ATTACHMENT 4b TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

	)
In the Matter of:	)
PRIVATE FUEL STORAGE, LLC,	) Docket No. 72-22
(Independent Spent Fuel	) ASLBP No. 97-732-02-ISFSI
Storage Installation)	)
	)

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84114

On June 5, 2002 the above-entitled matter came on for hearing, pursuant to notice, before:

MICHAEL C. FARRAR, CHAIRMAN
Administrative Judge
U. S. Nuclear Regulatory Commission

DR. JERRY R. KLINE
Administrative Judge
Atomic Safety & Licensing Board Panel

DR. PETER S. LAM
Administrative Judge
Atomic Safety & Licensing Board Panel

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EXAMINATION

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EXHIBITS

shaking Table."

201 Regulatory Guide 1.165, one page from Appendix B. 9958/10069

202 Topical report for Yucca Mountain, August 1997, with Table C-2. 9958/

203 Basis for Seismic Provisions for DOE-STD-1020 by Kennedy and Short 9958/

204 Update of Deterministic Ground Motion Assessments, Revision 1 9958/

205 e-mail communication, Dr. Arabasz to Ivan Wong with attachments 9958/

206 Seismic Hazards Evaluation of the Los Alamos National Laboratory, 24 February 1995 9958/

207 DOE-STD-1020-2002, cover page and page C-6, including Table C-3 9958/

208 "Risk Reduction Ratio, Mean Return Period of Design Basis Earthquake (DBE) Ground Motions, and Target Performance Goal." 9958/

209 Excerpts from bullets referred to by Dr. Arabasz, bullets on the Staff's modified rulemaking Plan, SECY-01-0178 9958/

QQ 2002 DOE standard, first 15 pages of Appendix C 9958/

RR Three pages from article by Dr. Arabasz and R.K. McGuire titled "An Introduction to Probabilistic Seismic Hazard Analysis 9958/

2, when you refer to risk, are you referring to radiological risk?

A. No. What I'm referring to is the risk as referenced in Appendix B to Reg Guide 1.165. And the context there, first of all, of the citation that -- excuse me, the text that Mr. Turk asked me to -- to read from the November 9 document, the context, as I recall, began, if one were considering the reference probability of a -- a nuclear power plant at the PFS site then. And Regulatory Guide 1.165 in Appendix B begins with Section B.1 saying, "This appendix describes a procedure that is acceptable to the NRC staff to determine the reference probability, an annual probability of exceeding the Safe Shutdown Earthquake," and so on. It describes the reference probability of 1x10-5 which we've heard about many times in this hearing, and then in terms of an alternative reference probability, it says that -- and I'm reading from part of Section B.3 --

Q. This is State's Exhibit 201; is that

correct?

A. That's correct. The large paragraph on the left-hand side of the page, about the fifth line down begins, This reference probability --

meaning the 1x10-5 -- is also to be used in conjunction with sites not in the eastern and central United States (CEUS) and for sites for which LLNL and EPRI methods and data have not been used or are not available. However, the final SSE at a higher reference probability may be more appropriate and acceptable for some sites considering the slope characteristics of the site hazard curves, the overall uncertainty in calculations (i.e., differences between mean and median hazard estimates) and the knowledge of the seismic sources that contribute to the hazard. Reference B.4 includes a procedure to determine an alternative reference probability on the risk-based considerations. Its application will also be reviewed on a case-by-case basis.

The reference to B.4 is a position paper, I believe it was by the Nuclear Energy Institute, and it simply is a precursor to NUREG CR-6728 which puts forward thinking about what one should do if one wants to achieve risk consistency from site to site across the country. And the elements that enter into that consideration include the relative slopes of hazard curves in different parts of the country, the robustness of the SSCs or the -- whatever elements are being designed, basically the design conservatisms and so on.

So in that context the risk is risk consistency for the same probability of failure across the country. It doesn't relate to radiological risk or a formal PRA, as understood.

Q. So is that what you were referring to on page 9259 of the transcript?

A. Correct. The wording of risk analysis is referenced to Appendix B in Reg Guide 1.165.

MS. CHANCELLOR: Your Honor, I'd move for admission of State's Exhibit 201.

JUDGE FARRAR: Any objection?

MR. GAUKLER: No objection.

MR. TURK: Voir dire, Your Honor? I believe the witness misunderstands the document.

MS. CHANCELLOR: Whether he misunderstands the document or not, he has testified as to what he gets from this document, and it's relevant to his testimony.

(The Board confers off the record.)

JUDGE FARRAR: Mr. Turk, you may be entitled to question this witness about his views, but I can't see having Staff voir dire on a Staff document.

ATTACHMENT 5 TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of:	)	Docket No. 72-22-ISFSI
PRIVATE FUEL STORAGE, LLC	)	ASLBP No. 97-732-02-ISFSI
(Independent Spent Fuel Storage Installation)	)	September 5, 2002

STATE OF UTAH'S PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW ON UNIFIED CONTENTION UTAH L/QQ

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Fred G Nelson, Assistant Attorney General
Connie Nakahara, Special Assistant Attorney General
Diane Curran, Special Assistant Attorney General
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Attorneys for State of Utah

CONTENTION PART E: Seismic Exemption Request

A. Issue: Has PFS shown by a preponderance of the evidence that there is sufficient conservatism built into PFS's ISFSI design such that its ISFSI design and subsequent consequences from a seismic event will not endanger life or property or the common defense and security and it is otherwise in the public interest to allow PFS a substantially lower design standard than mandated by the existing seismic regulations.

B. Regulations/Guidance

1. 10 CFR § 72.7. An exemption from 10 CFR § 72.102(f)(1) is authorized by law, will not endanger life or property or the common defense and security and is otherwise in the public interest.

2. 10 CFR § 72.104(a). Normal operations and anticipated occurrences annual dose limit must not exceed 75 mrem.

3. 10 CFR § 106(b). Any individual located on or beyond the nearest boundary of the controlled area may not receive from any design basis accident a total effective dose equivalent of 5 rem.

4. DOE Standard 1020-02, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* (January 2002)

5. NUREG/CR 6738, *Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard-and-Risk-Consistent Ground Motion Spectra Guidelines*, October 2001 (2 volumes).

6. NUREG 1567, *Standard Review Plan for Spent Fuel Dry Storage Facilities* (March 2002).

7. NUREG 1617, *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel* (March 2000).

C. Findings of Fact

Overview

447. The difficulty facing this Board in evaluating PFS's request to use probabilistic earthquake ground motions with a 2,000-year return period value, equivalent to a 5×10^{-4} year mean annual probability of exceedance ("MAPE")[63], for the design basis earthquake at the PFS site is that earthquake science and engineering involve many uncertainties. Ultimately, this Board must decide what is an acceptable level of risk. Should such a decision take into account the operational life of the facility? Strictly annual risk? Does Dr. Cornell's assertion of conservatism in the ISFSI design approach assure a sufficient margin of safety? Has the Staff put forward a well-founded rationale for accepting a 2,000-year return period value with the PSHA methodology? These are some of the questions the Board must address in making its decision.

448. The intra-plate setting of the Central and Eastern United States ("CEUS"), east of the Rocky Mountains, involves very old geology, thick sediment cover, and low levels of seismicity, making it difficult to get a scientific understanding of the nature and cause of

[63]A note is in order on terminology used in these findings. "Return period" is the average time between consecutive events of the same or greater severity and is sometime designated as MRP or mean return period. The annual probability of exceedance of an event is the reciprocal of the return period of that event. In terms of the DOE-STD-1020 paradigm, "performance goal" is used as the annual probability of exceedance of acceptable behavior limits (*i.e.*, behavior limits beyond which damage/failure is unacceptable). *See* Utah Exh. 208; DOE-STD-1020-2002, Table C-3, Staff Exh. QQ.

earthquakes in the CEUS. Tr. (Cornell) at 7891-92. There is a better understanding of earthquake occurrence along the tectonic plate margins in the Western United States, *i.e.*, along the Pacific coast, because earthquakes are more frequent and thus there are more data. Consequently, there is less uncertainty in the hazard assessments for these areas of the Western United States (near the plate boundaries) than in the CEUS. Tr. (Cornell) at 7892-93; *see also* Tr. (Arabasz) at 9138-39. However, in the Intermountain West, where the Skull Valley site is located, the situation is complex. Tr. (Cornell) at 7896; Tr. (Arabasz) at 9176-77.

449. The State offered expert testimony by a highly qualified seismologist, Dr. Walter Arabasz, on the seismic activity in the region of the PFS site. Since 1977, Dr. Arabasz, who is in charge of the University of Utah Seismograph Stations, has been studying and monitoring earthquakes in Utah and has made this the mainstay of his career. Tr. (Arabasz) at 9200. Dr. Arabasz testified that compared to the rate of earthquake activity on the plate boundaries in California, large active faults in the Intermountain area have relatively longer return periods. In the Salt Lake valley, the return period for a large surface-rupturing earthquake on the Wasatch fault is about 1,400 years whereas in Skull Valley the return period on the Stansbury fault is much longer. Tr. (Arabasz) at 9203. There is sparse information for large earthquake recurrence on the Stansbury fault (5 to 6 miles from the PFS site), the last earthquake having occurred on the order of 8,000 years ago and a prior event 15,000 or more years ago. What is known is that the Stansbury fault has been storing up energy for the past 8,000 years and is capable of delivering a large earthquake, but whether the next event will be tomorrow or thousands of years away is unknown. Tr.

(Arabasz) at 9203-04. Armed with this knowledge, the Board is cognizant of the potential energy that may be unleashed at the Skull Valley site yet mindful of the uncertainties in earthquake forecasting. This being the case, the Board considers it prudent to be circumspect when evaluating the safety of the PFS facility.

450. There are two sides to the earthquake safety equation: (a) what is the capacity of the structures and foundations at the PFS site to withstand an earthquake; and (b) what is the demand or design basis earthquake that the capacity must meet. *See e.g.*, Cornell Tstmy, Post Tr. 7856 at 13-15; Arabasz Tstmy, Post Tr. 9098 at 6; Tr. (Arabasz) at 10047-48. For the demand side of the equation, at the current stage of NRC regulatory development on formulating the design basis earthquake for an ISFSI, there is no fixed reference frame for the failure probability of SSCs. By contrast to NRC, the U.S. Department of Energy ("DOE") framework has evolved to the point where DOE has ranked its facilities into four groupings and has established a probability of failure (termed P_F in DOE Table C-3, Staff Exh. QQ) of SSCs as a target performance goal for each of those groupings. Furthermore, ISFSI SSCs of concern at PFS (*e.g.*, casks, foundations composed, in part, of soil-cement) are atypical of those at nuclear power plants, for which there is a greater knowledge base. Tr. (McCann) at 8277. In this proceeding, PFS and the Staff are asking the Board to agree with them that the capacity side of the equation will do all the heavy lifting. Can the Board be confident that the asserted conservatism in design has indeed been achieved, given that the reference frame for ISFSI SSC failure probabilities is, at best, in a nascent state of development? The importance of the exemption part of the contention (the demand side) is that the Board must determine what is the appropriate

design basis earthquake ("DBE") to ensure an adequate margin of safety because sufficient protection depends on both the probability of occurrence of the seismic event as well as the level of conservatism incorporated into the SSC design.

Benchmark Probability for the DBE at the PFS Site

451. Part 72 currently requires PFS to assess the maximum vibratory ground motion that could be experienced at the PFS site using deterministic seismic hazard analysis methodology. Part 72[64] cross references the standard that formerly applied to nuclear power plants, *i.e.*, 10 CFR Part 100, Appendix A. Under the changes in the NPPs' requirement, codified at 10 CFR § 100.23, a NPP applicant now refers to NRC guidance (Reg. Guide 1.165) where the "reference probability" for determining the SSE from a probabilistic seismic hazard analysis is specified to be that probability which has an annual median probability of 1×10^{-5} of exceeding the SSE, which is equivalent to a mean annual exceedance probability of 1×10^{-4} (or a return period of 10,000 years) for the CEUS; there is the option that an applicant may request and justify the use of a higher reference probability for a site not in the CEUS (*e.g.*, in the western United States). Reg. Guide 1.165 at 1.165-12 (State Exh. 201); Tr. (Cornell) 8001-02.

452. As a starting point, the Board finds that it is reasonable to assume that the reference probability for a hypothetical NPP at the PFS site sets the upper benchmark for establishing the DBE for the PFS facility.

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[64]*See* 10 CFR § 72.102(b); *see also* § 72.102(f)(1): "For sites that have been evaluated under the criteria of appendix A of 10 CFR part 100, the DE [design earthquake] must be equivalent to the safe shutdown earthquake ("SSE") for a nuclear power plant."

453. As described in testimony by all parties, if a NPP were to be sited at the PFS site, acceptable design levels would be established using ground motions with a mean annual return period somewhere between 5,000 years and 10,000 years. Tr. (Arabasz) at 10111-14, 10120-24; Cornell Tstmy, Post Tr. 7856 at 42, 47-48; Tr. (Stamatakos) at 12717-18; (McCann) at 8337-38); Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 26-29.

