option offered by the Staff in the Tedesco letter.[25] The spectral shape of Regulatory Guide 1.60 is based on accelerograms taken on widely varying local site geologic conditions -- conditions ranging from rock to soft soil. Therefore, this response spectrum is "site independent." Moreover, when scaled to an assumed zero period ground acceleration value (0.19g) representative of an Intensity VII-VIII or Magnitude 5.3 earthquake as suggested in the October 14, 1980 Tedesco letter, the Regulatory Guide 1.60 response spectrum generally defines a level of ground motion in excess of that which the site would experience due to the occurrence of such an earthquake at the site.[26]

12. At the time that Regulatory Guide 1.60 was constructed the number of strong motion records in existence was relatively small. There were not enough strong motion records to construct different response spectra for sites with different foundation conditions. In recent years a large number of strong motion recordings have become available from earthquakes of various magnitudes at different distances and for a variety of foundation conditions. At the present time, site specific response spectra corresponding to specific site foundation conditions can be constructed for most sites.[27] This was the second option proposed in the October 14, 1980 Tedesco letter.

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[25] Holt Ex. 3.

[26] Holt, prepared testimony at p. 6, following Tr. 4539.

[27] Holt Ex. 3; Holt, prepared testimony at p. 6, following Tr. 4539.

13. Basically, the SSRS method involves constructing response spectra from records of ground motion recorded by accelerometers located at sites similar to Midland from earthquakes similar in magnitude to the proposed SSE. Thus the important criteria for selecting these earthquake records are the range of magnitudes for the earthquakes, the distance from the epicenter to the recording station, and the recording station geology and foundation conditions. The October 14, 1980 Tedesco letter dictates the use of a magnitude range of 5.3 $\pm$ 0.5, epicentral distances of less than 25 kilometers, and recording instruments on soil.[28]

14. Constructing the SSRS for Midland, as was also true for the construction of the Regulatory Guide 1.60 response spectrum, involved combination of a selected series of earthquake records into a single "smoothed" response spectrum.[29] 10 C.F.R. Part 100, Appendix A does not specify how this is to be done. It does not require the use of deterministic methods. Moreover, the statistical process of combining earthquake records clearly results in a probabilistic statement. That is, the only meaningful interpretation of a response spectrum constructed by combining many different individual earthquake records at, for example, the 84th percentile is the following: assuming the postulated earthquake occurs at the site, the resulting vibratory ground motion is expected to fall within

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28 Holt, prepared testimony at pp. 6-7, following Tr. 4539; Holt Ex. 3.

29 10 C.F.R. Part 100, Appendix A, §VI(a)(1).

this response spectrum 84 percent of the time. This is the only step in the SSRS approach used in this case which is explicitly probabilistic. Significantly, it is no more probabilistic than use of the Regulatory Guide 1.60 spectral shape, which was constructed in a similar way.[30]

15. 10 C.F.R. Part 100, Appendix A mandates consideration of the geologic conditions of the nuclear power plant site.[31] The SSRS methodology, because it attempts to match earthquake records to site conditions, is actually more consistent with Appendix A than is use of the site independent Regulatory Guide 1.60 response spectrum.

16. The Licensing Board concludes that the methodology used by Applicant and the NRC Staff in developing the SSRS for the Midland site is compatible with 10 C.F.R. Part 100, Appendix A.[32]

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[30] See Applicant's Brief, at p. 11. There was one additional deterministic judgment made by the NRC Staff before approving the SSRS submitted by Applicant. The SSRS were raised in the long period (greater than one second) region to coincide with the FSAR design spectrum. See paragraph 5 and note 8, supra. This was done to account for the possibility of extremely large earthquakes at great distance. See Holt, prepared testimony at p. 8, following Tr. 4539; Holt Exs. 1, 11; Tr. 5117-5118.

[31] See 10 C.F.R. Part 100, Appendix A, §§IV(a)(1), (3), (4), (5), and V(a)(1)(iv)(third sentence).

[32] We are informed that the NRC Staff has developed "site specific response spectra" using a different methodology than that described above for use in its Systematic Evaluation Program (which includes the LaCrosse Boiling Water Reactor). The SEP "site specific response spectra" are based on a complex synthesis of deterministic judgments and probablistic modeling, which does not include defining "tectonic provinces" or "Safe Shutdown Earthquakes" in accordance with the Appendix A methodology. This SEP methodology is not involved in this case, and we express no opinion as to its validity. See Applicant's Brief, at p. 6 n. 3.

C. THE SELECTION OF THE PROPER TECTONIC PROVINCE AND APPROPRIATE CONTROLLING EARTHQUAKE FOR MIDLAND

17. 10 C.F.R. Part 100, Appendix A defines a "tectonic province" as "a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein.[33] Appendix A dictates that the Safe Shutdown Earthquake intensity should be, as a minimum, equal to the maximum historic earthquake intensity experienced within the tectonic province of the site.[34] Thus the selection of the appropriate tectonic province is an important step in establishing the postulated seismic hazard at a nuclear power plant site.

18. No tectonic province was approved by the AEC at the Midland construction permit stage since that review predated the promulgation of 10 C.F.R. Part 100, Appendix A. It has been the Applicant's consistent position in its initial FSAR submission and throughout this proceeding that the Midland site lies within a tectonic province referred to as the Michigan Basin.[35] The Michigan Basin can be described geologically as

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33 10 C.F.R. Part 100, Appendix A, §III(h); see note 17, supra. While this definition refers only to geologic structural features, other portions of Appendix A make it clear that seismological information, including seismicity, may be used in defining tectonic provices. E.g., 10 C.F.R. Part 100, Appendix A §V(a) ("The design basis for the maximum vibratory ground motion . . . should be determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and the surrounding region").

34 10 C.F.R. Part 100, Appendix A, §V(a).

35 FSAR, p. 2.5-5; Holt, prepared testimony at p. 11, following Tr. 4539; Holt Ex. 5, p. 4.

a saucer-like regional structural basin, nearly 200 miles in diameter which underlies the southern peninsula of Michigan and parts of adjoining states.[36] The Michigan Basin's crystalline basement rock is nearly 6,000 to 8,000 feet deeper than the basement rock arches that surround it.[37]

19. The Michigan Basin is an area of low seismicity when compared to other sites surrounding it in the Central Stable Region.[38] The arches on the southern end of the Michigan Basin have experienced earthquakes of approximate magnitude 5.0 and intensities VII or slightly larger. Within the Michigan Basin the largest magnitude has been 4.5 and maximum intensity has been VI. Midland, which is centered in the Basin, has experienced a maximum intensity of IV to V in historical times, based upon a conservative attenuation estimate.[39]

20. The NRC Staff was reluctant at first to accept the Applicant's designation of the Michigan Basin as the proper tectonic province for Midland. In the October 14, 1980 Tedesco letter the Staff stated that it had found "insufficient support that the Central Region can be subdivided into separate tectonic provinces."[40] Accordingly, to expedite its review, the Staff

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[36] Holt, prepared testimony at p. 11, Holt Ex. 9; Holt, Tr. 4555-4556.

[37] Holt, prepared testimony at pp. 11-12, following Tr. 4539; Holt Ex. 10, p. 2; Holt, Tr. 4558-4559, 466[illegible]-4669.

[38] Holt, prepared testimony at p. 14, following Tr. 4539; Holt Ex. 10, p. 8.

[39] Holt, prepared testimony at p. 12, following Tr. 4539; Holt Ex. 10, p. 2; Holt, Tr. 4568-4570.

[40] Holt Ex. 3.

initially asked the Applicant to assume that the Central Stable Region was the appropriate tectonic province.[41] This choice led to the identification of the March 9, 1937 Anna, Ohio earthquake (MMI=VII-VIII) as the controlling earthquake for Midland.[42]

21. The Central Stable Region is a very large region defined not by the characteristics of the crystalline basement rock which underlies it, but by the sedimentary rock strata which overlie the basement. This sedimentary rock was formed from sediments deposited by the Great Inland Sea two hundred to six hundred million years ago. While the extent of the Central Stable Region is not clear, it would include most of the Central United States from Ohio to the Rocky Mountain front and from the Canadian Shield to the Mississippi embayment (roughly the 38th parallel).[43]

22. While the construction of the SSRS proceeded on the basis of the assumptions listed in the October 14, 1980 Tedesco letter, both the NRC Staff and the Applicant recognized that the identification of the Central Stable Region as a single tectonic province was unsatisfactory. In the first place, in the central United States earthquakes typically originate in the crystalline basement rock; therefore defining a tectonic

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41 Kimball, prepared testimony at pp. 4-5, following Tr. 4690.

42 Holt Ex. 3.

43 Holt, prepared testimony at pp. 13, 19, following Tr. 4539; Holt, Tr. 4557; see also Kimball, prepared testimony at p. 3, following Tr. 4690.

province on the basis of the overlying veneer of sedimentary rock is unreasonable.[44] Moreover, the similarity of surface geology of the Central Stable Region does not explain the fact that different areas within the Central Stable Region exhibit different levels of seismic activity.[45]

23. Even after the October 14, 1980 Tedesco letter, the NRC Staff and Applicant made further attempts to resolve how the broad Central Stable Region (as defined by surface geology) should be divided into tectonic provinces that would more adequately explain the diversity of the underlying levels of seismic activity within the Central Stable Region.[46] Unfortunately, since the crystalline basement rock in which earthquakes originate is, in the Michigan area, buried roughly two miles below the surface, the geophysical tools by which one can empirically determine geological structural features of the basement rocks have limited value.[47] Accordingly, analyses of historic seismicity are the best available means for inferring the geologic mechanisms causing earthquakes.[48] Accordingly, it

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[44] Holt, prepared testimony at p. 13, following Tr. 4539; Holt, Tr. 4555-4556; Kimball, prepared testimony at pp. 3-4, following Tr. 4690.

[45] Holt, Tr. 4558; Kimball, prepared testimony at pp. 3-4, following Tr. 4690; Holt, prepared testimony at pp. 13-14, following Tr. 4539.

[46] Kimball, prepared testimony at p. 4, following Tr. 4690.

[47] Holt, Tr. 4559-4561.

[48] Kimball, prepared testimony at p. 4, following Tr. 4690; Holt, Tr. 4561.

was primarily on the basis of such seismicity analyses that the NRC Staff eventually concurred with the Applicant that the Central Stable Region could be subdivided into a smaller tectonic province including the Midland site.

24. The Applicant performed a probabilistic seismic hazard analysis of the Midland site to test the appropriateness of the uses of the Central Stable Region and the Anna-type magnitude 5.3 controlling earthquake.[49] For this purpose the Applicant's consultant selected an earthquake occurrence model and a ground motion model. The earthquake occurrence model was based on the selection of seismic source zones and an analysis of the rate of activity and largest historical earthquake in each zone. The ground motion model related the size of each earthquake to ground shaking. Originally, the Applicant performed the seismic hazard analysis for three alternate seismic source models. The first model is based upon the results of Nuttli and Brill (1981) which associate seismic activity with arches and basins in the Central United States ("CUS"). The two source zones nearest to Midland are the Michigan Basin and Cincinnati Findlay-Kankakee Arch. The second model separated out the Anna, Ohio and Attica-Niagara, New York areas. The third model treated the Central Stable Region as one unit.[50]

25. After the Applicant's initial analysis, the Staff requested that the Applicant compute the seismic hazard for

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[49] Holt Ex. 10; Kimball, prepared testimony at pp. 16-21, following Tr. 4690.

[50] Holt, Tr. 4562-4565; Kimball, prepared testimony at p. 17, following Tr. 4690.

five additional sites in the CUS. These sites were chosen by the Staff to represent the expected range of activity levels for the CUS. The five sites that were selected are in Western New York, Northeastern Ohio, Northwestern Ohio, Northern Illinois-Indiana border, and Southeastern Wisconsin.[51] The results showed the Midland site to have lower expected intensities than the other five sites at all exceedance probabilities.[52]

26. The Applicant's formal probabilistic analysis confirms that the Midland site is in an area of relatively lower seismic hazard as compared to other sites surrounding the Michigan Basin in the Central Stable Region.[53] The resultant relative probabilities confirm that the Midland site is not near any important seismic sources, tectonic structures, or capable faults which are demonstrable geologically or seismologically.[54] Thus historical experience and the probabilistic seismic hazard results demonstrate a nonuniformity of seismic ground motion potential within the Central Stable Region. The relative differences range to two intensity units at the examined Central Stable Region sites at some given probability level and to between one and two orders of magnitude variations

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51 Kimball, prepared testimony at pp. 17-18, following Tr. 4690.

52 Holt Ex. 10, pp. 5-9; Kimball, prepared testimony at p. 18, following Tr. 4690.

53 Holt, prepared testimony at p. 14, following Tr. 4539; Holt Ex. 10, p. 8; Kimball, prepared testimony at p. 18, following Tr. 4690

54 Holt Ex. 10, p. 5.

in annual probability at some given seismic intensity.[55] Of the three models in the original seismic hazard analysis, the Applicant puts more weight on Model 1, the Michigan Basin and Cincinnati Findlay-Kankakee Arch model (50 percent), than on Model 2, the separated Anna and Attica-Niagara areas model (30 percent), or Model 3, the entire Central Stable Region model (20 percent). This placed the Midland site 0.57 intensity units lower, on the average, than the five typical CUS sites.[56] The Staff weighed each model equally and found the Midland site, on the average, to be about 0.50 intensity units lower than the five typical sites. Using Model 2 alone the Staff found the Midland site to be 0.70 intensity units lower on the average. The Staff then used the Applicant's weights of 50-30-20, its own weights of 33 1/3 percent each, and Model 2 on its own, and determined that Midland is about 0.50 to 0.70 intensity units lower. By converting this to magnitude the Staff found that Midland is about 0.25 to 0.35 magnitude units lower than the five typical CUS sites.[57]

27. The magnitude difference of 0.25 to 0.35 convinced the Staff that, for the purposes of seismic design and review, Midland is in a different seismotectonic province than other areas of the Central Stable Region, including the Anna site. The Staff also determined that Midland's seismotectonic province

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55 Holt Ex. 10, p. 8.

56 Kimball, prepared testimony at p. 18, following Tr. 4690; Holt, Tr. 4564.

57 Kimball, prepared testimony at pp. 18-20, following Tr. 4690; Kimball, Tr. 4789-4791.

requires the use of a magnitude 5.0 controlling earthquake while other areas of the Central Stable Region require the use of an Anna-type earthquake of magnitude 5.3.[58]

28. The Staff's tectonic province for Midland does not coincide with the tectonic province that was submitted by the Applicant, i.e., the Michigan Basin. Mr. Kimball testified that the Staff's tectonic province contains most of the lower peninsula of Michigan, most of Wisconsin, and part of Minnesota.[59] It extends over 200 miles to the northeast of the Midland site.[60] Mr. Kimball testified that the largest historical earthquakes for the Staff's tectonic province have a magnitude range of 4.7 to 5.0 with a maximum intensity of VII.[61] Mr. Kimball also testified that whichever tectonic province was accepted, the Applicant's or the Staff's, the SSRS as shown in Holt Exhibit 1 is a conservative representation of the seismic hazard to the Midland site.[62]

29. 10 C.F.R. Part 100, Appendix A requires one to take into account the possibility of large earthquakes occurring in tectonic provinces neighboring the tectonic province which includes the site. The highest historically reported earthquake in any such neighboring tectonic province (which cannot

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58 Kimball, prepared testimony at pp. 20-21, following Tr. 4690; Kimball, Tr. 4699-4700; Holt, Tr. 4586-4587.

59 Kimball, Tr. 4745.

60 Kimball, Tr. 4771-4772.

61 Kimball, Tr. 4769, 4787.

62 Kimball, Tr. 4792, 4797.

be reasonably related to a tectonic structure) is postulated to occur at the closest point to the site on the boundary of the tectonic province.[63] Mr. Kimball testified that for the Staff's tectonic province the largest earthquake which must be postulated to occur on the boundary would be the magnitude 5.3 Anna, Ohio earthquake.[64] Anna, Ohio is 205 miles from the Midland site. Mr. Holt testified that in the direction of Anna the boundary of the Michigan Basin tectonic province, drawn along the arch of the Basin, is 200 miles from the Midland site. However, he concedes that, depending on what portion of the arch is used, the boundary could be as close as 150 and 170 miles from the Midland site. Mr. Holt also testified that an Anna-type earthquake of magnitude 5.3 would have to occur substantially closer, in the order of 100 miles closer, to exceed the magnitude 5.0 SSRS at the Midland site.[65] Mr. Kimball testified that based on the Staff's calculations the Anna-type earthquake would have to occur less than 50 miles from the site, and perhaps less than 35 kilometers (25 miles) from the site before it would produce ground motion exceeding the magnitude 5.0 event at the site.[66] Therefore, despite the

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[63] 10 C.F.R. Part 100, Appendix A, §§V(a)(1)(iii), IV(a)(6). Appendix A requires this to be done only for tectonic provinces any part of which are located within 200 miles of the site.

[64] Kimball, Tr. 4770-4771. It should be noted that the Anna, Ohio earthquake may be reasonably related to tectonic structures, in which case Appendix A would not require postulating it to occur at the boundary of the tectonic province. Holt, Tr. 4571-4573, 4611-4614, 4647; Kimball, Tr. 4715-4716.

[65] Holt, Tr. 4571-4580.