454. The Staff has argued, with some qualification, that based on a survey of five NPPs in the Western United States ("WUS"), the reference probability for a hypothetical NPP at the PFS site would be a mean annual exceedance probability of 2×10^{-4} (5,000-year MRP). Tr. (McCann) at 8326, 8337-38; Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 26-29; Stamatakos Rebuttal, Post Tr. 12648 at 4-5. Two of the five NPPs in the survey are located in California, one is in Arizona, and two are in Washington state. State's Exh. 202.[65] We do not agree with Dr. McCann's assessment and with Dr. Stamatakos' position that the average MAPE of 2×10^{-4} from the five NPPs represents a value that is applicable to the entire WUS. Stamatakos Rebuttal, Post Tr. 12648 at 4-5. First, at least three of the five NPPs in the survey are located near tectonic plate boundaries along the Western coast, have steep hazard curves, and are not simply representative of the Intermountain area. Second, the Palo Verde site in Arizona, in an area of low seismicity and with a mean exceedance probability corresponding to a 26,000-year return period earthquake,[66] is not only an outlier in the calculation of the sample mean but its MAPE argues against the applicability of a

[65]Excerpts, Topical Report YMP/TR-003-NP, *Preclosure Seismic Design Methodology for a Geologic Repository at Yucca Mountain,* Rev. 2 (8/97), DOE.

[66]Tr. (Cornell) at 8033;Tr. (Arabasz) at 9177-78, 10096.

5,000-year MAPE to the entire WUS. Third, we do not believe that extrapolating an average MAPE from such a small number of NPPs to the Skull Valley site – or to any other hypothetical NPP site in the WUS away from the plate boundary – would withstand critical scrutiny in a NPP licensing hearing. Representing that the sample mean characterizes "nuclear power plants in the Western United States" is defensible only semantically.

455. It is apparent that although the 5,000-year MRP may justifiably apply at WUS NPP sites where there are steep hazard curves, such as near tectonic plate boundaries, it does not necessarily apply in the Intermountain west. For example, DOE-STD-1020-2002 sets a greater probability of exceedance (*i.e.*, a shorter return period) for sites located near tectonic plate boundaries than other DOE sites. Staff Exh. QQ at Table C-3. For PC-4 facilities – equivalent to NPPs – the standard for sites located near tectonic plate boundaries is 2×10^{-4} (*i.e.*, a 5,000-year return period) whereas for non-plate tectonic sites the return period is 10,000 years.[67] Id.

456. Dr. Arabasz presented a qualitative analysis of nuclear facility sites in the WUS, including the Basin and Range province, and used a literature review and the steepness of hazard curves at some of those sites to ascertain whether the implied probability of exceeding a SSE corresponded to a 5,000-year MRP or a 10,000-year MRP. Dr. Arabasz is an expert with extensive professional experience in studying and monitoring earthquakes in the Basin and Range province, and the Board gives substantial deference to

[67]Dr. Cornell, *citing* DOE-STD-1020-94, Table C-3 at C-5, also noted the basis for the different risk reduction ratios for "Western sites" is that the western sites are near tectonic boundaries, where the hazard curves are considerably steeper. Cornell Tstmy Post Tr. 7856, at 16-17, n.5.

his analysis.

457. Dr. Arabasz first looked at available information. SECY-98-071, Staff Exh. S, documents the grant of an exemption to the Idaho National Engineering and Environmental Laboratory ("INEEL") to store Three Mile Island, Unit 2 ("TMI-2") fuel, including the following, at p. 2: "Based on 10 CFR 100.23 requirements, as described in Regulatory Guide 1.165, 'Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion,' a future nuclear power plant in the western United States can use as a safe shutdown earthquake the 10,000-year return period mean ground motion." Tr. (Arabasz) at 10093-94. Thus, in the foregoing document, issued in April 1998 – eight months after August 1997 when DOE published Yucca Mountain Topical Report YMP/TR-003-NP in which the average MAPE for five NPPs in the WUS was reported (State's Exh. 202, Table C-2) – the Staff accepted a 10,000-year MRP as an appropriate SSE reference standard for a NPP at the INEEL ISFSI site.

458. Another piece of information before Dr. Arabasz was DOE's effort to equate a design basis ground motion at Yucca Mountain to the SSE reference probability for a NPP. Even though it had calculated an average MAPE of about 2×10^{-4} (5,000-year MRP) for five NPPs in the WUS, as reported in its Yucca Mountain Topical Report YMP/TR-003-NP, Table C-2, State's Exh. 202, DOE chose not to use 5,000 years but 10,000 years as the MRP for the Yucca Mountain DBE. Tr. (Arabasz) at 10095; 10120-10121.

459. For more information relevant to an appropriate SSE reference probability eastward of the plate boundary into the Intermountain area, Dr. Arabasz turned to Kennedy & Short's paper titled <u>Basis for Seismic Provisions of DOE-STD-1020</u> (April 1994), in

which they give an overview of the slopes of the seismic hazard curves and show how they vary across the country. Kennedy & Short, Table A-2 (State Exh. 203), use a value, A_R, to describe "'the ratio of ground motions corresponding to a tenfold reduction in exceedance probability.'" Tr. (Arabasz) at 10099 (*quoting* Kennedy & Short at 2-1). In effect, the ratio is a measure of how much ground motions increase as the annual probability decreases. From seismic hazard curves at several nuclear sites, Kennedy & Short provide ratios for the probability intervals 1×10^{-5} to 1×10^{-4}, designated as A5/A4, and 1×10^{-4} to 1×10^{-3} (A4/A3). As can be seen from State Exh. 203, eastern sites tend to have the relatively highest ratios, high seismic sites near tectonic plate boundaries tend to have the relatively lowest values, and western sites not near tectonic plate boundaries tend to have intermediate ratios.[68] Armed with this information, Dr. Arabasz added to Kennedy & Short Table A-2 after determining the value of A5/A4 and A4/A3 for four of the five western sites of DOE Table C-2, State Exh. 202 (Diablo Canyon values were already determined by Kennedy & Short) and for the Yucca Mountain site. It is apparent that three of the five NPP sites on DOE Table C-2 (Diablo Canyon, San Onofre, and Washington Nuclear Plant 3 near Satsop) are near tectonic plate boundaries and have low ratios of A5/A4 (steep hazard curves) of about 1.5 or less; Palo Verde and Yucca Mountain have A_R ratios more like eastern sites. From comparing Kennedy and Short's Table A-2, State Exh. 203, with Table C-3 of DOE STD-1020-2002 (State Exh. 207), Dr. Arabasz concluded the following for A5/A4 ratios in

[68]The lower the ratio, the less relative change in ground motions when you move to the right on the hazard curve and hence the steeper the slope in log-log space. Tr. (Arabasz) at 10101-02.

the range of 1.5:

> Under the DOE framework using Table C-3, one would achieve large risk reduction ratios that would justify the use of the 5,000-year P sub H value [probability of exceeding the seismic hazard]. When we have slopes of the order of 2 in A5/A4 space, for example, under western DOE sites not near tectonic plate boundaries, INEEL [sic, INEL][69], Los Alamos, Hanford, the assumption is that the engineering judgment was made as part of the DOE design approach that these A5/A4 slopes did not justify the 5,000-year return period motion.

Tr. (Arabasz) 10108; *see also* Tr. (Arabasz) at 10105-06.

460. Dr. Arabasz continued his qualitative analysis of non-coastal western sites by using as a proxy for NPP information a review of the 84th percentile deterministic motions for the INEEL, PFS, Yucca Mountain, and Los Alamos sites. He observed, qualitatively, that without exception the ground motion values approach or exceed 10,000 years. Tr. (Arabasz) 10109-14, 10120-24. Dr. Arabasz's presentation credibly shows that as you move eastward from the plate boundary to Hanford, Palo Verde, Yucca Mountain, INEEL, Los Alamos and the PFS site, the appropriate SSE reference probability for a NPP would not appropriately be pegged at 2×10^{-4} (5,000-year MRP) but rather at approximately 1×10^{-4} (10,000-year MRP).

461. Contrary to Dr. Arabasz's testimony, Dr. Stamatakos in his rebuttal testimony maintained that the average MAPE of 2×10^{-4} (5,000-year MRP) for five existing NPPs in the WUS "is applicable to the entire Western United States." Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 4. Responding, in part, to his understanding of testimony by Dr.

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[69] Quotations from the hearing transcript with obvious transcription errors are handled by putting the corrected wording in the quotation bracketed by sic plus the incorrect transcript wording.

Arabasz (*see* Tr. (Stamatakos) at 12705-06), Dr. Stamatakos also asserted that "there is not a clear difference between the shapes or slopes of most hazard curves in the intermountain west (including the PFS site), and sites that are near tectonic plate boundaries." Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 5. He further explained, "My point is that when I look at the underlying factors that control the hazard curves I don't see a logical connection at least as a geologist necessarily between the shape or slope of the hazard curves and whether or not they are located right on a plate boundary or not." Tr. (Stamatakos) at 12705-06. It is clear to the Board that Dr. Arabasz did not imply that "only tectonic plate nuclear power plants may have a shorter return period than the 10,000 return period (MAPE = 1×10^{-4})" (Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 4), or that somehow the shape or slope of a hazard curve is like a genetic marker that identifies whether a site is near or away from a tectonic plate boundary and, hence, whether the site qualifies or not for a higher seismic hazard exceedance probability (lower MRP) under DOE-STD-1020. *See* State Exh. 207 at Table C-3, footnote. The key point overlooked by Dr. Stamatakos is that under DOE guidance, the steepness of the hazard curve at a site, specified either in terms of a parameter A_R, the ratio of ground motions corresponding to a tenfold reduction in exceedance probability (Tr. (Arabasz) at 10098-99) or equivalently by a slope parameter k_H (Staff Exh. QQ at C-9), determines whether one achieves a risk reduction ratio of 20 or more that can justify, in the case of DOE PC-4 facilities, a 5,000-year reference ground motion versus a 10,000-year ground motion. Tr. (Arabasz) at 10105-06, 10108. In his prefiled testimony, Dr. Cornell quantitatively shows how the risk reduction ratio – a measure of the degree of conservatism inherent in design procedures and acceptance criteria – directly relates to the slope of a PSHA hazard curve. Cornell Tstmy, Post Tr. 7856 at Attachment A. The Board gives no weight to Dr. Stamatakos' rebuttal testimony. It either does not address or is inconsistent with the testimony by Dr. Arabasz and Dr. Cornell which shows that it is not the location of the site per se near a tectonic plate boundary; rather, it is the slope or steepness of the hazard curve that is the important factor in arriving at a risk reduction factor of 20 or more, which in turn is the rationale under DOE Standard 1020 to allow a 5,000-MRP.

462. Another point put forward by Dr. Stamatakos in his rebuttal testimony to justify a SSE reference probability of 2×10^{-4} (5,000-year MRP) for a hypothetical NPP at the PFS site is that the latter meets a "clear definition [in DOE-1020-2002 at C-9] of high hazard sites that fall in the 'near tectonic plate boundary' classification." Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 5. Under cross-examination, Dr. Stamatakos strained to defend construing his "clear definition" but persisted in trying to link the PFS site to ones qualifying for a higher hazard exceedance probability (lower MRP) under DOE-STD-1020. Tr. at 12709-13. Dr. Stamatakos attempted to characterize the PFS site as comparable to sites near tectonic plate boundaries because of its proximity to active faults, high recurrence rates, and high seismicity. Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 5; Tr. at 12712. Dr. Arabasz and Dr. Stamatakos disagree on whether the PFS site would be characterized as having "high seismicity" (Tr. (Stamatakos) at 12721-25) or nearby faults with "high recurrence rates" – or equivalently high slip rates. Tr. (Stamatakos) at 12724-25, 12727-39, 12753-56. The Board finds that at bottom, Dr. Stamatakos's subjective characterization of the PFS site from a geological point of view vis-a-vis DOE-STD-1020 is quixotic (*see* Tr. at

(Arabasz) 10231-32); what is fundamentally important for the selection of appropriate seismic hazard exceedance probabilities in DOE-STD-1020 is the engineering analysis and judgment based on the slopes of hazard curves and consequent risk reduction ratios. Staff Exh. QQ at Appendix C. The Board finds it significant that Dr. Cornell – who has quantitatively analyzed risk reduction ratios and the slope of the PSHA seismic hazard curve at the PFS site (Cornell Tstmy, Post Tr. 7856 at Att. A) – states in his prefiled testimony that "1×10^{-4} per annum, which has been found to be the mean estimate of the annual probability of exceedance of the design basis earthquake (DBE) of the typical nuclear power plant in all regions of the United States, is the appropriate basis from which to establish, via the principles of the risk-graded philosophy adopted by the Commission, the mean annual probability of exceedance of the DBE of an ISFSI anywhere in the country, including specifically at the PFSF site." Cornell Tstmy, Post Tr. 7856 at 48. Again, Dr. Stamatakos' rebuttal testimony does not withstand scrutiny and it does not overcome the evidence that the SSE reference probability for a hypothetical NPP at the PFS site is about 1×10^{-4} (10,000-year MRP).

463. The weight of the evidence presented in the hearing is that a technically defensible SSE for a NPP sited in the Intermountain area would have a return period of approximately 10,000 years and, therefore, the upper-end DBE benchmark for the PFS site should be a MAPE of 1×10^{-4}.

464. A number of regulatory codes are now using a 2,500-year return period as the basis for seismic design. For example, DOE-STD-1020-2002 uses a 2,500-year ground motion for the design of PC-3 facilities – those facilities similar to ISFSIs – not near tectonic

plate boundaries. Staff Exh. QQ at Table C-3. Also, the International Building Code 2000 ("IBC 2000") is based on seismic hazard defined in terms of Maximum Considered Earthquake ground motions associated with a 2,500-year return period earthquake. Staff Exh. II at iii.

465. Under the IBC 2000, the building code currently in force in Utah, the design basis for certain buildings is a 2,500-year return period earthquake. According to the code, you first enter the hazard curve at 2,500 years and obtain the ground motions; then you multiply those ground motions by two thirds. An Importance Factor is used for certain structures, such as those that contain hazardous materials; in such cases you multiply ground motions obtained after the two-thirds reduction by 1.5 and this gets you back to the 2,500-year ground motions. Tr. (Cornell) at 7902-05.