[66] Kimball, Tr. 4784.

fact that the borders of the Staff's and the Applicant's tectonic provinces do not coincide and are somewhat inexact, an earthquake on the border would not exceed the Midland SSRS ground motion at the site.[67]

30. The Licensing Board finds that the Midland site is in a separate tectonic province from Anna, Ohio and that the appropriate Seismic Margin Earthquake for Midland should have a magnitude of 5.0. We need not decide whether the Staff's or the Applicant's tectonic province is the proper one because we find that either province would have a controlling earthquake of magnitude 5.0.

D. THE CHARACTERIZATION OF GROUND MOTION FOR MIDLAND

31. 10 C.F.R. Part 100, Appendix A, Paragraph VI states that the vibratory ground motion produced by the Safe Shutdown Earthquake shall be defined by response spectra.[68] Under the SSRS approach used for Midland, records of ground motion recorded

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[67] In response to questions from the Board, Mr. Kimball discussed the possible relevance of a large earthquake which occurred in Tamiskaming, Canada. Mr. Kimball testified that the Tamiskaming epicenter was more than 320 miles from the Midland site. Mr. Kimball further testified that, although the NRC Staff has not formally reviewed the question, he believed that the Tamiskaming earthquake could probably be tied to a structure and that structure would not come within 300 miles of the site. Finally, Mr. Kimball testified that even if the Tamiskaming earthquake could not be associated with a tectonic structure, the boundary of its tectonic province would be much more than 100 miles from the site. The ground motion produced at the site by such an earthquake at such a distance would be much less than the Midland SSRS. Kimball, Tr. 4771-4781, 4807-4809, 4814.

[68] <u>See</u> note 5, <u>supra</u>.

by accelerometers located at sites with local geologic conditions similar to Midland during earthquakes similar in magnitude to the postulated SME were selected. These records were used to generate many different response spectra which were then statistically combined to form smoothed Site Specific Response Spectra.[69] As discussed below, there was disagreement between the NRC Staff and Applicant whether Applicant should have used certain records of the June 26, 1966 Parkfield, California earthquake in generating SSRS representing ground motion at the Midland site due to an Anna-type, magnitude 5.3 earthquake as postulated in the October 14, 1980 Tedesco letter.[70] There was also initial disagreement as to the appropriate spectral level at which the response spectra generated from different records should be statistically combined to form the SSRS.[71] Both of these issues became moot, however, when the NRC Staff came to the conclusion that a smaller tectonic province than the Central Stable Region could be justified, and that the controlling earthquake for the Midland site should be a magnitude 5.0 event.[72] Both the NRC staff and Applicant are in agreement

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69 Holt, prepared testimony at pp. 6, 17, following Tr. 4539.

70 Holt, prepared testimony at pp. 9, 15-16, following Tr. 4539; Holt Ex. 6, pp. 11-14, 37-38, 40; Holt Ex. 7; Holt, Tr. 4584, 4594-4595, 4615-4630, 4640-4643, 4669-4684; Kimball, prepared testimony at 12-16, following Tr. 4690; Kimball, Tr. 4691, 4695-4696, 4711-4713, 4723-4728, 4738-4741, 4820-4826.

71 Holt, prepared testimony at pp. 17-18, following Tr. 4539; Holt, Tr. 4594; Kimball, prepared testimony at pp. 10-11, following Tr. 4690. See also paragraphs 55-58, infra.

72 Holt, Tr. 4542, 4586-4587; Kimball, prepared testimony at pp. 21-22, following Tr. 4690; Kimball, Tr. 4723-4727, 4823.

that the SSRS shown in Holt Exhibits 1 and 11 are conservative representations of the ground motion which would be produced by a magnitude 5.0 earthquake at the Midland site.[73]

32. To construct the SSRS for Midland, Applicant selected records of ground motion recorded by accelerometers located at sites similar to Midland from earthquakes similar in magnitude to the proposed SME.[74] The important criteria for selecting these earthquake records were the range of magnitudes for the earthquakes, the distance from the epicenter to the recording station, and the recording station's geologic and foundation conditions.[75] The Tedesco letter dictates a magnitude range of 5.3 ± 0.5 M_{blg}, epicentral distance of less than 25 kilometers, and recording instruments on soil. The 5.3 magnitude was meant to correspond to an Anna-type earthquake. The requirement that recording instruments be located on soil was meant to ensure similarity to foundation conditions at Midland. The epicentral distance of 25 kilometers or less was selected to simulate the occurrence of such an earthquake "at the site" of the nuclear plant.[76]

33. The original ground surface of the Midland site is underlain by approximately 360 feet of glacial deposits which overlie the site bedrock formation, the Saginaw Shale. The

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[73] Kimball, prepared testimony at pp. 21-23, following Tr. 4690; Holt, Tr. 4586-4587.

[74] Holt, prepared testimony at p. 6, following Tr. 4539; Holt Ex. 5, pp.3-4.

[75] Holt, prepared testimony at pp. 6-7, following Tr. 4539; Holt Ex. 5, p.3.

[76] Holt Ex. 3; Holt, prepared testimony at pp. 6-7, following Tr. 4539.

geologic and material description of the soils column beneath the site were determined by deep borings. Seismic measurements determined the compressional "P" and shear "S" wave velocities.[77]

34. In selecting the appropriate accelerograms, Applicant first took all available strong motion records with epicentral distances less than 40 kilometers and M_L magnitude ranging from 4.5 to 6.0. Next, the local geologic characteristics of the recording stations were considered. The amount of information available on the foundation conditions varies greatly from station to station. For cases where detailed information such as test borings, seismic surveys, and compressional and shear wave velocities was not available, site formulation conditions were estimated for available geologic maps, and where applicable, from geotechnical and geophysical data extrapolated from adjacent sites. The geologic characteristics of each recording station were then rated in terms of their similarity to those at Midland. In determining which records were appropriate, the Applicant's consultant evaluated two principal site characteristics: the thickness of the crustal layer beneath the station and the shear wave velocity contrast layers.[78] Other considerations caused accelerograms to be disregarded as inappropriate. The recording instrument may have been inappropriately located, or there may have been other problems with the station. The recording station may have been too close to a surface rupture or otherwise have been influenced by the "near field" effects

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[77] Holt Ex. 5, p. 6 and Figure 1.

[78] Holt Ex. 5, pp. 6-8.

of capable faulting, phenomena which are not expected to occur at the Midland site.[79]

35. The selection of the appropriate accelerograms resulted in 44 total horizontal components generated by 10 earthquakes. Five of the earthquakes occurred in California, and the other five are part of the Friuli, Italy aftershock sequence. Of the 44 total horizontal components, 20 were recorded in California and the other 24 in northern Italy. The magnitudes range from 4.9 to 5.5 with a mean magnitude of 5.35 M_L. The earthquakes occurred within the earth's crust with epicentral distances ranging from 7 to 33 kilometers with a mean of 17.6 kilometers.[80]

36. Response spectra were then derived from the accelerograms.[81] The response spectra of the 44 horizontal components were computed for several values of critical damping. Then, the log normal median, mean, and 84th percentile response spectra for 5 percent initial damping were produced.[82]

37. The resulting SSRS for Midland fell off sharply in the long period region. The Staff expressed concern about this fact. Long period ground motion would come from extremely large earthquakes at great distances. Because there is a paucity of strong motion records for such earthquakes and because the Midland FSAR design spectrum exceeded the SSRS at

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[79] Holt, prepared testimony at p. 7, following Tr. 4539; Holt Ex. 6, Figure 3. <u>See</u> paragraphs 47, 52, <u>infra</u>.

[80] Holt Ex. 5, pp. 10-11; <u>see</u> <u>also</u> Holt, Tr. 4582.

[81] Holt Ex. 5, pp. 12-15 and Figure 10; <u>see</u> <u>also</u> Holt, Tr. 4630-4632.

[82] Holt Ex. 5, pp. 14-15 and Figure 11.

those long periods, the 84th percentile response spectra was raised to the FSAR design spectra level in this long period (greater than one second) region.[83] The final SSRS for the Midland site at the original ground surface is shown in Holt Exhibit 1.

38. 10 C.F.R. Part 100, Appendix A, Section (V)(1)(f)(iv) requires the development of response spectra at "each of the various foundation locations of the nuclear power plant." Most of the Seismic Category I structures at Midland are, or following soils remedial measures will be, founded near the original ground surface on glacial fill. However, the Diesel Generator Building and the Borated Water Storage Tanks are founded on plant fill.[84]

39. An SSRS for the top of the fill material was developed by matching foundation conditions under the Diesel Generator

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83 Holt, prepared testimony at pp. 8-9, following Tr. 4539; Holt, Tr. 4603-4606; Holt Ex. 6, Figures 1.1, 1.2; see also Holt Exs. 1, 11.

84 Holt, prepared testimony at p. 9, following Tr. 4539; see also "Safety Evaluation Report related to the Operation of Midland Plant, Units 1 and 2, Supplement No. 2," §2.5.4.1.2, Table 2-3, at p. 2-13. This document, the original Safety Evaluation Report, a First Supplement and an Errata sheet were marked collectively as Staff Exhibit 14. These documents will hereinafter be referred to in their order of precedence as "SER," "SSER #1," and "SSER #2". Although Staff Ex. 14 was received into evidence at Tr. 8715, only those portions of these documents which were specifically identified and sponsored by Staff witnesses as their testimony have been relied upon by the Licensing Board as evidentiary bases for this Partial Initial Decision. See Southern California Edison Company (San Onofre Nuclear Generating Station, Units 2 and 3) ALAB-717, ___ NRC ___ (March 4, 1983). [Applicant will provide an appropriate Table of sponsored SER and SSER sections in subsequent findings. Note that Section 2.5.2 of the SER, which summarizes the NRC Staff's position on seismology, was prepared after the evidentiary hearings on that subject and is not part of the evidentiary record.]

Building to similar foundation conditions at accelerometer stations recording strong motions from Anna, Ohio type earthquakes (M_{blg} = 5.3 ± 0.5).[85] Approximately 30 feet of fill material has been placed on top of the original ground surface. The compressional "P" and shear "S" wave velocities of the fill were determined on the basis of seismic cross-hole tests.[86]

40. The same general methodology, as described in paragraphs 32-35, for developing SSRS for the original ground level was used in developing the SSRS for the top of the fill material.[87] The resulting spectrum is Holt Exhibit 2.

41. The long period end of the resulting SSRS for the top of the fill shown in Holt Exhibit 2 was also raised to coincide with the FSAR design spectrum to account for the possibility of extremely large earthquakes at great distances. The final SSRS for the top of the fill is shown in Holt Exhibit 11.[88]

42. Another approach for deriving a response spectrum at the top of the fill was also taken. By multiplying the SSRS for the original ground surface by appropriate frequency-dependent amplification factors that account for the 30 feet of compacted fill, a response spectrum was derived which predicts less ground motion than does the SSRS derived for the top

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85 Holt, prepared testimony at pp. 9-10, following Tr. 4539; Holt Ex. 8.

86 See paragraph 33 and note 77, supra.

87 Holt Ex. 8, pp. 5-7.

88 Holt, Tr. 4637-4638; Tr. 5109-5114, 5117-5118.

of the fill.[89] This alternative approach was undertaken by E. VanMarcke, E. Kausel, and E. Samaras of the Massachusetts Institute of Technology.[90] The study used a computer program, "SHAKE," to evaluate the relative response between the top of the fill at the Diesel Generator Building and the original ground surface in terms of the the ratio of response spectra. While the frequencies at which the maximum response spectra amplification occur are very nearly the same for the two independent studies, the SSRS amplification is larger than the theoretically computed amplification at all frequencies of interest. Applicant proposes that this Licensing Board approve the higher, and more conservative, spectrum, i.e., the SSRS for the top of the fill material which is Holt Exhibit 11.[91]

43. The NRC Staff employed Dr. Hadala of the United States Army Corps of Engineers to review the Applicant's SHAKE analysis. Dr. Hadala also conducted his own SHAKE analysis. Dr. Hadala concluded that the SSRS for the top of the fill developed by the Applicant through the analysis of empirical data is more conservative than the one developed by application of theoretically calculated amplification factors.[92]

44. The Staff reviewed the Applicant's proposed SSRS and met with the Applicant on April 16, 1981. The Staff requested

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[89] Holt, prepared testimony at p. 10, following Tr. 4539.

[90] Holt Ex. 8, Appendix B.

[91] Holt, prepared testimony at p. 10, following Tr. 4539; Tr. 5109-5114, 5117-5118.

[92] Kimball, prepared testimony at p. 25, following Tr. 4690; Hadala, prepared testimony at pp. 1-7, following Tr. 5081; Hadala, Tr. 5083, 5088; Holt, Tr. 4595-4596.

that various sensitivity tests be performed on the data from which the SSRS for the original surface was derived. After reviewing this additional information the Staff concluded that, in general, the data set was not very sensitive to small variations in input parameters and showed expected results when subjected to systematic parameter variations.[93]

I. THE USE OF THE PARKFIELD RECORDS

45. At the April 16, 1981 meeting the NRC Staff questioned whether a set of strong motion records from the June 26, 1966 Parkfield, California earthquake should have been used in establishing a SSRS for an Anna-type, magnitude 5.3 event for Midland. The Staff requested that, if the subsurface soil conditions and shear wave velocity profiles were appropriate, records for the Parkfield earthquake recorded at three stations known as Cholame 5, Cholame 8, and Cholame 12 be included in the SSRS and be subjected to sensitivity tests.[94]

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[93] Holt Ex. 6; Kimball, prepared testimony at pp. 11-12, following Tr. 4690. The Staff also used the sensitivity results from Holt Ex. 6 in confirming the conservativism of the top of fill SSRS. Kimball, prepared testimony at p. 25, following Tr. 4690.

[94] Holt Ex. 6, pp. 1-7, 11-14; Kimball, prepared testimony at pp. 11-12, following Tr. 4690. There were two other records of the Parkfield earthquake which the Staff did not urge be included in the SSRS data set. See Holt Ex. 5, Table 1 and Figure 3. The data that was recorded at a station called Temblor, which is founded on rock was excluded for that reason. Kimball, Tr. 4820-4821. The second record comes from a station called Cholame 2. This was appropriately excluded because of the location of the station, which was only 80 meters from the fault and "right down the barrel of the earthquake rupture" which subjected the station to enhanced ground motion due to a phenomenon called "focussing." Kimball, Tr. 4821-4822. Cf. Pacific Gas & Electric Company (Diablo Canyon Nuclear Power Plant, Units 1 and 2), ALAB-644, 13 N.R.C. 903, 944-950, esp. 946 n. 157 (1981).

46. The Applicant subsequently determined that the subsurface soil characteristics and shear wave velocity profiles at Cholame 5, Cholame 8, and Cholame 12 were similar to those at the Midland site.[95] While still finding the Parkfield records inappropriate, the Applicant constructed a response spectra adding the Parkfield records to the data set and performed the sensitivity tests as requested by the Staff. The resultant response spectra at the 50th and 84th percentiles are compared with the SSRS proposed by Applicant (and ultimately accepted by the NRC Staff) in Holt Exhibit 6, Figure 3.2.4. The difference between the two response spectra is between 10 and 30 percent, in the range of frequencies in which these response spectra exceed the FSAR SSE (0.12g) design spectrum.[96] By far the most significant effect is due to inclusion of the Cholame 5 record, which is the station closest to the fault among those recommended for inclusion by the Staff.[97]

47. Applicant's witness, Mr. Holt, testified that it was inappropriate in developing SSRS for a site such as Midland, which is not close to any capable faults or tectonic structures, to select records such as the Parkfield records which are influenced by the proximity of the accelerogram stations to the rupturing fault. Such records are therefore referred to as

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[95] Holt Ex. 6, pp. 11-12.

[96] Kimball, prepared testimony at pp. 21-22 and Figure 2, following Tr. 4690; Holt, Tr. 4622-4626.

[97] Holt, Tr. 4625-4626.

"near field."[98] In the case of the 1966 Parkfield earthquake, the Cholame stations were laid out almost perpendicular to the fault system. Cholame 2 was 80 meters from the fault, Cholame 5 was about 5 kilometers, Cholame 8 was about 9 to 10 kilometers, and Cholame 12 was about 14 to 15 kilometers from the fault.[99]

48. Mr. Holt also testified that the 1966 Parkfield earthquake records were influenced not only by the observed rupture along the fault but also reflect an incoherent supersonic rupture across seismic barriers which occurred during that earthquake. These characteristics cannot reasonably be expected to occur in any earthquake in the Central Stable Region or the Michigan Basin.[100] Mr. Holt was supported by Dr. Otto Nuttli, a noted expert on Midwestern earthquakes, in these conclusions.[101]

49. Finally, Mr. Holt suggested that the size of the Parkfield earthquake may have been greater than the target magnitude of 5.3 ± 0.5 for Midland.[102]

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98 Holt, prepared testimony at pp. 15-16, following Tr. 4539; Holt Ex. 6, pp. 2-5, 11-14; Holt Ex. 7; Holt, Tr. 4606-4614, 4656-4661. A helpful description of the phenomenon of "near field" ground motion appears in the Appeal Board's decision in <u>Pacific Gas & Electric Company</u> (<u>Diablo Canyon Nuclear Power Plant, Units 1 and 2</u>), ALAB-644, 13 N.R.C. 903, 926, 928-935 (1981).

99 Holt, Tr. 4623-4624, 4627; Holt Ex. 7, Figure 2 (note that this figure may be misleading without the explanation at Tr. 4627).