466. Dr. Bartlett testified that interstate highway bridges in Utah are constructed using a 2,500-year design basis earthquake. Tr. (Bartlett) at 12807, 12977. Such structures must survive a 2,500-year event with essentially no structural damage. Id. at 12977.

467. It is evident that at the low end, the DBE benchmark for the PFS site sensibly must be at least 2,500 years. Currently, interstate highway bridges in Utah, certain buildings under the IBC 2000 building code, and PC-3 facilities under DOE-STD-1020-2002, all use a 2,500-year DBE. In addition to an inadequate margin of safety, there is a public policy concern that by allowing a 2,000-year DBE for the PFS nuclear facility it will have a lower DBE than that now required by other standards. At a minimum, setting the DBE for a nuclear facility lower than that for other non-nuclear structures or DOE PC-3 facilities poses a real public perception problem – as Dr. Arabasz testified: "[a]bsent the

coterie [sic, codery] of the cognoscenti [sic, cognoscente], who can explain it..." Tr. (Arabasz) at 9208. Certainly the evidence presented in this proceeding does not justify a 5×10^{-4} MAPE that PFS has requested and the Staff has endorsed.

468. We further note that when the Commission granted consent to the Staff to go forward with rulemaking, it mandated the Staff to seek comments and justification for a DBE in the range of 2,000-years to 10,000-years. *See* Staff Requirements Memo (November 19, 2001), Staff Exh. U. Therefore, to date, the Commission has not endorsed a 2,000-year DBE.

Staff's Rationale for PFS's Seismic Exemption

469. In general the Staff now relies on the following to support an exemption to 10 CFR § 72.102(f) and instead allow a 2,000-year MRP earthquake (5×10^{-4} MAPE) for the PFS site: (a) Commission statements that the radiological hazards posed by ISFSIs are less hazardous than those posed by NPPs; (b) the reference probability for the safe shutdown earthquake for a NPP being 1×10^{-4} MAPE and the average mean annual probability of exceeding the SSE at five existing NPPs in the WUS being 2×10^{-4}; (c) 2,000-year MRP in DOE-STD-1020-94 for PC-3 facilities; (d) grant of an exemption to INEEL; and (e) conservatism in PFS's probabilistic seismic hazardous analysis ("PSHA"). *See* Con-SER at 2-50 to 2-51; Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 18-21, and State Exh. 209.

470. The Staff has issued four documents that are illustrative of the Staff's logic aimed at justifying a 2,000-year MAPE for ISFSIs: the December 15, 1999 Safety Evaluation Report ("SER"); the September 29, 2000 SER; the March 2002 Consolidated SER; and the September 26, 2001 rationale for a 2,000-year MRP in Modified Rulemaking Plan, SECY-01-

0178. Relevant excerpts from these documents are contained in State Exh. 209. The Staff has consistently relied on the MAPE for PC-3 facilities in DOE-STD-1020 and the grant of an exemption to INEEL among its time-varying justifications for PFS's exemption. Other parts of the rationale for the exemption have fallen by the wayside to be replaced by different justifications.

471. In the December 15, 1999 SER the Staff relied on a statement by PFS's contractor, Geomatrix, that a 2,000-year mean return period is appropriate for the design earthquake at the PFS site. The Board finds that reliance on the Applicant's exemption request does not justify approval thereof.

472. In the 1999 SER, the Staff also relied on an old version of the Uniform Building Code that recommended using peak ground motion values that have a 90-percent probability of not being exceed in 50 years for seismic design to analogize that peak ground motion values that have a 99 percent likelihood of not being exceeded in a 20 year licensed ISFSI would correspond to a 2,000-year MRP. This logic did not appear in the other iterations of the SER but it appears in a somewhat different form in the rationale in the Modified Rulemaking Plan, SECY-01-0178.

473. In the rationale of its Modified Rulemaking Plan the Staff analogized that a 20 year licensed ISFSI with 5×10^{-4} MAPE (2,000-year MRP) would have the same total probability of exceeding its design earthquake during its lifetime as would the Yucca Mountain pre-closure facility with a 1×10^{-4} MAPE (10,000-year MRP)[70] and an operational

[70] *Cf* ISFSI: $5 \times 10^{-4} \times 20$ years $= 1 \times 10^{-2}$
with Yucca facility: $1 \times 10^{-4} \times 100$ years $= 1 \times 10^{-2}$

life of 100 years. State Exh. 209 (at 4). The Board finds that this logic has a different implication for the PFS ISFSI. If the Staff were to compare validly the 40 year operational life of the PFS ISFSI with the 100 year operational life of the Yucca Mountain pre-closure facility, then the total probability of exceeding the design earthquake at both facilities would be identical only if the DBE at the PFS ISFSI had a MAPE of approximately 2.5×10^{-4} (MRP approximately 4,000 years). Arabasz Tstmy, Post Tr. 9098 at 14; Tr. (Arabasz) at 9204-09.

474. The Commission's statement that ISFSIs pose a lower radiological risk than NPPs does not in and of itself justify a five fold decrease from 10,000 years to 2,000 years in the MRP for an ISFSI's design ground motions. Moreover, the Board has already found that the Staff is on shaky ground in relying on a 5,000-year MRP for the SSE at a nuclear power plant site in the Intermountain West - as opposed to a western coastal site.

DOE Standard 1020

475. The Staff relies on DOE Standard 1020 both explicitly and implicitly to justify a 2,000-year return period for the DBE of the PFS ISFSI. Tr. (Arabasz) at 10143-45. However, the Staff disavows adopting DOE Standard 1020 (Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 30-31; Tr. (Arabasz) at 9270) and claims to rely on it only as a point of reference and for consideration of risk. Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 30-31; Stamatakos Rebuttal Tstmy, Post Tr. 12648 at 2. The key problem in the Staff's reliance on DOE Standard 1020 to justify a MAPE of 2×10^{-4} (2,000-year MRP) as specified in DOE-STD-94 for a Performance Category-3 facility, is that the Staff eschews the DOE design approach that fundamentally and quantitatively couples the MAPE for any

performance category with a target seismic performance goal. Arabasz Tstmy, Post Tr. 9098 at 9-10; Tr. (Arabasz) at 9270; 10144-45. Unlike PFS, whose arguments at least attempt to justify the exemption request in terms parallel to DOE's risk reduction performance standard, the Staff distances itself from this basic part of the DOE paradigm. The Board finds that the Staff's partial reliance on DOE Standard 1020 does not offer support for an exemption to allow a 2,000-year MRP at the PFS site.

INEEL Exemption for TMI-2 ISFSI

476. The Staff also relies on the grant to DOE-INEEL of an exemption from 10 CFR § 72.104(f) for storage in an ISFSI of rubblized fuel debris from the Three Mile Island Unit II reactor (TMI-2 ISFSI). The facts and site conditions at INEEL are different from those at PFS. INEEL is located on federal reservation of vast size – approximately 800-900 square miles – and the nearest resident is tens of miles from the site. Tr. (Chen) at 8185, 8187-88. At INEEL, the TMI-2 ISFSI is located on the Idaho chemical processing plant ("IPCC") site. Ground motions at the IPCC site are 0.30 g for a 2,000-year MRP and 0.47 g for a 10,000-year MRP. State Exh. 127 at p. 4-1. The IPCC – a higher risk facility than the TMI-2 ISFSI – was designed to peak horizontal accelerations of 0.36 g. Id. The TMI-2 ISFSI was also designed to 0.36 g horizontal design value which means its ground motions fall somewhere between a 3,000- to 4,000-year MRP. Tr. (Chen) at 8184; Arabasz Tstmy, Post Tr. 9098 at 12. Fuel at INEEL is stored in 30 horizontal concrete modules, that under earthquake conditions are not expected to slide. Tr. (Chen) at 8186-87.

477. In contrast to the INEEL site, PFS is located within two miles of the nearest resident and the land to the north of the site is contiguous with privately owned land. FEIS

at xxxviii (Staff Exh. E); Tr. (Donnell) 12578-81. Furthermore, the Board cannot rule out that someday the land to the north of the PFS site could be developed for residential uses. Tr. (Donnell) at 12579-82. PFS will not store 30 casks but 4,000 casks containing spent fuel from commercial nuclear power plants. The design values at PFS are those for a 2,000-year MRP. Further, PFS uses an unconventional design in which PFS and the Staff consider sliding of the casks and the pads under earthquake conditions to be beneficial because sliding dissipates seismic energy that the casks and foundations would otherwise have to resist. Tr. (Pomerening) at 6634-35, 6652; (Soler) at 10658.

478. The Board finds that the site specific circumstances relating to DOE's 2,000-year exemption request for the INEEL TMI-2 ISFSI do not make that exemption a compelling precedent, and thus that exemption has little if any bearing in this case.

Geomatrix Probabalistic Seismic Hazard Analysis

479. The State acknowledges that the Geomatrix investigators who conducted a probabilistic seismic hazard analysis ("PSHA") for the PFS site, as contractors for the Applicant, are highly competent. Tr. (Arabasz) at 9322-23. Also, there is general agreement among the parties that Geomatrix conducted an adequate PSHA to depict the potential hazard at the PFS site. *See, e.g.*, Tr. (Arabasz) at 9119-20. The Staff, however, goes on to take the view that Geomatrix produced a "conservative" PSHA. Stamatakos, Chen, McCann, Post Tr. 8050 at 13-17; Tr. (Stamatakos) at 8113, 8220-21, 8225, 12763; Con-SER at 2-38 to -40, 2-48. PFS does not make this claim. The Staff's reliance on the conservative nature of Geomatrix's PSHA to support a grant of a 2,000-year MRP to PFS (Con-SER at 2-38 to -40) and its assertion that the Applicant's conservative estimate of hazard provides an

additional margin of safety in the seismic design (Stamatakos, Chen, McCann, Post Tr. 8050 at 17) are founded on erroneous premises, questionable speculation about what the relative PSHA outcome should have been, and one-party analyses subject to scientific challenge.

480. A PSHA typically is an enormous undertaking involving seismic source characterization, ground motion modeling, and hazard calculations. Tr (Arabasz). at 9115-18, 9330. As such there is an incredible spectrum of parameters and values to be aggregated into the process of calculating the hazard. Id. at 9878. Central to a well executed PSHA is capturing the technically supportable and legitimate range of informed opinion representing the whole scientific community on specific aspects of the PSHA. Id. at 9861-62.

481. The Staff did not conduct its own PSHA; it chiefly reviewed the geological and seismological inputs to Geomatrix's PSHA, evaluated Geomatrix's probabilistic and deterministic hazard results, and performed some independent analysis, notably slip tendency. Tr. (Stamatakos) at 8090-91; (Arabasz) 9861-62; Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 12-18; Con-SER at 2-35. In order to buttress its claim that the Geomatrix PSHA is conservative, the Staff uses the slip tendency analysis conducted by Dr. Stamatakos and his colleagues at Southwest Research Institute (Tr. (Stamatakos) at 8089) and also makes comparisons to PSHA results for sites in and around Salt Lake City. Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 16-17. Scrutiny of the Staff's analysis and its PSHA comparisons does not substantiate the Staff's claim that Geomatrix's PSHA results are conservative.

482. Slip tendency analysis is a modeling technique designed to assess stress states

and potential fault activity.[71] As used by the Staff, *i.e.*, for the purpose of assessing potential fault activity, the analysis requires as a starting point a specification of the orientation and relative magnitudes of stresses acting on the local geology of Skull Valley. As the Staff explains in its prefiled testimony:

> In slip tendency analysis, the underlying assumption is that the regional stress state controls slip tendency and that there are no significant deviations due to local perturbations of the stress conditions. The assumption is supported by a similar slip tendency analysis of the Wasatch fault, which shows the highest slip tendency values for the segments of the fault considered to be most active (Machette et al., 1991). . . . [The] orientation for the principal stresses was based on recent global positioning satellite information (Martinez et al., 1998a).

Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 14. Because the stress state at Skull Valley is unknown, the Staff had to assume the applicability of regional stress information from elsewhere. The Staff reported that it used a horizontal minimum principal stress with an azimuth of 085°, citing Martinez et al., 1998. Id.; Tr. (Stamatakos) at 8087. But the cited Martinez paper (State Exh. 184) does not contain this value; rather, the Staff arrived at this value by subjectively "tuning" the regional stress field in the Wasatch Front area to get maximum slip tendency on parts of faults with known paleoseismic (prehistoric) slip like the Wasatch fault. Tr. (Stamatakos) at 8091-92, 8191.

483. Based on the results of its tuned slip tendency analysis, the Staff argues that the East fault has a relatively low slip tendency value and is therefore less likely to slip than faults or fault segments further from the site. Stamatakos/Chen/McCann Tstmy, Post Tr.

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[71] *See e.g.*, Morris et al., 1996, cited in Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 14.

8050 at 15. This conclusion ignores the Staff's acknowledgment of Geomatrix's finding that, "In all the alternative models and because of the evidence for surface rupture of late Quaternary deposits, the East fault is considered seismogenic and assigned a probability of activity of 1." Staff Exh. Q at 2-17 (*emphasis added*). Based on offsets of those late Quaternary deposits in the immediate vicinity of the PFS site, Geomatrix assessed for the East fault a most likely slip rate of 0.2 mm per year – the same order of magnitude as the most likely slip rate of 0.4 mm per year for the Stansbury fault. State Exh. 185 at Table 6-2; *see, e.g.*, Con-SER reference, Geomatrix Consultants, Inc. 1999a at 48-49. The Board finds that the evidence of surface rupture of late Quaternary deposits by the East fault is a far more cogent indicator of the fault's seismogenic potential and of the local stress conditions near the PFS site in Skull Valley than what the Staff guesses them to be from its hypothetical, subjectively tuned modeling. At best, the Staff's interpretation of the stress state in Skull Valley would be one competing opinion in a PSHA, subject to challenge by other experts. *See* Tr. (Arabasz) at 9862. Further, corresponding inferences the Staff makes from the slip tendency analysis about conservatism in Geomatrix's assessed site-to-source distances and maximum magnitudes (Con-SER at 2-38; Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 15-16) are also arguable and not established conclusions.

484. The seismogenic potential of the West fault is another basis on which the Staff argues that Geomatrix's PSHA is conservative because the Staff concludes the West fault is a splay of the larger East fault, incapable of independently generating large magnitude earthquakes. Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 13; Tr. (Stamatakos) at 8222; (Arabasz) 9842-43; Con-SER at 2-33. The Board finds that this argument is

inconsequential insofar as the Staff acknowledges that alternative models for the geometry and extent of the West fault have little effect on the total hazard, and that the West fault – whether as an independent source or a secondary feature – has a minimal influence on the hazard computed by Geomatrix. Con-SER at 2-46; *see also* State Exh. 185 at Fig. 6-12.

485. Another major line of reasoning the Staff uses to conclude the Geomatrix PSHA is conservative is a comparison to PSHA results in and around Salt Lake City, which leads the Staff to claim that Geomatrix's PSHA may have led to an "overly conservative" hazard result by as much as 50% or more. Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 13, 16-17. An erroneous premise pervading these comparisons by the Staff is that "fault sources near Salt Lake City are larger and more seismically active than fault sources near the PFS site." Id. at 16; *see also*, for example, Tr. (Stamatakos) at 8112, 8115, 8221-22; (McCann) 8225. In pre-filed testimony Dr. Stamatakos claimed that the Wasatch fault "has a slip rate nearly ten times greater than the Stansbury or East Faults (cf. Martinez et al., 1998; Geomatrix Consultants, Inc., 1999a), and is capable of producing significantly larger magnitude earthquakes than the faults near the proposed PFS Facility site in Skull Valley (cf. Machette et al., 1991; Geomatrix Consultants, Inc., 1999a)." Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 17; Tr. (Arabasz) at 9865.

486. The Stansbury and East faults are the two largest contributors to the total mean hazard at the PFS site for return periods greater than a few hundred years (State Exh. 185 at Fig. 6-12) and have the highest-weighted slip rates of 0.4 mm/yr and 0.2 mm/yr, respectively. Id. at Table 6-2; Tr. at (Stamatakos) 8234, 9876. The mean maximum magnitudes assessed by Geomatrix for these two faults are 7.0 and 6.5, respectively. Con-

SER at 2-47; Tr. (Stamatakos) at 8238. The corresponding geological slip rate assessed by Geomatrix for the Salt Lake City segment of the Wasatch fault is 1.1 mm/yr (State Exh. 185 at Table 6-2; Tr. (Stamatakos) at 8234-35; (Arabasz) 9877), and the maximum magnitude for this segment of the Wasatch fault ranges from about 6.7 to 7.1 (State Exh. 185 at Fig. 6.2; Tr. (Stamatakos) at 8240). During testimony Dr. Stamatakos admitted that the Geomatrix data indicate the slip rate on the Wasatch fault is "roughly a factor of three" – not ten – greater than the slip rate on the Stansbury fault. Tr. (Stamatakos) at 8235-36. According to Dr. Stamatakos, the factor of ten comes from adopting slip rates "up to five millimeters per year" for the Wasatch fault based on global positioning system ("GPS") data from Martinez et al., 1998. Tr. (Stamatakos) at 8236; State Exh. 184. However, he also admitted, "Well, certainly there is some controversy in the scientific community about how you actually interpret the GPS slip rates." Tr. (Stamatakos) at 8237. Attempting to compare slip rates mixing GPS information and conventional geological information is a dubious proposition. Tr. (Arabasz) at 10130-31. In the case at hand, relying on the paper by Martinez et al., 1998, to argue that the Wasatch fault has a slip rate of about 5 mm/yr is not scientifically defensible. Quoting directly from that paper, Dr. Arabasz established first, that the authors themselves are uncertain whether the GPS deformation field they observed is due to loading of the Wasatch fault or to some other cause, including homogeneous crustal extension (Tr. (Arabasz) at 10129-30), and, second, that the authors' uncertainty arises from "a lack of broader GPS coverage and the limitations of the current resolution of the GPS measurements." Id. at 10130.

487. The Staff makes two basic comparisons between Geomatrix's PSHA results

and the counterpart hazard results for sites in or near Salt Lake City. First, it notes that, "[T]he results of the Applicant's PSHA for Skull Valley (Geomatrix Consultants, Inc., 2001a) suggest that it is 1.5 times more likely that a ground motion of 0.5g horizontal peak ground acceleration or greater will be exceeded at the PFS site (assuming hard rock site conditions), than at Salt Lake City, based on the USGS National Earthquake Hazard Reduction Program (Frankel et al., 1997)." Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 16; *see also* Staff Exh. JJ at 5. Dr. Arabasz made the point in his testimony that there are significant shortcomings in this comparison by the Staff. Tr. (Arabasz) at 9864-65. The following facts are relevant to the comparison. The exact location of the Salt Lake City PSHA calculation is uncertain. Tr. (Stamatakos) at 8215-16. The hazard calculation for Salt Lake City is based on the USGS National Earthquake Hazard Reduction Program (id. at 8109), whose hazard calculations would not be acceptable for the SAR at the PFS site. Id. at 8111. Although not explicitly acknowledged by Dr. Stamatakos, the reason for the latter is that the national hazard mapping is done on a regional scale and includes only major active faults. Id. at 8110. Dr. Stamatakos did not know "everything the GS did in this [the Salt Lake City] analysis," but presumed that "the Wasatch fault probably controls a lot of what is in that hazard." Id. at 8110-11. In Geomatrix's site-specific PSHA for the PFS site, the East fault is only 0.9 km from the Canister Transfer Building, has a mean maximum magnitude of 6.5, and is a major contributor together with the Stansbury and East Cedar Mountain faults to the total mean hazard; all three faults are within 9 km of the PFS site. Con-SER at 2-47; *see also* Tr. (McCann) at 8232. Given the slip rates of 0.4 mm/yr, 0.2 mm/yr, and 0.07 mm/yr for the Stansbury, East, and East Cedar Mountain faults, respectively (State Exh. 185 at

Table 6-2), there is a combined slip rate of 0.67 mm/yr contributing to the annual earthquake activity rate, which is 74% of the Wasatch fault's slip rate of 1.1 mm/yr. Slip rates, maximum magnitudes, distances, and near-source effects are all part of the complex interplay of parameters in the Geomatrix PSHA. Tr. (Arabasz) 9878-79. The site-specific Geomatrix PSHA hazard results at the PFS site (for rock site conditions) are an integrated outcome of the seismic source characterization, just as the USGS's regional PSHS hazard results are at Salt Lake City (also for rock site conditions). The Board find, as presented in this proceeding, that the Staff's claimed conservatism cannot be evaluated by comparing the two bottom lines. Without independently performing site-specific PSHAs for the two sites, the Staff's inference that the Geomatrix PSHA is conservative by comparison to sites in or near Salt Lake City is only speculation.

488. The second comparison the Staff makes between Geomatrix's PSHA results and counterpart results near Salt Lake City relates to hazard calculations at nine sites in the I-15 corridor in the Salt Lake Valley. Stamatakos/Chen/McCann Tstmy, Post Tr. 8050 at 17. The Staff observes that Geomatrix's 2,000-year horizontal peak ground acceleration (soil hazard) is actually higher than the 2,500-year ground motions (also on soil) at the I-15 sites. Id. The Staff explicitly reviewed Geomatrix's revised ground motion modeling in 2001, which involved development of a detailed shear-wave soil profile to calculate site response, and noted: "This change in the shear-wave profile and site response model led to a significant increase in estimated ground motions at the PFS site." Con-SER at 2-41. In fact, the 2,000-year peak horizontal ground motion increased 35% from 0.528g to 0.711g. Id. at Table 2-2. This misleading comparison is easily dealt with: without stripping off the site

responses at the PFS and I-15 sites, the Staff's comparison of PSHA results is meaningless.

489. A proposition raised by Dr. McCann to support the conservative nature of Geomatrix's hazard results is that at very low ground motions the hazard curves at the PFS site have the same annual frequencies of exceedance as the hazard curve for Salt Lake City. Tr. (McCann) at 8224-25; Staff Exh. JJ at 5. The Board finds Dr. McCann's proposition is misleading because to validly compare very low ground motions between the PFS and Salt Lake City hazard curves, one has to examine and compare the methodology used by Geomatrix in its site-specific PSHA with that used by the USGS in its regional PSHA – specifically, how background seismicity for the lowest magnitudes considered was analyzed and areally smoothed. Dr. McCann also observed that the rate of occurrence of earthquakes exceeding low ground motions at Skull Valley and Salt Lake City comes very close to that for the San Francisco Bay Bridge hazard curve (Staff Exh. JJ at 5) and thus, "[T]he Skull Valley site appears to be challenging some of the more seismically active areas in the country . . ." Tr. (McCann) at 8225. Again, comparison of these hazard curves at the lowest ground motions cannot be done validly without scrutinizing the respective methodologies used. As a check, however, if one grants the similarity of the Skull Valley and Salt Lake City hazard curves at low ground motions (Staff Exh. JJ at 5), one can examine the mean hazard curves computed in a uniform way by the USGS for Salt Lake City and San Francisco, as presented in Figure 3 on page 4 of Staff Exh. JJ.[72] In this figure, for 0.1g peak acceleration, Salt Lake City has approximately the same frequency of exceedance relative to San Francisco as it does

[72]Note the different appearance of log-log plot compared to Staff's log-linear plot on page 5 therein.

compared to the San Francisco Bay Bridge in the figure on page 5 of the same exhibit. Thus, one would conclude, according to Dr. McCann's reasoning, that both Salt Lake City and Skull Valley are "challenging" San Francisco's hazard. The Board finds that the Staff's testimony does not support its claim that Geomatrix's hazard results are conservative.

490. After lengthy testimony and cross-examination, Dr. Stamatakos still holds to the view that Geomatrix provided a conservative seismic hazard estimate for the PFS site. Tr. at (Stamatakos) 12763. Dr. Arabasz, on the other hand, agreed to the adequacy of Geomatrix's PSHA (Tr. at (Arabasz) 9119) but would not agree that its hazard results were conservative (*e.g.*, id. at 9861-63, 9878-79, 10128-31).

491. Dr. Stamatakos's bottom-line position is that either Geomatrix provided a very conservative seismic hazard curve or, if the hazard results are accurate, the PFS site deserves to be treated as a tectonic plate boundary site, which would justify a higher reference exceedance probability (lower MRP). Tr. (Stamatakos) at 12753-54, 12763. This appears to be a false dilemma. We have already found that the first part of the proposition is opposed by evidence that Geomatrix's PFSA is not conservative, and the second part is opposed by evidence that the benchmark probability for the DBE at the PFS site is not 2×10^{-4}. The Board gives considerable weight to Dr. Arabasz's view that the large predicted ground motions at the PFS site are due to the unusual closeness of the East fault and the controlling earthquakes (Tr. (Arabasz) at 10228-29), and the hazard at the site would not justify 5,000-year SSE ground motions in the case of a hypothetical nuclear power plant (Tr. 10113-14).

492. We are faced here with two competing opinions: one by Dr. Arabasz and

the other by Dr. Stamatakos. On balance we give greater weight to Dr. Arabasz's testimony . We make this judgment based on the depth of Dr. Arabasz's familiarity and experience with earthquake conditions in Utah, seismology, and seismic hazard analysis. We note Dr. Stamatakos's training and professional experience in structural geology and geophysics, and his involvement in multidisciplinary studies at the Center for Nuclear Waste Regulatory Analysis. While his insights and views have merited careful attention, the many substantive challenges to his arguments appear to reflect a lesser degree of experience with the broad scope of PSHA issues that are central here.

493. Whether or not the Applicant has produced a DSHA that fully meets the requirements of 10 CFR 100 Appendix A is a residual issue. Tr. (Arabasz) at 9152-53. Assuming the allowance of a PSHA, the issue has been set aside by stipulation and is not a problem for hearing unless PFS or the Staff attempt to use DSHA results to validate some level of conservatism in the PSHA results. Id. at 9152-54.

494. The Board finds that the Applicant's PSHA is adequate. The Board does not find sufficiently convincing evidence to support the Staff's claim that the Applicant's PSHA hazard results are conservative or overly conservative. In sum, the evidence does not support a finding that the Staff may rely on claimed conservatism in the Geomatrix PSHA or a 5,000-year benchmark probability as rationale for PFS's 2,000-year DBE exemption request.

ATTACHMENT 6a TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

	)
In the Matter of:	)
PRIVATE FUEL STORAGE, LLC,	) Docket No. 72-22
(Independent Spent Fuel	) ASLBP No. 97-732-02-ISFSI
Storage Installation)	)
	)

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84114

On June 5, 2002 the above-entitled matter came on for hearing, pursuant to notice, before:

MICHAEL C. FARRAR, CHAIRMAN
Administrative Judge
U. S. Nuclear Regulatory Commission

DR. JERRY R. KLINE
Administrative Judge
Atomic Safety & Licensing Board Panel

DR. PETER S. LAM
Administrative Judge
Atomic Safety & Licensing Board Panel

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EXAMINATION

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EXHIBITS

shaking Table."