100 Holt, prepared testimony at p. 16, following Tr. 4539; Holt, Tr. 4606-4614, 4641-4643, 4656-4661.

101 Holt, prepared testimony at p. 16, following Tr. 4539; Holt Ex. 7, Appendix I.

102 Holt Ex. 7, pp. 7-9; Holt, Tr. 4584.

50. The N.R.C. staff witness, Mr. Kimball, disagreed with Applicant as to the relevance of the Parkfield records. Mr. Kimball pointed out that a voluminous amount of literature has been published concerning the Parkfield event, and that there is wide variation of expert opinion concerning the various anomalies which Mr. Holt stated characterize the Parkfield acceleration time histories.[103] In particular, there is lack of uniform agreement among experts as to the rupture length of the earthquake (raising questions how close the recordings were to the epicenter or fault, and thus whether they were "near field"). There is some question whether the earthquake ruptured the surface. The Parkfield earthquake has been modeled by Arcubeta and Day (1980) without assuming surface rupture, and the synthetic ground motion records so produced were in overall agreement with the data.[104] Mr. Kimball also referred to numerical modeling performed by Del Mar Technical Associates (1980) of another California earthquake, the October 15, 1979 Imperial Valley event, which suggests that the effects of surface rupture are severely attenuated as a function of distance from the fault due to the increased amount of material attenuation in shallow soil layers. The Staff relied on this result in their position that only the Cholame 2 records (within

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103 Kimball, prepared testimony at pp. 13-14, following Tr. 4690.

104 Kimball, prepared testimony at p. 14, following Tr. 4690.

80 meters of the fault) and not the Cholame 5, 8 and 12 records should be excluded from the Midland data set.[105]

51. Mr. Kimball also stated that given the uncertainty which exists concerning earthquake sources in the Central United States (such as stress drop, fault rupture length, fault displacement, and rupture velocity), the source characteristics of the 1966 Parkfield event should be considered as being included within the range of this uncertainty.[106]

52. Mr. Kimball agreed with Mr. Holt that detailed geologic investigations at the Midland site had determined that there are no capable faults near the site. For that reason, he agreed that a "near field response spectrum" similar to those created for some California plants close to capable faults would be inappropriate for Midland. But, Mr. Kimball stated that, in characterizing ground motion in the central and eastern United States, the Staff includes the possibility that some of the records used may have "near field" type characteristics, even though the overall characterization of the response spectrum so created would not be "near field."[107]

53. The Board does not need to resolve the issue of whether the Parkfield records should be excluded from the Midland data set because of their alleged "near field" charac-

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105 Kimball, prepared testimony at p. 15, following Tr. 4690.

106 Kimball, prepared testimony at pp. 15-16, following Tr. 4690.

107 Kimball, Tr. 4729-4731, 4822; <u>cf</u> Holt, Tr. 4606-4614.

teristics, because another independent basis for exclusion exists. Mr. Kimball testified that the appropriate magnitude for the 1966 Parkfield earthquake is M_L = 5.65. Thus, while Mr. Kimball could not agree with Mr. Holt that the Parkfield earthquake may have been excluded from the original magnitude range of M_{blg} = 5.3 ± 0.5 set forth in the October 14, 1980 Tedesco letter, he concluded that the Parkfield records should be excluded from the M_{blg} = 5.0 ± 0.5 target range ultimately accepted by the NRC Staff as a result of their acceptance of a smaller tectonic province for Midland.[108] Moreover, the NRC Staff concluded that the SSRS (without Parkfield records) proposed by Applicant for magnitude 5.3 SSE would exceed the ground motion due to the occurrence of a magnitude 5.0 earthquake at Midland, and thus is appropriately conservative.[109]

54. Because the Parkfield records have a substantial effect on the SSRS which we are called upon to approve, the Board explored in some detail whether the magnitude of the 1966

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[108] Kimball, Tr. 4691, 4697, 4723-4725, 4727; see also Holt, Tr. 4542. There was some confusion in the record with respect to different magnitude scales which were used in selecting earthquakes for inclusion in the Midland data set. This confusion was eventually cleared up by Mr. Kimball at Tr. 4691-4696. Essentially, the Richter magnitude, M_L, was used in selecting California and Italian earthquakes. This magnitude is roughly equivalent to M_{blg}, which is a scale used for central and eastern United States earthquakes and which is the magnitude used in the October 14, 1980 Tedesco letter. These magnitude scales are not equivalent to a third kind of magnitude, M_b, measured in the Western United States.

[109] This conclusion was made with respect to both the original ground surface SSRS (Holt Ex. 1) and the top of fill SSRS (Holt Ex. 11). Kimball, prepared testimony at pp. 21-25, following Tr. 4690; see also Holt, Tr. 4541-4542, 457(.

Parkfield earthquake had been appropriately characterized as $M_L = 5.65$. We also explored whether the range of magnitudes specified by the NRC Staff (± 0.5) was adequate.[110] We are satisfied as to these points, and our conclusion is that the Parkfield records have been appropriately excluded in characterizing the ground motion due to the occurrence of the postulated magnitude 5.0 earthquake at Midland.

II. SELECTION OF THE 84TH PERCENTILE AS THE REPRESENTATIVE SPECTRAL LEVEL.

55. 10 C.F.R. Part 100, Appendix A, Section VI(a) requires that once appropriate ground motion records are collected they must be combined to form a single smoothed response spectrum. Smooth response spectra are constructed by statistically combining the records of many different earthquakes. The result is a probabilistic level of ground motion, i.e., the percentile or spectral level indicates the probability that, assuming the postulated earthquake occurs, the ground motion will be within that response spectrum.[111]

56. In the October 14, 1980 Tedesco letter, the NRC Staff took the position that the appropriate representation of the Midland Site Specific Response Spectra as derived from appropriately selected ground motion records would be the 84th percentile (mean plus one standard deviation). This choice of

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110 Kimball, Tr. 4736-4740.

111 Holt, prepared testimony at pp. 17-18, following Tr. 4539. See also note 5, supra.

the mean plus one standard deviation was based on past practice (Sequoyah OL SER, March 1979; Fermi OL SER, June 1981). It was also the level used to derive the Regulatory Guide 1.60 spectral shape and is consistent with the Staff's revisions to the Standard Review Plan dealing with the use of SSRS.[112]

57. Applicant's witness, Mr. Holt, stated in his prepared testimony that the use of the mean plus one standard deviation in this context is not required by 10 C.F.R. Part 100, Appendix A or by statistics. He observed that if one is logically to establish an appropriate spectral level for earthquake ground motion for a given site (which would be a probabilistic determination), then there are two probabilistic factors to be considered: first, the probability of the occurrence of the earthquake and, second, given the earthquake's occurrence, the probability that a certain ground motion (amplitude and frequency) will occur. The dominant factor is the occurrence of the earthquake. Mr. Holt argued that it would be unreasonable to use the same response spectra for a site in the middle of the Michigan Basin as for sites in the Central Stable Region outside the Michigan Basin with greater seismic hazard. Accordingly, Mr. Holt suggested that different percentile levels could be used in constructing response spectra as one way of accounting for differences in seismicity and seismic hazard among different sites in the Central Stable

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112 Kimball, prepared testimony at p. 10, following Tr. 4690.

Region.[113] However, Mr. Holt concluded that a preferable approach would be to recognize that the Central Stable Region is not a tectonic province.[114]

58. As stated previously in paragraph 27, the NRC Staff ultimately agreed with Mr. Holt that a smaller tectonic province than the Central Stable Region should be used for purposes of determining the seismic hazard at Midland. Accordingly, Applicant agreed that the 84th percentile spectrum could be used in constructing an appropriate representation of the ground motion due to the controlling magnitude 5.0 earthquake.[115] Since this Board also concludes that a magnitude 5.0 event is the appropriate Seismic Margin Earthquake for Midland, we need not decide whether some lesser spectral level may be justified in constructing site specific response spectra for other sites.

E. THE DEVELOPMENT OF DYNAMIC MATHEMATICAL MODELS FOR THE AUXILIARY BUILDING, SWPS, AND BWST.

59. The May 5, 1981 Atomic Safety and Licensing Board Prehearing Conference Order directed, inter alia, that the

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[113] Holt, prepared testimony at pp. 17-18, following Tr. 4539. Mr. Holt suggested that a mean-centered value would be more appropriate for the Midland site than the 84th percentile. Holt, prepared testimony at pp. 17-18. Holt Ex. 10, p. 9 indicates that the SSRS recommended by Applicant and ultimately accepted by the NRC Staff lies within the 72nd and 76th percentile response spectra for a magnitude 5.3 earthquake, including the Parkfield records.

[114] Holt, prepared testimony at p. 18, following Tr. 4539.