201 Regulatory Guide 1.165, one page from Appendix B. 9958/10069

202 Topical report for Yucca Mountain, August 1997, with Table C-2. 9958/

203 Basis for Seismic Provisions for DOE-STD-1020 by Kennedy and Short 9958/

discussion, the State's cross-examination relating to the comparison of slip rates on the Salt Lake segment of the Wasatch fault and the Stansbury fault and the reference in the Staff's Exhibit PP on page 18 where it says, "Ground motions estimated by the applicant in Skull Valley are higher than those for the I-15 corridor despite the close proximity of Salt Lake City to the Wasatch fault which has a slip rate nearly 10 times larger than the Stansbury or East faults. Reference. Martinez et al., 1998; Geomatrix Consultants 1999a."

Q. I recall that cross-examination. And what is your view of what the difference in slip rates is between the Wasatch and the Stansbury?

A. The slip rates on the Wasatch fault, the Salt Lake City segment, on the order of 1 plus millimeters per year and the slip rate on the Stansbury fault .4 millimeters per year, approximately.

Q. And where do you get the Stansbury fault slip rate from?

A. That's from the Geomatrix Consultants information. I can't recall if that was entered as an Exhibit.

Q. You're familiar with the Martinez paper that was cited by the Staff?

A. Yes, I am.

Q. Are you familiar with that paper?

A. If you're going to point me to a line and ask me for acute memory, no. Yes, I'm familiar with the paper.

Q. The Martinez paper, as I recall, utilized GPS positioning as a basis for its calculation of slip rates, correct?

A. Correct, in part.

Q. And the Martinez paper had a slip rate calculated for the Wasatch fault greater than you just indicated, correct?

A. That's correct. And the subject of considerable controversy.

Q. Is it correct that the Martinez paper estimated the slip rate to be approximately 5 millimeters per year on the Wasatch fault near Salt Lake City?

MS. CHANCELLOR: Does Dr. Arabasz need

to see a copy of the Martinez paper? It's a little unfair to ask him to recall from memory a technical paper. I'm looking for it. I think the State may have entered it as part of an Exhibit.

MR. TURK: Dr. Stamatakos recalls that

it was an Exhibit.

MS. CHANCELLOR: Offered as an Exhibit, I don't think it was --

JUDGE FARRAR: Let's see if we can't put it in the witness' hands rather than have him try to recall it from memory.

MS. CHANCELLOR: I have a copy of it, your Honor.

DR. ARABASZ: I have a copy, your Honor.

MS. CHANCELLOR: It's State's Exhibit 184.

Q. (By Mr. Turk) Is the slip rate estimated by the Martinez paper on page 569 in the table at the bottom or is there another part of the paper you would point us to?

A. Perhaps your expert Dr. Stamatakos could help point me to a slip rate as associating it specifically with the Wasatch fault.

MR. TURK: Can we take a moment, your

Honor?

JUDGE FARRAR: Yes.

Q. (By Mr. Turk) In fact, the Martinez paper has a lot of different numbers in it. But if you look at the chart that appears at the top of

page 569, which is Figure 3.
A. Yes, I see that.
Q. You see there's a strong vertical line indicated to be the Wasatch Fault Zone?
A. Yes.
Q. And then to the side, to the right side of the area marked Wasatch Fault Zone, do you see different estimates of slip rates?
A. I'm reading the caption to see if these are, in fact, slip rates. They're not identified in the caption as slip rates.
Q. Are these extension rates?
A. They're described as derived average strain and velocities.
Q. Right. Then if you go down to the bottom of the page, Table 1, the next to last vertical column labeled Horizontal Displacement or Fault Slip Rate in millimeters per year?
A. Yes.
Q. And you see there are different slip

rates stated?

A. I see that.

Q. And those are the rates that are estimated by Martinez?

A. Correct.

Q. And he does not estimate a 1 millimeter slip as you describe in your testimony. The slip rate that he describes is significantly larger, correct? For instance, the very first one, he estimates it to be 2.7, plus or minus 1.3. So there's a range of 4 millimeters down to 1.4 millimeters?

A. The author is a she, Linda Martinez, and --

Q. First could you tell me if I'm reading that correctly?

A. Yes.

Q. Thank you. Go on.

MS. CHANCELLOR: Can the witness complete his answer?

MR. TURK: I would be happy to. I just wanted an answer to the question I had asked before he explains.

DR. ARABASZ: I'll pause for a moment and sigh because -- and I'll simply offer an explanation of why I'm not enamored of this paper or would take its results to influence my judgment on its relevant comparison between the Wasatch and the Skull Valley situation.

As chair of the Seismic Safety

Commission, one of the authors of this paper came to the Commission, presented the results, and basically was advocating attention to the considerably enhanced seismic hazard on the Wasatch fault compared to what was conventionally believed from the geological information.

An extensive review of the data was undertaken by the Commission and with the result that it was believed that the GPS data were preliminary, the implications uncertain, particularly as relating to an interpretation of the implications of the deformation rates aggregated from surface GPS measuring points and what implication they had for slip rates on individual faults, whether the Wasatch fault or unknown faults, within the domain for which the surface deformation was being monitored.

Q. (By Mr. Turk) You indicated that the results seemed to be uncertain or preliminary. Has there been more work done by the Martinez, Merkins and Smith authors with respect to the subject of this paper?

A. Reports -- or results have been reported, to the best of my awareness, in meeting abstracts and oral presentations and/or posters. I will admit that I am not an expert in GPS. I am aware of an ongoing debate within the scientific community about the interpretations and implications of observed GPS deformation rates as they relate to geologically observed slip rates.

Q. The authors have not retracted this paper or submitted any correction to it or modification to it, have they?

A. To my awareness, no.

Q. So to your awareness the authors have not stepped back from their estimate of the slip rate for the Wasatch fault since they published this paper in 1998, correct?

A. What I'm taking time to review --

Q. That's fine.

A. -- as to whether they, indeed, reached the conclusion of associating this deformation entirely with the Wasatch fault. And I think in a general way their inclination is to associate it with the Wasatch fault, and I believe that's subject to debate.

Q. Okay.

MS. CHANCELLOR: Your Honor --

Q. (By Mr. Turk) But my question was, to your knowledge, the authors have not stepped back from their estimate of this slip rate for the Wasatch fault since they published their paper in 1998?

A. To my awareness, no. I am aware that the results have been contested in a scientific forum, including, if I recall, an SSA abstract submitted by Dr. Pechman, which was -- and the controversy at the time reported in GeoTimes.

MS. CHANCELLOR: Your Honor, if I may, State's Exhibit 184 has been offered, offered or not, but it has not been admitted into evidence. It was offered at transcript page 8092. I would request at this time it be entered into the record.

JUDGE FARRAR: Do you have a copy there you can just hand us for a moment?

MR. TURK: May we go off the record for a moment?

JUDGE FARRAR: Yes.

(Discussion held off the record.)

JUDGE FARRAR: Let's go back on. Back

on the record. We're talking about State Exhibit 184 which was offered -- no, which was identified.

MS. CHANCELLOR: Identified, and I believe offered -- certainly identified on May 11th and marked as State's Exhibit 184.

ATTACHMENT 6b TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

)
In the Matter of:)
PRIVATE FUEL STORAGE, LLC,) Docket No. 72-22
(Independent Spent Fuel) ASLBP No. 97-732-02-ISFSI
Storage Installation))
)

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84114

On June 6, 2002 the above-entitled matter came
on for hearing, pursuant to notice, before:

MICHAEL C. FARRAR, CHAIRMAN
Administrative Judge
U. S. Nuclear Regulatory Commission

DR. JERRY R. KLINE
Administrative Judge
Atomic Safety & Licensing Board Panel

DR. PETER S. LAM
Administrative Judge
Atomic Safety & Licensing Board Panel

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you for that.

MR. TURK: 205.

MS. CHANCELLOR: 205. Thank you.

JUDGE FARRAR: Thank you for that additional clarification. Mr. Turk, I think you wanted to go off the record.

MR. TURK: If I can, your Honor, just for a few minutes.

(Discussion off the record.)

JUDGE FARRAR: Back on the record.

Q. (By Ms. Chancellor) Dr. Arabasz, you may recall a discussion yesterday with respect to the Martinez paper, and Mr. Turk had you refer to NRC Exhibit PP on page 18 in which there was a discussion about the Martinez paper used by the Staff to support a slip rate of nearly ten times larger -- that the Wasatch fault has a slip rate nearly ten times larger than the Stansbury fault. Do you recall that line of questioning?

A. Yes, I do.

Q. What problem do you have with the Staff
using the Martinez paper to argue that the PSHA at
the PFS site is conservative?
A. With more time referring to the paper, I
returned to it and I have my own copy. I don't

have the exhibit number identified.

Q. That's fine.

A. I would like to read from the paper, but presumably you need the exhibit reference.

MR. TURK: May we have just a moment?

MS. CHANCELLOR: State's Exhibit 184.

MR. TURK: Yes.

A. Referring to the abstract, the left column on page 567, and approximately two thirds of the way down through the abstract there's a sentence that begins, "While we do not yet know the source of this unexpected contemporary deformation," namely the increased deformation observed by GPS, the text continues, "loading of the" -- excuse me. I guess I've confounded the recorder, probably, by not reading verbatim. Let me begin again and I'll read it verbatim.

"While we do not yet know the source of this unexpected contemporary deformation, possible mechanisms include homogeneous crustal extension, loading of the Wasatch and adjacent faults, and pressure solution creep." In other words, the interpretation of the observation was uncertain. One possible modeling interpretation is that the deformation was reflecting higher slip on the

Wasatch fault, but there were other interpretations that the authors were considering.

On page 569, right-hand column in the section Implications of High Strain Rates, the second paragraph reads, "To examine possible sources of the GPS measured horizontal deformation field, Martinez [1996] constructed simple dislocation models for plausible geometries of the Wasatch and nearby faults similar to those of Savage et al. [1992]. Within the observed measurement uncertainties the results were found to be consistent with 1) approximately 4 to 5 millimeters per year of localized slip on a varied fault plane tipping 60 degrees west, or 2) uniform east-west straight of a homogeneous crustal block. It is not yet possible to distinguish between these two end member models because of a lack of broader GPS coverage and the limitations of the current resolution of the GPS measurements."

In other words, the interpretation

remains uncertain as to what the cause of those observed high strain rates are.

Q. And in the Martinez paper, did they use the same methodology in comparing slip rates on the Wasatch and Stansbury faults?

A. No. We visited this earlier in my testimony that one had information on geodetic deformation rates from GPS measurements in the vicinity of the Wasatch fault. One had geological slip rate information, namely, information on displaced geological horizons of known or estimated age where one estimated the slip rate from the displacement divided by the time interval. And so we have a comparison of geological slip rate information on the Wasatch, geological slip rate information on the Stansbury fault, GPS information in the vicinity of the Wasatch fault, no comparable GPS information in the vicinity of the Stansbury fault.

Q. And do you consider it acceptable to do a comparison using different methodologies?

A. If this were a rigorous PSH exercise with let's say a multiteam approach, it might be attempted. It would be subject to lots of criticism and, in my view, it probably would be beaten down.

Q. Thank you. Finally, Dr. Arabasz, I'd like you to turn to State's Exhibit 209. This is first page Safety Evaluation Report for systems not directly associated with storage pads of Private

ATTACHMENT 7 to
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

washingtonpost.com

Heard About the Near-Accident at the Ohio Nuclear Plant? I'm Not Surprised

By Victor Gilinsky

Sunday, April 28, 2002; Page B01

You wouldn't know it from the bland pronouncements of the Nuclear Regulatory Commission (NRC), but the U.S. nuclear industry just had its closest brush with disaster since the 1979 Three Mile Island accident. The Davis-Besse nuclear power plant, located about 30 miles east of Toledo, Ohio, was operating with a rust hole in the top of its reactor pressure vessel -- a hole wide and deep enough to put your fist into. All that was left to contain the reactor's highly pressurized supply of cooling water around the reactor core was a three-eighths inch liner of stainless steel, and the liner had started to bulge ominously. If the liner had burst, it would have drained cooling water vital for safety and also threatened the reactor's emergency shutdown system.

The plant operator's neglect is bad enough. If this had occurred in Russia, we would be saying it could never happen here. Equally disturbing is the NRC's barely audible response.

The preliminary report of FirstEnergy, the nuclear plant owner, details what happened. During a routine refueling shutdown in February, the company inspected several dozen nozzles to check for cracks, as required by the NRC. The nozzles, located on the head of the reactor vessel, permit control rods to enter the vessel to shut down the reactor, quickly if necessary. A workman discovered the rust hole by luck -- when he happened to bang into one of the control rod tubes coming out of the top of the reactor and it moved. If the reactor had gone back into operation, as it very nearly did, the consequences could have been enormous in terms of public safety as well as the future of the nuclear industry.

It turned out that corrosion had reduced 70 pounds of steel, half a foot thick, to rust. The corrosion was caused by boric acid on the outside of the head. How did the acid get there? The water inside the reactor vessel contains dissolved boric acid, which is used to assist reactor control. Because boric acid corrodes carbon steel, the reactor vessel's interior is lined with stainless steel. The boric acid is not supposed to get to the vessel's exterior, which remains vulnerable to corrosion. But at Davis-Besse the reactor's water leaked through cracks -- it still isn't clear which ones -- and created a boric acid crust on the outside of the reactor head.

This accumulation and damage doesn't happen overnight. The company report explains the hole hadn't been found earlier because, "Boric acid that accumulated on the top of the [Reactor Pressure Vessel] head over a period of years inhibited the station's ability to confirm visually that neither nozzle leakage nor vessel corrosion was occurring." In plain English that means that the company watched the boric acid crust cover an increasing area of the head for years and did nothing about it. That's not all. Some of the reactor vessel rust became airborne and clogged the reactor building's air filters. The filters had previously been changed monthly, but from 1999 on they had to be changed every other day. The company's report says the possibility of corrosion "was not recognized as a safety significant issue by the staff and management of the plant." Obviously the NRC, which had inspectors on site, did not recognize it either.

How important is this? The reactor vessel head resembles a rounded lid that is bolted to the vessel. It's about 15 feet in diameter. The reactor vessel and the vessel head are designed and manufactured with exquisite care from special steel a half-foot thick (with the thin liner of stainless steel). The vessel and head of every reactor have to be monitored throughout their life to make sure that radiation has not caused the metal to become brittle. This is vital because the NRC licensed the plant on the assumption that a break in the reactor vessel is not credible. As a result, the reactor's safety analysis does not deal with breaks in the vessel wall. The reactor's emergency actions operators are trained to cope with breaks in pipes, not the vessel. Some safety systems might work for such a break; then again they might not. The problem was not studied. There would likely be unforeseen complications.

An obvious complication would involve malfunctioning of the control rod system that is supposed to stop the chain reaction in an emergency. There is no backup to the control rods for immediate shutdown. The plant's safety analysis considers the possibility that a limited number of rods, out of several dozen, could fail to drop. The control rod adjacent to the rust hole would have been one of these. But what about the damage that might be caused to other control rod drives above the head if a hole in the vessel unleashed a jet of steam and water coming out of the pressurized vessel? A telling sign that the industry understands the seriousness of the Davis-Besse problem is the silence from the Nuclear Energy Institute, the industry's lobbying arm, which is usually quick to spin a nuclear story. All in all, what happened at Davis-Besse was a narrow escape.

But that isn't the way the NRC has described it in public. The agency's spokesperson told the media that the rust hole didn't pose a safety threat. If the last bit of metal had failed and "allowed steam to escape," the NRC official said, safety systems would have immediately cooled the reactor. Anyway, he said, there would have been no danger to the public. "It's only when you get into the what-ifs that you would have had any leakage from the reactor cooling system." The man was talking through his hat. In reality, the NRC doesn't know what would have happened because the possibility has been considered too unlikely to plan for.

The failure to face up to reality reflects an unhealthy situation. Such spokesmen say what their bosses want them to say, and for several years, the NRC has been knocking itself out to please the industry. The situation worsened in 1998 when the NRC's Senate oversight committee, Environment and Public Works, with strong prompting from the industry association, threatened the NRC with a sharp budget cut. The NRC chairman got the message and revamped the agency's regulatory approach along the lines suggested by the industry. The current commission has by and large continued the same approach, but with a less experienced senior staff. The previous chairman had forced the resignation of the agency's most experienced and competent top officials, who had showed an unwelcome independence of mind.

Just before Davis-Besse's problem surfaced, the NRC gave the plant its quarterly rating under the new rating system. Davis-Besse got the top grade in all 18 categories. From my experience in two terms as an NRC commissioner, during which I visited most of the plants, including this one, I find it inconceivable that everything was fine at Davis-Besse except for one corrosion hole in the reactor vessel. If the plant managers let this problem go, they must have let others go, too. People working in nuclear plants are pretty smart and generally want to do a good job. But they stop asking questions about things that aren't right when they know what answer management is going to give them. At that point, danger lurks.

The NRC has investigated and has now asked other plants to check to make sure they are not suffering from the Davis-Besse problem, but on an unhurried schedule. To a greater extent than ever before we are relying for nuclear safety on the self-regulation of the nuclear operators. Most of them have done a good job, steadily improving their performance. But there are limits to the idea put forward by the industry that post-deregulation financial pressures make for better safety because the operators want to protect their investment. As we know, short-term bottom line orientation also leads some to overreaching, defer necessary modifications or neglect maintenance. Congress and NRC management need to acknowledge that private and public incentives differ.

The late Morris Udall, who as chairman of the House Interior Committee was the principal congressional overseer of the NRC in its eary years, used to say that a forceful and respected NRC was an essential condition of nuclear power. It is still true.

Victor Gilinsky, a Washington-based consultant on energy, was an NRC commissioner from 1975 to 1984.

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ATTACHMENT 8 to
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

Cracks appear in NRC's new rules
09/22/02
Stephen Koff
Plain Dealer Bureau Chief

Washington
- Yielding to lobbying by the nuclear power industry and pressure from Congress, the Nuclear Regulatory Commission has changed - some would say relaxed - the way it regulates in recent years.
The change has saved the companies millions of dollars in compliance costs, but in some cases it also has risked safety, according to interviews with industry and regulatory insiders and critics and an extensive review of public documents. A Plain Dealer review shows:

The nuclear power industry, a savvy political player with deep pockets, leaned on Congress when it felt that NRC inspectors were being too harsh and wouldn't listen to its pleas. Congress in turn pressured the NRC, threatening to slice the agency's budget unless it backed off.
The nuclear industry profited from the changes - the Nuclear Energy Institute, the industry's lobbying group, estimated from a 1999 survey that each of the nation's 104 plants could save as much as $5 million a year with the regulatory changes.
Those changes altered the NRC's focus, shifting its sweeping enforcement strategy to one centered on areas most critical to safety. But the new focus relies heavily on self-policing by the corporations that own the power plants and on assumptions about what could go wrong. Those assumptions haven't always proved correct.
The worst known case of false assumptions was at the Davis-Besse nuclear power plant in Oak Harbor, near Toledo. Stainless-steel nozzles that pass through the lid above the reactor cracked, leaking boric acid - which ate an 8-inch-diameter hole in the lid. Only a thin stainless-steel liner kept the reactor's high-pressure coolant from causing a serious accident.
The hole, discovered in March, was the result of years of neglect by plant owner FirstEnergy Corp. of Akron - and the industrywide assumption that a failure of the lid would be unlikely.
The plant, meanwhile, had received the NRC's top safety ratings.
Earlier error
The NRC's failure was reminiscent of an embarrassment in February 2000 when a steam generator tube ruptured at Consolidated Edison's Indian Point nuclear power plant north of New York City. A small amount of radioactive material leaked into the Hudson River.
As at Davis-Besse, NRC staff members had concerns that some plant

components at the Indian Point plant might be weak. But the NRC didn't pay close attention to the methodology used in an engineering report from the plant that said everything was fine. It turned out that the methodology was badly flawed. Instead of questioning the methodology, the NRC took the utility at its word, the agency's inspector general later reported. The reasons: The NRC project manager assigned to the plant said that steam generators were outside his area of expertise and that the staff generally relied on the utilities to evaluate their own data.

Likewise, a junior NRC engineer who had concerns about Indian Point was afraid to ask follow-up questions - because, according to the inspector general's investigation, she was told not to burden the utility unnecessarily. The agency "frowned upon" asking a utility more than one round of questions, she reported.

This is the rap the NRC faces: It is "too close to the nuclear power industry." So says U.S. Sen. Harry Reid of Nevada, who has dealt with the NRC for years and is bitter about losing the fight to keep nuclear waste out of his state. "They are a lapdog for the nuclear power industry," he says.

He is not the first to make that accusation. Fifteen years ago, the House Interior Committee issued a 44-page investigative report with a title that neatly summed up its findings: "NRC Coziness With Industry."

NRC Chairman Richard Meserve calls the criticism "very unfair." He and others at the agency say nuclear plants are safer than ever, a result of the decades of experience that power plant operators and the government now have. The agency cites statistics that show fewer workers are exposed to radiation, fewer shutdowns are required for emergencies, and more plants are running more hours and generating more electricity than ever.

"If you look at all these indicators, you've got this slope that comes down to everything's working today," says Frank Gillespie, an NRC deputy director in charge of regulatory improvement.

Numbers game

Some of these statistics are skewed, note critics such as the environmental groups Greenpeace and Public Citizen - plants don't shut down as often in part because the NRC now lets them keep operating while they make certain repairs, unlike in the past. But most skeptics don't argue with the overall record.

"By almost any measure, Davis-Besse being a horrible exception, the performance of the industry in terms of objective indicators has improved pretty substantially over the past decade," says Edward McGaffigan Jr., one of the NRC's five commissioners.

But it would take only one bad accident to turn those statistics on their ear. And the NRC's more lenient approach during the last two years toward oversight leaves too big a risk that a nuclear accident will occur, critics say. The agency, formed to protect public safety by keeping a sharp eye on the industry, instead has become a cheerleader for nuclear

power, say authorities who include former NRC commissioners.
With Davis-Besse, the NRC "seemed to regard its mission as putting out a lot of reassurances that were at odds with the actual evidence," says Peter Bradford, a former NRC commissioner.
"There was this attitude of patting people on the back and saying, 'OK, go back to work,' while they really didn't have a clue," says Victor Gilinsky, another former commissioner.
The NRC operates on a set of engineering-backed assumptions that help it focus on power plants, systems and equipment that need more thorough and frequent monitoring. The system is "risk-informed" in NRC parlance: Engineers use complex formulas and matrices based on experience and studies to decide which components have the highest risk of breaking or leaking.
The system is designed to help nuclear plant operators and inspectors prioritize. It lets an inspector "adjust how often you look at things that are running well and try to focus your inspection on things that are not running well," says Gillespie, who helped shepherd in this new regulatory focus.
System upgrade
The agency started phasing in the system in 1999 and fully implemented it in 2000. NRC officials say that they had wanted an analytical system for years because it would offer a more objective approach but that they had to wait for the necessary computer modeling to improve.
The nuclear industry and the Nuclear Energy Institute, its lobbying arm, had been pushing for risk-informed oversight as well. It complained that the old regulatory system - a prescriptive series of rules enforced unevenly - did not distinguish between risky violations and benign infractions.
That meant citations for having an electrical equipment operating manual that failed to include an instruction to plug the equipment in, says Steve Floyd, NEI senior director of regulatory reform, citing real examples.
Another plant was written up after an employee left a book atop a control panel. As the inspector reasoned, a minor earthquake could have shaken the panel and the book could then have hit a control button.
NRC inspectors, says Floyd, were "running amok" looking for infractions.
The NEI was so interested in risk-informed oversight that it prepared a policy paper and held a conference in Orlando, Fla., in 1996 to talk it over with nuclear plant operators. But on the morning those executives were on their way to the airport for the conference, a bombshell dropped that set their efforts back several years: Time magazine came out with a cover story on how poorly the NRC was regulating the plants.
The Time story focused on the Millstone nuclear plant in Waterford, Conn., which had been improperly handling spent nuclear fuel and ignoring safety requirements. When a conscientious worker complained, the plant's owner ignored him. In despair, he went to the NRC - and found that the agency

had known about the problem for a decade but never tried to stop it.
The NRC, said Time, "may be more concerned with propping up an embattled, economically straitened industry than with ensuring public safety." And the Millstone plant, it said, "is merely the latest in a long string of cases in which the NRC bungled its mandate and overlooked serious safety problems until whistleblowers came forward."

Indeed, the General Accounting Office, the investigative arm of Congress, found that other utilities, too, were not correcting their safety deficiencies - and that the NRC allowed the problems to persist.

Temporary fix

The result was predictable: Congress held hearings, a chastened NRC swore it would improve, and the NEI shelved its proposal for regulatory change.
By 1998, the power plants were chafing under the NRC's leash. The NEI went to Congress, complaining to sympathetic members about the NRC - not that the agency was tough but that it was petty, inconsistent and unpredictable.

"We had a lot of problems with the NRC, and we realized we were not going to get the NRC's attention unless we went to their boss," recalls Floyd. "And Congress is their boss."

One longtime nuclear-power supporter, Sen. Pete Domenici, a New Mexico Republican, chaired a Senate appropriations subcommittee that oversaw the NRC's budget. In a hearing in spring 1998, he told the agency to back off - or he'd cut its budget for plant inspections by 40 percent.

The NRC heard him loud and clear. "Shirley Jackson is a smart lady," says Floyd, referring to the woman then in charge of the NRC, "and she got the message from the congressional hearing."

Jackson, now president of Rensselaer Polytechnic Institute in upstate New York, did not respond to several requests for an interview. But Commissioner McGaffigan says of Domenici: "We needed a kick in the pants back when he gave us the kick in the pants."

Working with the Nuclear Energy Institute, the agency wrote up its new plans. Goaded by Congress, it also fine-tuned several strategic goals, among them: Don't burden power plants with unnecessary regulations.

"In all honesty, this agency goes through cycles," McGaffigan says. "After Three Mile Island [in 1979], people tell me that we just put a whole bunch of rules on the books. And when you look at them from the point of view of their cost-benefit effectiveness, they don't hack it." Changing the focus did more than save money, he says; it helped the agency prioritize its inspections and enforcement.

Fuzzy math

What worries skeptics is the mathematically modeled assumptions used in deciding where to put those priorities. For instance, the NRC and the industry decided that some components - such as reactor vessel lids - posed little risk. After all, how could a stationary piece of steel 6-1/2 inches thick possibly break?

But the industry had been aware of the cracking of stainless steel nozzles in the lid - the source of the Davis-Besse corrosion, it later turned out - for more than a decade. In France, the state-owned utility in the early 1990s began a program of replacing vessel lids on all its reactors because of concern about such cracking.

To the NRC, however, the "chances of failure [of the lid] were so low that it didn't even appear on their radar screen," says David Lochbaum, a nuclear-safety engineer with the Union of Concerned Scientists.