[115] Holt, Tr. 4594.

mathematical models to be used for dynamic analyses of structures as modified by the remedial soil settlement measures, including the bases for the derivation of the spring constants, be considered in the soils hearings. The testimony on the seismic margin review was postponed until subsequent stages of the OL proceedings.[116] Testimony on the dynamic mathematical models was heard on December 14-15, 1981.[117] The Applicant's consultant, Dr. Robert P. Kennedy of Structural Mechanics Associates, Inc. ("SMA") testified on the dynamic mathematical models being used to perform the seismic evaluation of structures in conjunction with the foundation remedial work.[118] Dr. Kennedy summarized the dynamic models developed for (1) the auxiliary building -- control tower -- electrical penetration area ("Auxiliary Building") which is an interconnected foundation system; (2) the Service Water Pump Structure ("SWPS"); and (3) the Borated Water Storage Tank ("BWST"). The Auxiliary Building and SWPS models were developed by Bechtel Corporation and reviewed by Dr. Kennedy and SMA. The BWST model was developed by Dr. Kennedy and SMA.[119] The NRC Staff structural reviewer, Mr. Frank Rinaldi, and the Staff's consultants, Dr. Paul Hadala of the Corps of Engineers and Mr. John Matra of the

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116 <u>See</u> paragraph 7, <u>supra</u>.

117 Tr. 5998-6136, 6250-6286.

118 Kennedy, Tr. 5998-6121.

119 Kennedy, prepared testimony at p. 1, following Tr. 5995; Kennedy, Tr. 6006-6008.

Naval Surface Weapons Laboratory, presented the results of their review of Applicant's dynamic models.[120]

60. Dynamic mathematical models are used to define the response characteristics of a structure subjected to a dynamic forcing function.[121] For the seismic evaluation of complex buildings, such as the Auxiliary Building and the SWPS, a two-step modeling procedure is commonly used. First, an overall dynamic response model of the complete structure is developed. This model must be adequate to determine the seismic-induced forces, shears, moments, displacements, and accelerations at all important locations throughout the structure, as well as to determine the seismic input to equipment mounted on the structure. Second, detailed static models for local regions of the complex structure are developed. These detailed static models are used to convert the overall seismic-induced responses (step one) to local forces and stresses for use in the seismic evaluation of the design of individual structural elements. The dynamic mathematical models presented by Dr. Kennedy are only intended for the first step, i.e., to determine adequately and conservatively the overall seismic-induced forces, shears, moments, displacements, and accelerations throughout the Auxil-

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120 Rinaldi and Matra, prepared testimony following Tr. 6129; Rinaldi, Matra, and Hadala, Tr. 6121-6136, 6252-6286.

121 The mathematical representation of structures by dynamic models is not always necessary. For a very simple building, or for simple below ground structures such as valve pits and retaining walls, an analyst can determine the natural frequency of vibration and thus the structural responses without constructing a dynamic model. Kennedy, prepared testimony at p. 6, following Tr. 5995.

iary Building, SWPS, and BWST structures and foundations and to determine the seismic input to equipment mounted on these structures.[122]

61. The mathematical models for overall dynamic response of the actual structural systems have the appearance of a series of interconnected "lollypops" with the "ball" of each "lollypop" representing a concentrated mass point and the "stick" representing a concentrated stiffness element. The responses (accelerations and displacements) of each ball, which are obtained from a dynamic analysis using the model, define the responses of specific locations within the actual structure. Similarly, the responses (forces, shears, and moments) computed within each stick of the mathematical model define these same responses within the seismic-resistant structural system represented by the stiffness elements in the actual structural system.[123]

62. The overall dynamic response of a complex structural system to seismic input is heavily influenced by (1) the distribution of mass (weight divided by gravity) throughout the structural system; (2) the distribution of stiffness (the forces required to produce a unit deformation of the structural

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122 Kennedy, prepared testimony at pp. 2-3, following Tr. 5995; Kennedy, Tr. 6009-6010, 6102-6105. Applicant described the detailed static (finite element) models used in designing the remedial underpinning work in other testimony. See prepared testimony of Burke, Corley, Gould, Johnson and Sozen following Tr. 5509 (Aux. Bldg.); prepared testimony of Boos, Burke, Gould and Shunmugavel, following Tr. 9490 (SWPS); prepared testimony of Boos and Hanson, following Tr. 7186 (BWST).

123 Kennedy, prepared testimony at pp. 5-6, and Figures 3, 4, 5, 6, 7, 10, 11, 12, and 14, following Tr. 5995.

system); (3) how the structure is founded on the supporting soil (soil-structure interaction); (4) how the major separate structural systems are interconnected (for example, how is the main auxiliary building connected to the control tower and the auxiliary building); and (5) the amount of energy dissipation capability (damping within the structural system and the radiation of energy away from the structure through the supporting soil).[124] Dr. Kennedy's testimony addresses each of these subjects, but this Partial Initial Decision will summarize only Applicant's treatment of soil-structure interaction and energy dissipation capability, which have special pertinence to this proceeding.

63. A soil-structure interaction model must (1) feed the seismic input into the building models at the appropriate elevations and plan view locations (center of rigidity of the supporting soil); (2) account for the reduced stiffness of the overall building system due to the flexibility of the supporting soil; and (3) conservatively account for the radiation of energy (associated with building response relative to the soil) from the building into the surrounding soil.[125]

64. The soil-structure interaction effect on complex buildings such as the Auxiliary Building is a complex and controversial subject. A complete interaction analysis is beyond the current state-of-the-art and cannot be performed for

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[124] Kennedy, prepared testimony at pp. 3-4, following Tr. 5995.

[125] Kennedy, prepared testimony at p. 5, following Tr. 5995.

complex buildings. Therefore, all soil-structural interaction modeling involves approximations and assumptions. However, conservative seismic evaluations can be performed and safe structures can be designed by conservatively approximating soil-structure interaction effects and by varying the parameters.[126] Dr. Kennedy testified that the soil-structure interaction models incorporated into the Auxiliary Building, SWPS, and BWST dynamic models for the foundation remedial work are very simple. They do not represent the most advanced state-of-the-art, but they were developed in such a way as to conservatively overpredict the seismic response of the structures.[127]

65. In analyzing soil-structure interaction there are basically two approaches: an impedance function or half-space approach and a wave propagation or shear beam approach. Both are approved in the current version of the Standard Review Plan.[128] The Applicant has used the impedance function approach. The impedance function approach can model complete three-dimensional behavior, but it is impossible within the current

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[126] Kennedy, prepared testimony at p. 7, following Tr. 5995. Experts agree that a complete soil-structure interaction analysis would have to (1) account for the variation of soil properties with depth, (2) give appropriate consideration to the material nonlinear behavior of soil, (3) consider the three-dimensional nature of the problem, (4) consider the complex nature of wave propagation which produced the ground motions, (5) consider possible interaction with neighboring structures, and (6) consider the overall three-dimensional response characteristics of the structure. Id.

[127] Kennedy, prepared testimony at pp. 7-8, following Tr. 5995.

[128] Rinaldi, Tr. 6274-6275; see also Kennedy, Tr. 6057-6058.

state-of-the-art to do a complete wave propagation approach that takes into account the complete three-dimensional behavior of complex buildings like the Auxiliary Building, SWPS and BWST. Furthermore while both approaches must be done carefully, and while the wave propagation approach generally will predict the more accurate responses, it is very difficult to insure conservative responses from the wave propagation approach without performing many parameter variations. Dr. Kennedy testified that while a wave propagation approach could have been used there would have been no advantage in doing so.[129]

66. The impedance functions used in modeling soil-structure interaction effects of the Auxiliary Building, SWPS, and BWST consist of real terms, which can be modeled as stiffness linkages ("sticks") between the structure and soil, and imaginary terms, which can be modeled as dashpots (viscous or velocity-proportional dampers) which radiate energy out from the structure to the soil. Best estimate soil properties provided by Dames and Moore were used to establish the impedance function stiffness and dashpot values.[130] The additional

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129 Kennedy, Tr. 6053-6058, 6107-6108.

130 Dames and Moore arrived at this best estimate of soils properties based upon a number of considerations. First, they made estimates of the effective modulus of elasticity based on laboratory tests conducted on soil samples from the site. Dames and Moore made another estimate using empirical formulae which are based on overburden pressure and the type of materials. Finally, Dames and Moore also made comparisons with shear modula obtained from similar sites (LaSalle and Greenwood). Dames and Moore's best estimate of soils properties reflected a weighted average of these estimates. Strain degradation of the soil stiffness properties was included in establishing these properties. Kennedy, Tr. 6078-6081, prepared testimony at p. 8, following Tr. 5995.

stiffening effects of the soil on the side walls due to the embedment of the foundation below the ground surface level were incorporated.[131] Because of uncertainties in soil properties and in the mathematical modeling of soil-structure interaction, there is significant uncertainty in the "softening" effect on soil-structure interaction.[132] In order to cover this uncertainty the Applicant and its Consultant varied the soil-structure interaction stiffnesses within the range from 0.5 to 1.5 times the "best estimate" soil-structure interaction stiffnesses. Dr. Kennedy testified that using this wide range of soil properties avoids the need for more sophisticated soil-structure interaction modeling.[133]

67. Dr. Paul Hadala of the Corps of Engineers evaluated for the NRC Staff the methods used by Applicant in calculating soil spring constants and damping parameters for the Auxiliary Building, the SWPS, and the BWST. Dr. Hadala used a different method of calculation than Applicant. Dr. Hadala used field measured seismic shear wave velocities in the plant fill and in the glacial till to derive a shear modulus. Dr. Hadala then made a reduction based on the work of Seed and Idris to account

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131 Kennedy, prepared testimony at p. 8, following Tr. 5995.