As a result, keeping an eye on the lid was a low priority to the NRC's two resident inspectors at Davis-Besse. The agency sent out periodic notices warning that nozzles in contact with boric acid could be prone to cracking and that boric acid was corrosive. But it was up to the plants, not the NRC, to check for damage. The nozzles allow rods that control the nuclear reaction to pass through the lid.

Asked how the resident inspectors could have overlooked clues to the problem - including the repeated clogging of air filters with a brownish substance that proved to be airborne rust from the corroding lid - NRC officials said the inspectors had many other matters to attend to.

In that regard, the steel lid on Davis-Besse may represent the biggest flaw in the NRC's new oversight system: Its assumptions may or may not be correct.

"There are still unknowns after all these years," says Thomas Murley, a retired NRC director of reactor regulation. "That was not foreseen, and therefore it was not modeled in the risk assessment."

Gillespie, the deputy director who defends the system, allows this: "There is an old quote that somebody in my 30 years of history said: 'The industry and the NRC are very good at preventing what we know about. But it's the instance that we haven't preplanned for that's going to get us.' "

Overlooked area

Some within the NRC suggest that too many such instances are possible. For one, many of the plant analyses do not adequately take into account the risk of human error, according to a recent internal NRC draft report.

George Lanik, a team leader in the NRC branch that studies regulatory effectiveness, examined problems at power plants from 1993 through 2000. He looked at the "accident precursors" - events that led to the problems in the first place - and many were caused by human error.

Some 42 percent of the incidents in what could have become serious accidents were "due to the events not typically modeled" on risk assessment, Lanik wrote.

"It's the surprises, and the things that we haven't got in those models yet, that are going to come back to bite us," he says.

But to avoid being unpleasantly surprised, top NRC officials say, every nuclear power plant has a series of safety systems that are intended to preclude or contain virtually any disaster before it hurts the public. NRC officials noted until recently that, despite the corrosion in the Davis-Besse lid, the stainless steel liner on the underside of the damaged head kept the radioactive coolant contained. But the NRC officials learned this month that that notion, too, might give dangerously false comfort. Subsequent tests showed that the liner was cracked and thinner than they had known. Further, they acknowledge, the liner was never intended to be a part of the safety system.

The NRC is reviewing just what went wrong at Davis-Besse and how much of the blame it shares. An NRC task force expects to release a "lessons learned" report by the end of the month. NRC criminal investigators have been looking into why NRC officials allowed Davis-Besse to keep operating beyond the end of December when they knew there could be a problem.

The agency is clearly expecting to wind up with egg on its face. Says Chairman Meserve: "I don't know what the lessons-learned task force at Davis-Besse is going to say. But I presume that they will have some comments about whether there were failures in our oversight program that need to be addressed.

"I expect that would be fertile ground with them," Meserve says. "And if there are, this is something we're going to change."

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ATTACHMENT 9a TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

	)
In the Matter of:	)
PRIVATE FUEL STORAGE, LLC,	) Docket No. 72-22
(Independent Spent Fuel	) ASLBP No. 97-732-02-ISFSI
Storage Installation)	)
	)

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84114

On May 17, 2002 the above-entitled matter came on for hearing, pursuant to notice, before:

MICHAEL C. FARRAR, CHAIRMAN
Administrative Judge
U. S. Nuclear Regulatory Commission

DR. JERRY R. KLINE
Administrative Judge
Atomic Safety & Licensing Board Panel

DR. PETER S. LAM
Administrative Judge
Atomic Safety & Licensing Board Panel

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determining the appropriate design basis for the PFSF, to compare its mean return period design basis earthquake to the equivalent to a mean annual probability of exceedance of one times ten to the minus four?

A. Correct.

Q. Now I'd like to turn to Basis 4 of the contention which is the Staff's reference to DOE Standard 1020-94. And if I understand your testimony with respect to Basis 4 and what we have discussed today, you don't disagree with the 1020-94 concept; correct?

A. I do not disagree with it. Correct.

Q. And your concern is that the Staff did not fully implement what you believe to be the 1020-94 concept, or adopt it. Is that what you are saying?

A. Correct. I believe the Staff selectively chose a number out of this paradigm without, again, embracing the total approach involved.

Q. And if I understand the DOE paradigm as
we have been talking about is you have a design
basis earthquake and you have some margin in your
design such that you achieve a probability of

failure that is less than the design period
earthquake?
A. Correct.
Q. And the paradigm in terms of if you establish that you have this conservatism, then you -- strike that.
When you talk about the DOE paradigm, you are talking about establishing the conservatism by which you establish that you meet a particular target performance level; correct?
A. Correct. First you agree that there is a target seismic performance goal.
Q. And assuming that -- do you have any opinion in terms of the procedures or process by which you go about establishing whether you have any particular risk reduction factor or not?
A. Do I have an opinion?
Q. Yes.
A. I have been educated on two occasions now by Dr. Cornell about how that is done on the

design side by engineers. I don't live on that
side, and so I don't have this practical
experience. But I have now a more full
appreciation of it.

Q. And you would -- so you would agree, as we talked about before, if the margin that Dr. Cornell talks about in his testimony is shown to exist, then he would have established a target performance level equivalent to a PC-3 category document of one times ten to the minus four?

A. We are back to that big hypothetical, with a capital H.

Q. So the answer is yes, with the same caveat you gave before?

A. Yes.

Q. Okay. Now, with respect to Basis 5, which concerns the INEEL exemptions --

A. Yes.

Q. Again, in accordance with what we just discussed before, your issue just goes to the precedental value of that exemption as you see it. Is that correct?

A. Yes. That is the key point. Whether it was a clear and compelling precedent.

Q. And doesn't affect the substance of the issue we were just talking about in terms of whether or not -- the key question we talked about, whether or not we have this or have shown this conservatism; correct?

A. Correct.

ATTACHMENT 9b TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

)
In the Matter of:)
PRIVATE FUEL STORAGE, LLC,) Docket No. 72-22
(Independent Spent Fuel) ASLBP No. 97-732-02-ISFSI
Storage Installation))
)

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84114

On June 6, 2002 the above-entitled matter came on for hearing, pursuant to notice, before:

MICHAEL C. FARRAR, CHAIRMAN
Administrative Judge
U. S. Nuclear Regulatory Commission

DR. JERRY R. KLINE
Administrative Judge
Atomic Safety & Licensing Board Panel

DR. PETER S. LAM
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prepared by Geomatrix Consultants, Inc., February 1999.

UU	Pages 1, 12, and 16 of Reg Guide 1.165 dated March 1997	10187/10193
VV	Letter from David J. Modeen, May 25, 1994, with attachments	10194/10196

you for that.

MR. TURK: 205.

MS. CHANCELLOR: 205. Thank you.

JUDGE FARRAR: Thank you for that additional clarification. Mr. Turk, I think you wanted to go off the record.

MR. TURK: If I can, your Honor, just for a few minutes.

(Discussion off the record.)

JUDGE FARRAR: Back on the record.

Q. (By Ms. Chancellor) Dr. Arabasz, you may recall a discussion yesterday with respect to the Martinez paper, and Mr. Turk had you refer to NRC Exhibit PP on page 18 in which there was a discussion about the Martinez paper used by the Staff to support a slip rate of nearly ten times larger -- that the Wasatch fault has a slip rate nearly ten times larger than the Stansbury fault. Do you recall that line of questioning?

A. Yes, I do.

Q. What problem do you have with the Staff using the Martinez paper to argue that the PSHA at the PFS site is conservative?

A. With more time referring to the paper, I returned to it and I have my own copy. I don't have the exhibit number identified.

Q. That's fine.

A. I would like to read from the paper, but presumably you need the exhibit reference.

MR. TURK: May we have just a moment?

MS. CHANCELLOR: State's Exhibit 184.

MR. TURK: Yes.

A. Referring to the abstract, the left column on page 567, and approximately two thirds of the way down through the abstract there's a sentence that begins, "While we do not yet know the source of this unexpected contemporary deformation," namely the increased deformation observed by GPS, the text continues, "loading of the" -- excuse me. I guess I've confounded the recorder, probably, by not reading verbatim. Let me begin again and I'll read it verbatim.

"While we do not yet know the source of this unexpected contemporary deformation, possible mechanisms include homogeneous crustal extension, loading of the Wasatch and adjacent faults, and pressure solution creep." In other words, the interpretation of the observation was uncertain. One possible modeling interpretation is that the deformation was reflecting higher slip on the

Wasatch fault, but there were other interpretations that the authors were considering.

On page 569, right-hand column in the section Implications of High Strain Rates, the second paragraph reads, "To examine possible sources of the GPS measured horizontal deformation field, Martinez [1996] constructed simple dislocation models for plausible geometries of the Wasatch and nearby faults similar to those of Savage et al. [1992]. Within the observed measurement uncertainties the results were found to be consistent with 1) approximately 4 to 5 millimeters per year of localized slip on a varied fault plane tipping 60 degrees west, or 2) uniform east-west straight of a homogeneous crustal block. It is not yet possible to distinguish between these two end member models because of a lack of broader GPS coverage and the limitations of the current resolution of the GPS measurements."

In other words, the interpretation

remains uncertain as to what the cause of those observed high strain rates are.

Q. And in the Martinez paper, did they use the same methodology in comparing slip rates on the Wasatch and Stansbury faults?

A. No. We visited this earlier in my testimony that one had information on geodetic deformation rates from GPS measurements in the vicinity of the Wasatch fault. One had geological slip rate information, namely, information on displaced geological horizons of known or estimated age where one estimated the slip rate from the displacement divided by the time interval. And so we have a comparison of geological slip rate information on the Wasatch, geological slip rate information on the Stansbury fault, GPS information in the vicinity of the Wasatch fault, no comparable GPS information in the vicinity of the Stansbury fault.

Q. And do you consider it acceptable to do a comparison using different methodologies?

A. If this were a rigorous PSH exercise with let's say a multiteam approach, it might be attempted. It would be subject to lots of criticism and, in my view, it probably would be beaten down.

Q. Thank you. Finally, Dr. Arabasz, I'd like you to turn to State's Exhibit 209. This is first page Safety Evaluation Report for systems not directly associated with storage pads of Private

ATTACHMENT 10 TO
STATE OF UTAH'S COMMENTS ON
PROPOSED RULE, 67 FED. REG. 47745 (2002)

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of:	)	Docket No. 72-22-ISFSI
PRIVATE FUEL STORAGE, LLC	)	ASLBP No. 97-732-02-ISFSI
(Independent Spent Fuel Storage Installation)	)	September 5, 2002

STATE OF UTAH'S PROPOSED FINDINGS OF FACT AND CONCLUSIONS OF LAW ON UNIFIED CONTENTION UTAH L/QQ

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NOTE: THIS EXCERPT CONTAINS ERRATA CORRECTIONS PER "Errata to State of Utah's Findings of Fact and Conclusions of Law on Unified Contention Utah L/QQ," filed September 11, 2002.

CONTENTION PART D: Cask Stability

A. Issue: Has PFS met its burden of showing that the free standing HI-STORM 100 casks experience excessive sliding, uplift, collision, or tip over under design basis ground motions at the PFS site?

B. Regulations/Guidance:

See "Seismic Design and Foundation Stability" above.

C. Findings of Fact - Cask Stabilitiy

248. State expert, Dr. Farhang Ostadan explains that "typically for design," a designer knows the design parameters and specification based on experience. Tr. (Ostadan) at 7311-12. If the analyses is not "right," the designer still has confidence in the design based on past experience. Id. Seismic engineers often rely on design redundancies, such as anchoring the cask, because of the uncertainties in input parameters. Id. at 7340, 7342. A key issue in this case, opined by Dr. Ostadan, is that PFS relies solely on the accuracy of the nonlinear predictions of cask response because of the lack of past experience with PFS's unique and unconservative design, the lack of redundancy in PFS's design, and the lack of test data to validate the nonlinear seismic analyses of the freestanding cask. Id. at 7312, 7335-36, 7340-41. In other words, Dr. Ostadan is concerned that if Holtec's nonlinear seismic analysis of freestanding cask is wrong, the cask may react to ground motions differently than predicted. Id. at 7342.

249. Dr. Ostadan notes that seismic engineers "know a great deal" about how "conventional" designs perform during earthquakes. Tr. (Ostadan) at 7342-43. In this case, Dr. Ostadan further opines that because of the "lack of appropriate test data and experience

data, you may wonder now how credible the results are." Id. at 7343. Based on Dr. Ostadan's experience, he was unaware of any nuclear facility where the designers knew that the facility would be located over a major active fault, such as in this case. Id. Furthermore, Dr. Ostadan knew of no nuclear facility with shallowly embedded foundations that estimated three inches of settlement during the design phase as in this case. Id. at 7351. When considering the unconventional nuclear facility design, the lack of experience and test data, the slim design margins, and the complexity of the nonlinear analyses, Dr. Ostadan emphasized "I would not, if I was the one, solely rely on a nonlinear program for my project. I would be most vulnerable if I do that." Id. at 7353.

250. At the time of the May 2002 hearings, NRC had licensed 23 ISFSIs – 11 site specific licenses and 12 general licenses. Tr. (Guttmann) at 7045. In May, the 23 ISFSIs stored approximately 325 dry storage casks. Id. Of the 23 ISFSI sites, Mr. Guttmann was unaware of the number of sites where the ground motions exceeded or equaled 0.7 g, where the ISFSIs were supported by a soil cement layer. Id. at 7070-71. Mr. Guttmann had no knowledge of the number of free standing cylindrical casks or HI-STORM 100 casks in storage. Id. at 7069.