132 Kennedy, prepared testimony at p. 9, following Tr. 5995. The "softening" effect is the effect of soil-structure interaction on the natural frequencies and mode shapes of vibration of the structure. Id.

133 Kennedy, prepared testimony at p. 9, following Tr. 5995.

for the fact that strain levels in earthquakes are larger than those in field seismic shear wave velocity tests. His result was in close agreement with Applicant's best estimate soil properties.[134] Dr. Hadala testified that the methodology used by Applicant and its consultant in determining soil spring constants and damping parameters is a sound one which provides conservative answers for estimating the transmission of energy away from the structure due to radiation damping and the contribution of the foundation soil to the stiffness of the system.[135]

68. The ground response spectra are fed directly into the soil-structure interaction impedance elements, i.e., the stiffnesses and dashpots, and through them into the structure's foundation. This approach ignores the spatial variation, both vertically and horizontally, of earthquake ground motion. This spatial variation occurs because the ground motion arrives at the site as a result of a series of propagating waves, which have different incident angles relative to the ground surface. Ignoring vertical spatial variation results in a significant overprediction of the translational response of the structure and a slight underprediction of the rocking response. The net effect will be that the models in the Auxiliary Building and the SWPS will conservatively overpredict the response of the structures at lower elevations and produce approximately correct

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134 Hadala, Tr. 6130.

135 Hadala, Tr. 6131, 6278-6279.

or sometimes conservative responses at higher elevations.[136] Ignoring horizontal spatial variation also results in an overprediction of the translational response of the structure but within certain frequency ranges may result in underprediction of the torsional response. The net effect is to produce considerable conservatism in the response of the central portion of the structure but approximately correct responses in the extremities of the structure.[137] Dr. Kennedy testified that the soil-structure interaction models for the Auxiliary Building, SWPS and BWST are adequate for conservatively computing responses as long as the benefits of the spatial variations in earthquake ground motion are ignored.[138]

69. The assumption of the impedance function approach that soil beneath the foundation is an elastic half-space can lead to an overprediction of the radiation damping (the radiation of energy from the structure into the ground) because such an assumption does not account for the variation of soil properties with depth. Overprediction of the radiation damping results in excessive energy dissipation being incorporated into the overall dynamic model which can result in underprediction of the structural responses from this model. Applicant compen-

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[136] Kennedy, prepared testimony at pp. 9-10, following Tr. 5995; Kennedy, Tr. 6096-6102. Vertical spatial variation of ground motion has no impact on the BWST, which is founded at the ground surface. Kennedy, prepared testimony at p. 10, following Tr. 5995.

[137] Kennedy, prepared testimony at p. 10, following Tr. 5995; Kennedy, Tr. 6096-6102.

[138] Kennedy, prepared testimony at p. 10, following Tr. 5995; Kennedy, Tr. 6096-6102.

sates for this potential problem in two ways. First, the composite modal damping is computed for modes of structural vibration which are a combination of soil-structure interaction and flexible structural response. If this composite modal damping, which consists of structural damping, soil material damping, and radiation damping, exceeds 10 percent of critical then it is arbitrarily and conservatively limited to 10 percent of critical. Second, for modes of structural vibrations which are nearly exclusively soil-structure interaction modes, i.e., rigid body structural response modes, the radiation damping used will be limited to 75 percent of the theoretical radiation damping levels. (For modes of structural vibration which are nearly exclusively structural modes, the composite modal damping value is not influenced by radiation damping into the soil). Dr. Kennedy testified that the limitation of composite modal damping levels to 10 percent of critical has been proven by many studies to be an extremely conservative criterion which leads to overprediction of structural responses. Dr. Kennedy also testified that he found the layering effects beneath the Auxiliary Building, BWST, and SWPS to be minor and that the radiation damping levels would be at least 75 percent of the theoretical elastic half-space values. Finally, Dr. Kennedy testified that these criteria more than compensate for any unconservatism that may result from the use of elastic half-space theory to estimate radiation damping levels.[139]

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139 Kennedy, prepared testimony at p. 11, following Tr. 5995; Kennedy, Tr. 6063-6065, 6095.

70. The dynamic seismic models must also incorporate estimates of a structure's energy dissipation capability. Viscous damping, which measures the rate of energy dissipation, is defined as a percentage of critical damping where critical damping is the minimum level of damping at which a structure will not oscillate in free vibration. Earthquake ground motion feeds a limited amount of energy into the structure and equipment over the duration of the ground motion. The higher the damping (rate of energy dissipation) the lower is the maximum structural response resulting from the ground motion. In accordance with the general practice at the time of the Midland Plant design, the FSAR SSE damping levels were very low.[140] Since that time considerably higher damping levels have been justified, and the current design practice is to use Regulatory Guide 1.61 damping levels. Regulatory Guide 1.61 damping levels are considerably higher than those of the FSAR and result in a reduction of computed response. Use of the FSAR levels thus provide a source of conservatism. Dr. Kennedy testified that the Regulatory Guide 1.61 damping levels are generally considered to be overly conservative. Dr. Kennedy and other experts have recommended the use of even higher damping levels in the NRC's Systematic Evaluation Program, which is a review by the NRC Staff of existing licensed nuclear

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140 Kennedy, prepared testimony at p. 12 and Table 1, following Tr. 5995; Kennedy, Tr. 6035-6036.

power plants.[141] However, to introduce added conservatism the Applicant will use the Regulatory Guide 1.61 levels for the Seismic Margin Review and the even more conservative FSAR damping levels for the foundation remedial work.[142]

71. The Applicant and its consultant have submitted a dynamic model, developed and reviewed in accordance with the factors discussed in paragraphs 60-70, supra, for the Auxiliary Building. The Auxiliary Building is represented by a three-dimensional, lumped-mass stick model, with additional detail in the electrical penetration areas, which preserves the physical geometry of the various building components. A schematic plan of the Auxiliary Building subdivides it into the main auxiliary building, the control tower, and the two electrical penetration wings which are interconnected. The foundation remedial work is being performed beneath the control tower and the electrical penetration wings. Underpinning is being extended down to undisturbed glacial till. The overall dynamic response of the Auxiliary Building can be modeled using a series of vertical sticks (stiffness elements) with each representing a major portion of the building. The mass associated with the main auxiliary building and control tower has been lumped at the major floor elevations. For the wing areas, the

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[141] Kennedy recommended the use of NUREG/CR-0098. Kennedy, prepared testimony at p. 13, following Tr. 5995. For a comparison of FSAR, Regulatory Guide 1.61, and NUREG/CR-0098 damping levels see Kennedy, prepared testimony, Table 1, following Tr. 5995. See also Kennedy, Tr. 6036-6038.

[142] Kennedy, prepared testimony at pp. 12-13, following Tr. 5995; Kennedy, Tr. 6038-6040, 6115-6119.

mass associated with each plate element has been lumped in accordance with plate thickness, and the remaining mass associated with each wing has been lumped at the floor elevations. The stick (stiffness) elements have been located at the calculated centers of rigidity and are thus horizontally offset from the mass points and each other to account for torsional vibrations. The proposed underpinning designs for beneath the control tower and for the wing area have been accounted for, and the mass includes both the concrete and the effective entrapped soil.[143]

72. For the SWPS the Applicant and its consultant have submitted a three-dimensional lumped-mass stick model using beam elements. This model was developed in a manner similar to that used for the Auxiliary Building model. The foundation remedial work consists of placing an underpinning wall beneath the northern portion of the building so as to bring its foundation down to an elevation that is lower than the backfill. The overall dynamic response of the SWPS can be modeled using a single vertical stick. The mass of the structure is lumped at

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143 Kennedy, prepared testimony at pp. 13-17, Figures 2-7, following Tr. 5995; Rinaldi and Matra, prepared testimony at pp. 4-5, following Tr. 6129. For both the Auxiliary Building and the SWPS, the total weight of the entrapped soil is added to the horizontal inertial mass of the walls. Vertically, the walls are free to vibrate relative to the soil, and thus the soil has not been added to the vertical inertial mass. This increase in total weight increases the total shears and moments in the walls, thus increasing the design forces on the walls. This is based on the conservative assumption that the entrapped soil is moving with the walls. Kennedy, Tr. 6024-6026.

the major floor elevations. The water in the SWPS and the soil entrapped within the underpinning walls are accounted for.[144]

73. The model which has been submitted for the BWST was developed by Dr. Kennedy and SMA, and it replaces a model which Bechtel had developed.[145] The BWST is a vertical cylindrical tank which is supported by the soil beneath the tank and anchored to a ring foundation. The ring foundation must withstand the seismic-induced forces in the tank shell. These forces are nearly totally due to the water in the tank since the tank shell weight is negligible when compared to the weight of the borated water. Therefore, the primary seismic modeling concern is to model properly and conservatively the seismic forces induced by the water on the tank shell and thus also on the foundation. Dr. Kennedy testified that it is best to model the impulsive mode, the sloshing mode, and the vertical mode of fluid-structure interaction individually. The seismic forces imposed upon the tank shell and ring foundation are added by the square-root-sum-of-squares method. The impulsive mode is

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144 Kennedy, prepared testimony at pp. 17-18, Figures 8-12, following Tr. 5995; Rinaldi and Matra, prepared testimony at pp. 3-4, following Tr. 6129. See also note 143, supra in regard to entrapped soil.

145 The foundation of the BWST has been designed based upon the Bechtel dynamic model. The Bechtel model predicts higher loads on the foundation than the Kennedy model by about 20 percent or a factor of 1.2. Because BWST foundation design loads are based upon the higher Bechtel model extra conservatism is provided in the remedial work. Dr. Kennedy's model will be used in the Seismic Margin Review and in the checking of the forces on the tank for the SSRS. Kennedy, Tr. 5991-5994, 6006-6008; Rinaldi, Tr. 6279-6280.

modeled by vertical stick elements between mass points distributed up the tank shell. A dynamic model is not required to evaluate the forces in the sloshing and vertical modes. The forces in these two modes can be determined by mathematical equations.[146] Dr. Kennedy testified that the foundation ring does not affect seismic modeling except that the rings act as an anchor for vertical movement. Thus, the facts that the old foundation ring is out of plane and is cracked, and that another foundation ring will be added to the BWST foundation as a remedial measure, are irrelevant in the determination of seismic response of the BWST.[147]

74. Dr. Kennedy concluded that the dynamic models for the Auxiliary Building, SWPS and BWST are adequate for establishing the conservative seismic forces to be used in the design of the remedial work and in the Seismic Margin Review.[148]

75. In addition to the review of soil spring constants and damping parameters by Dr. Hadala, the NRC Staff's structural reviewer, Mr. Frank Rinaldi, and its consultant Mr. John Matra of the Naval Surface Weapons Laboratory reviewed the

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146 Kennedy, prepared testimony at pp. 19-22, Figures 13-14, Attachment B, following Tr. 5995.

147 Unlike Dr. Kennedy's model, which considers the tank to be supported by the soil at the base point of the tank, Bechtel's dynamic model includes the foundation ring. Dr. Kennedy explained that this is one of the reasons why his model is better and more accurate. Kennedy, Tr. 6044-6052, 6059-6063.

148 Kennedy, prepared testimony at p. 12, following Tr. 5995.

other aspects of Applicant's dynamic models.[149] The NRC Staff found that the methodologies used by the Applicant and its Consultant to develop and to review the dynamic mathematical models are within the state-of-the-art.[150] The Staff found that the Auxiliary Building and SWPS models adequately represented those structures within the state-of-the-art.[151] At the time of the hearings on December 14-15, 1981 the Staff had not been able to review the dynamic model for the BWST.[152] Subsequently, however, the NRC Staff did perform such a review and Mr. Rinaldi and Mr. Matra testified on February 17, 1982 that the Applicant's dynamic analysis of the BWST was satisfactory.[153]

76. The Licensing Board finds that the methodology used to develop the models for the Auxiliary Building, SWPS, and

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149 Mr. Rinaldi's and Mr. Matra's prepared testimony, following Tr. 6129 swept more broadly than Applicant's in that it also addressed the static (finite element) models for the Auxiliary Building, SWPS, and BWST. Because this portion of the Staff's testimony was preliminary in nature and was superceded by subsequent NRC Staff structural testimony with respect to the Auxiliary Building, the SWPS, and the BWST, it is not discussed further in this Partial Initial Decision.

150 Hadala, Tr. 6131; Rinaldi, Tr. 6131-6134, 6266; Matra, Tr. 6134.

151 Rinaldi and Matra, prepared testimony at pp. 9, 11-14, following Tr. 6129; Rinaldi, Tr. 6258.

152 When the Staff filed its prepared testimony it had not seen Dr. Kennedy's model for the BWST. At the time of the hearings on December 14-15, 1981 the Staff had seen Dr. Kennedy's model but had not reviewed it. Rinaldi, Tr. 6132-6133, 6254-6257, 6263. Cross examination, concerning the Kennedy BWST model, of the Staff witnesses was deferred. Tr. 6257.

153 Rinaldi and Matra, prepared testimony following Tr. 7537.

BWST was within the state-of-the-art. The Board concludes that these models are adequate for the purpose of defining seismic design forces to be used in the design of foundation remedial work, for conservatively estimating the seismic-induced forces in these structures, and for defining the seismic input to equipment, systems, and components mounted on these structures.

F. APPLICANT'S USE OF 1.5 X FSAR SSE RESPONSE SPECTRA AS SUBSTITUTE FOR SSRS.

77. Because no agreement had been reached with the NRC Staff with respect to the SSRS when the design of the remedial soils measures was begun, the Applicant incorporated what it believed to be a reasonable margin over FSAR seismic criteria into the design.[154] Specifically, the Applicant directed Bechtel to use 1.5 times the FSAR SSE response spectra in designing the remedial foundation measures for the Auxiliary Building, SWPS, and BWST.[155] Subsequently, Applicant committed that the agreed-upon SSRS would be the design basis for the remedial foundation measures, but it continued to use 1.5 times the FSAR SSE in the actual design work.[156] Because the SSRS exceed 1.5 times the FSAR SSE response spectra for some frequencies, the Board heard testimony from a number of witnesses

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[154] Affidavit of Thiru Thiruvengadam, dated March 6, 1981, at pp. 6-7, attached to Applicant's Motion to Defer Consideration of Seismic Issues Until the Operating License Proceeding, dated March 18, 1981.

[155] Kennedy, Tr. 5996-5997.

[156] Kennedy, Tr. 5996-5997.

as to the adequacy of Applicant's design procedure for the remedial foundation measures.[157]

78. Applicant has run dynamic analyses of the Auxiliary Building, SWPS, and BWST using the dynamic mathematical models of these structures to confirm the adequacy and conservatism of using design spectra of 1.5 times the FSAR SSE response spectra.[158] Dr. Kennedy testified that the SSRS responses for the BWST were 1.3 times the FSAR SSE spectra responses. For the SWPS, Bechtel's analyses showed that the SSRS responses were from 1.2 to 1.4 times the FSAR SSE spectra responses. The SSRS responses for the Auxiliary Building were generally from 1.2 to 1.4 times the FSAR SSE spectra responses.[159] However, in the missile shield the SSRS responses were 1.7 times the FSAR SSE spectra responses. Dr. Kennedy testified that the missile shield has no influence on nor is it influenced by the founda-

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157 The greatest difference between the FSAR SSE response spectra and the SSRS occurs between about 5 hertz and 15 hertz. In that range the FSAR SSE accelerations are about double the SSRS. Holt, Tr. 4639-4640.

158 Kennedy, Tr. 5996-6005, 6040-6041.

159 Kennedy, Tr. 6000-6005. For the BWST, this comparative analysis was done by SMA using the full range of soil properties described in paragraph 66, <u>supra</u>. Other witnesses, presented by the Applicant in this proceeding to describe the remedial foundation measures for the BWST, have confirmed that using 1.5 times the FSAR SSE is more conservative than using the SSRS. Hanson, Tr. 7278-7280; Boos, Tr. 7949-7951. For the SWPS and Auxiliary Building the comparative analysis was performed by Bechtel using only best estimate soil properties. Kennedy, Tr. 6003-6004, 6026-6028. Nevertheless, Dr. Kennedy believed that for these structures the conclusion that 1.5 times the FSAR spectrum leads to larger forces on the foundation than would result from the SSRS would still be valid when soil properties are varied. Kennedy, Tr. 6026-6027.

tion remedial work.[160] For each of these structures, the NRC Staff also has subsequently concluded that the use of 1.5 times the FSAR response spectra in designing the remedial foundation measures appears to have been conservative. This will be confirmed by the Staff in the Seismic Margin Review of the Midland Plant.[161] Accordingly, the Board finds that Applicant's use of 1.5 times the FSAR SSE response spectra as a substitute for the SSRS in designing the remedial foundation work is reasonable and conservative.

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[160] Kennedy, Tr. 6002-6003, 6029-6032.

[161] SSER #2, pp. 1-3 and 3-2. Rinaldi, prepared testimony at pp. 6-8, following Tr. 12080; Rinaldi, Tr. 12130-12131 (Auxiliary Building). Rinaldi, prepared testimony at p. 8, following Tr. 12080 (BWST). Rinaldi, Tr. 9694-9697, 9713-9718 (SWPS).