251. Only two sites, the Hatch (Georgia) and Dresden (Illinois) reactors, are currently storing an estimated 12 HI-STORM 100 casks[35]. Tr. (Singh) at 5918. The ground motions at Hatch and Dresden are 0.15 g (vertical) and 0.1 g (horizontal) (Tr. (Luk) at 6914-

[35]HI-STORM 100 S casks are in storage at the J.A. Fitzpatrick reactor (New York). Tr. (Singh) at 5915. Dr. Singh also anticipated HI-STORM 100 S casks to be used at the Columbia Generating Facility (Washington) and additional HI-STORM 100 casks at the Hatch reactor and Dresden in 2002. Id.

15) and 0.2 g zero period acceleration (State Exh. 121 at 38), respectively. Thus, the Licensing Board finds no site currently storing HI-STORM 100 casks that has estimated ground motions equal to or exceeding the ground motions estimated at the PFS site for either a 2,000-year or 10,000-year earthquake. Furthermore, no evidence was proffered that HI-STORM casks are currently stored on foundations supported by cement-treated soil and relatively soft clay. *See* Tr. (Singh) at 5989.

252. The Licensing Board finds insufficient evidence that the Staff has licensed free standing, cylindrical dry casks, similar to the HI-STORM 100 cask, at sites where the ground motions equaled or exceeded those for the 10,000-year earthquake at the PFS site. Additionally, the Licensing Board also finds insufficient evidence that the Staff has licensed free standing, cylindrical dry casks at sites where the design basis ground motion equaled or exceeded 0.7 g, the proposed design basis ground motion at the PFS site. The Licensing Board finds no evidence that any free standing dry storage casks are stored at sites similar to the PFS site, on shallowly embedded foundations, supported by a cement-treated soil layer and relatively soft clay foundation, subject to ground motions equal or exceeding 0.7 g.

253. Because PFS has an unconventional design that is unprecedented and unproven with no redundancies, the State claims that comprehensive analysis and testing are necessary to determine whether the HI-STORM 100 cask will excessively slide, uplift, or tip over under the 2,000-year DBE. Khan Tstmy., Post Tr. 7123 at 5-6. The State further claims that PFS has failed to conservatively account for the cumulative effects of potential ground motion on its design and thus, PFS's seismic analysis may significantly underestimate cask behavior. Id. Accordingly, in this section we consider the evidence presented with

respect to the opinions and analyses of the seismic behavior of a HI-STORM 100 cask at the proposed PFS site.

Standard

254. Staff witness, Jack Guttmann testified that the Staff's technical licensing decision is based on "standard practices, and standard review plan, commission guidance and polices, and regulations." Tr. (Guttmann) at 6827. Mr. Guttmann further testified that the "regulatory posture" is that the cask does not tip over. Id. at 6977. Thus, until an applicant requests an analysis otherwise, whether the cask tips over is the appropriate standard. Id. The Staff further states "[t]he acceptance criterion was that the casks must be stable in the sense that the center of the top cover of the cask must remain within the original contact circle that the cask makes with the pad." CSER at 5-30. The Licensing Board finds that the issue in this section is whether the Applicant has reasonably demonstrated that the HI-STORM 100 cask will not tip over when subject to the proposed design basis earthquake - a 2,000-year earthquake at the PFS site.

255. To support the PFS license application, the cask vendor, Holtec International Inc. ("Holtec") evaluated the cask stability of its HI-STORM 100 storage cask subject to a 2,000-year DBE at the PFS site in its report entitled *Multicask Response of PFS ISFSI from 2,000-yr Seismic Event (Revision 2)*, Rev. 1 (August 2001) ("Holtec 2,000-year report")

(proprietary document, State Exh. 173).[36], [37] Tr. (Gaukler) at 5941.

256. The evidence proffered on the seismic response of the cask is centered on various nonlinear computer analyses conducted on behalf of the three parties. State expert, Dr. Mohsin Khan warns that "nobody can [exactly] predict the nonlinear behavior." Tr. (Khan) at 9358. Moreover, because of the sensitivity in selection of input parameters, nonlinear analyses have sometimes been referred to as obtaining solutions from a "black box." Tr. (Ostadan) at 7335-36. PFS witness, Dr. Allin Cornell also confirmed Judge Farrar's concern that it is "possible to become too enamored of the [computer] models and lose sight of making sure [the models] are anchored in reality." Tr. (Cornell) at 8024. Similarly, PFS witness, Dr. Alan Soler testified, "you can't just say, because the computer program says it's so, that means it's so." Tr. (Soler) at 9775. Dr. Cornell emphasized that nonlinear analyses provide information and insight, but a critical question is "how much information to take from [nonlinear analysis] away towards making subsequent design judgments." Tr. (Cornell) at 8010. Given this background, we approach a review of the nonlinear analyses with a certain degree of circumspection.

Expert Witness Conflict of Interest.

257. Drs. Singh and Soler have a unique interest in the outcome of this hearing

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[36]Holtec International Inc. claimed the exhibit as proprietary information. Tr. (Gaukler) at 5945-46.

[37]This report was preceded by other Holtec cask stability analyses for the PFS site before the Applicant discovered it had severely underestimated the ground motions, which increased from 0.53g (horizontal) and 0.52g (vertical) to 0.711 g (horizontal) and 0.695 g (vertical). Bartlett/Ostadan Tstmy (Part D, dynamic analysis), Post Tr. 7268 at 4.

compared to all the other witnesses, in that Drs. Singh and Soler have an extensive financial interest in the Applicant prevailing in this case. Dr. Singh is the president and chief executive officer and Dr. Soler is the executive vice president of Holtec International. Tr. (Singh) at 5907-08. Drs. Singh, Soler, and another individual hold sole interest in the privately owned company, Holtec. Id. at 5917.

258. At the time of the hearing, Holtec had only 12 storage casks in use, all of which are HI-STORM 100 casks.[38] Tr. (Singh) at 5918. If the PFS facility attains fruition, Holtec, effectively Drs. Singh and Soler, have the potential to sell 4,000 storage casks and other products such as the HI-TRAC canister cask to the PFS project. Id. at 5910-11, 5920. Dr. Singh admitted that sales to PFS could reach the hundreds of millions of dollars by the "crudest estimate." Tr. (Singh) at 5910-11, 5920.

259. As recognized in NRC cases "most expert witnesses do receive compensation from the parties on whose behalf they testify. But their compensation is for their time and expertise, not for their testimony as such." Louisiana Power and Light Company (Waterford Steam Electric Station, Unit 3), ALAB-732, 17 NRC 1076, 1091 (1983). Here, the financial rewards from the successful outcome of this proceeding in favor of the Applicant are substantial. If PFS is licensed, the financial benefits to Dr. Singh and Dr. Soler, as two of three sole owners of the privately owned company - Holtec, will pale in

[38]As noted earlier, HI-STORM 100S casks are stored at the J.A. Fitzpatrick reactor (New York). Tr. (Singh) at 5915. Additional HI-STORM 100 and 100S casks will be loaded in 2002. *See* footnote 35 *supra*. In addition to the HI-STORM 100 cask system, Holtec markets the HI-STORM 100S and HI-STORM 100SA. Id. at 5914-15. The HI-STORM 100S is a "hugely improved version" of the 100 "to deploy . . . in high seismic regions." Id., and at 5911.

comparison to the usual expert witness compensation. The Licensing Board also finds that Dr. Singh and Dr. Soler have a substantial interest in both the licensing of the PFS facility and the affirmation by this Board of the Holtec analyses, including those conducted with the DYNAMO code, also owned, in part, by Dr. Singh and Dr. Soler. Based on the Licensing Board's decision concerning the propriety of Holtec's codes and methodologies, we note that the outcome in this case may have far reaching effects on Holtec's business.

260. Bias or interest in the outcome of this case "goes only to the persuasiveness or weight that should be accorded the expert's testimony." Waterford, 17 NRC at 1091 (*citing* 11 J. Moore & H. Bendix, Moore's Federal Practice ¶ 702.30[1] (2d ed. 1982)). The Board finds that Dr. Singh and Dr. Soler have a bias and interest in the outcome of this case. Accordingly, we find it apropos to consider those biases and interest in our deliberation of the weight to accord their testimony and other evidence relevant thereto.

Holtec's Experience In Performing Non-linear Analysis of Free Standing Casks.

261. Consistent with the 1993 U.S. Supreme Court case Daubert v. Merrell[39] which establishes the standard for expert witness testimony, the Licensing Board finds that the weight given evidence with respect to the cask stability analyses is dependent upon, a) the proffering witness' relevant education, training, and experience in performing nonlinear seismic analyses of free standing casks subject to site conditions similar to the proposed PFS (e.g., ground motions, soil conditions, etc.); b) whether the expert's testimony is based on sufficient facts; c) whether the testimony relating to cask stability is based on reliable

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[39] Daubert V. Merrell Dow Pharmaceuticals, Inc., 509 US 579 (1993).

principals and methods and; d) whether the witness has applied the principles and methods reliably to the facts of the case.[40]

262. Holtec testified that it performed site specific cask stability analyses for the PFS site and five other ISFSIs. Singh/Soler Tstmy, Post Tr. 5750 at 14. At three of the five ISFSIs sites, Holtec analyzed free standing casks: the Dresden site, where zero period acceleration is 0.2 g (State Exh. 121 at 38); the Entergy Northwest (Columbia Generating) site, where the zero period acceleration is about 0.5 g (State Exh. 120 at 18, 29); and the Tennessee Valley site, where the ground motion is approximately 0.5-0.6 g (State Exh. 121 at 38). At the fourth ISFSI, J.A. Fitzpatrick, there is no record evidence of the ground motions. Other than for the PFS site, the only other site where PFS has conducted a nonlinear analysis is at Diablo Canyon, a site with the ground motions were as high as the 2,000-year earthquake at PFS,[41] but this was on the HI-STORM 100SA, the anchored and "hugely improved" version of the HI-STORM 100 cask. Tr. (Soler) at 5930; Tr. (Singh) at 5911. The Board has already noted evidence of the significant site differences between the Diablo Canyon ISFSI site and the PFS site. *See* Contention D, Dynamic Analysis, *supra.* Further the Board finds that Holtec's analysis of the anchored HI-STORM analysis is not comparable to an analysis of an unanchored cask. Thus, the Licensing Board finds that the

[40]"[A] witness qualified as an expert by knowledge, skill, experience, training, or education, may testify thereto in the form of an opinion or otherwise if (1) the testimony is based upon sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case." Fed. R. Evid. 702 (*emphasis added*); *see also* Daubert, 509 U.S. at 588.

[41]The analyses performed for the Diablo Canyon ISFSI considered a ground motion "around" 0.9 g. Tr. (Soler) at 5929-30, -32.

record does not support that Dr. Soler and other Holtec analysts have any previous experience conducting nonlinear seismic analysis of free standing casks at ground motions that equal or exceed the 0.7 g ground motion for a 2,000-year earthquake at the PFS site.

263. Additionally, there are no known or anticipated sites that store or will store the unanchored casks supported by soil cement or cement-treated soil. Tr. (Singh) at 5989; *see also* (Guttmann) at 7070-71. The Licensing Board also finds that Dr. Soler and other Holtec analysts have no previous experience conducting nonlinear seismic analyses of free standing casks supported by cement-treated soil or soil cement foundations. Based on our finding that the proposed design of free standing, cylindrical casks supported by cement-treated soil and relatively soft clay foundation at 0.7 g peak ground motions is unprecedented, the Licensing Board further finds that no prior cask stability analyses, other than those conducted for the PFS site, provide direct, relevant experience in conducting the analysis for this case.

264. Dr. Singh claimed that Holtec has performed "thousands" of runs simulating freestanding structures; thus, a new model is "verified" against Holtec's data from past results. Tr. (Singh) at 9677. Holtec performed numerous seismic analyses of free standing spent fuel racks. Singh, Soler Tstmy, Post Tr. 5750 at 14. However, in the analysis of spent fuel racks, the racks are submerged in water and there are very small gaps between the racks; thus, Dr. Khan testified that the nonlinear stability analysis of a cask is "very different" from a free standing spent fuel rack. Tr. (Khan) at 7143. The record lacks sufficient facts to conclude that the analyses of free standing spent fuel racks are relevant to the experience and training necessary to conduct nonlinear seismic analysis of objects potentially subject to

large deformation and rotations at high ground motions.

265. In its analysis, Holtec modeled the effects of soil structure interaction through soil springs (linear and rotational) and dampers. Tr. (Soler) at 5993. Dr. Soler and Chuck Bullard, a Holtec employee, authored the various cask stability reports for the PFS site. Tr. (Soler) at 5992. Dr. Soler admitted that neither Mr. Bullard nor he had expertise in analyzing soil dynamics and foundation design (calculating the soil springs and dampers). Id. at 5996-57. Besides the analysis for Tennessee Valley Authority, the only soil dynamic work that Dr. Soler has performed is for this case. Id. at 5995.

266. The Licensing Board finds that Dr. Soler and Mr. Bullard have limited experience in soil dynamics and the foundation design, the calculation of soil springs, and the modeling of soil structure interaction effects in a nonlinear cask stability analysis.

267. The Licensing Board finds, a) Holtec has not performed seismic analyses of free standing casks at sites with ground motions equal to or greater than the 2,000-year earthquake at PFS; b) neither Dr. Soler nor any other identified Holtec analyst are experts in soil mechanics; c) Dr. Soler and another Holtec analyst have calculated the soil springs and dampers at only one other site; d) a lack of evidence that Holtec has prior experience analyzing seismic pad-to-pad interaction; and e) the lack of evidence of the relevance of prior free standing spent fuel rack seismic analysis to the analysis in this case. In sum, we find that Holtec and its witnesses have limited experience in performing nonlinear cask stability analysis at sites similar to the proposed PFS facility. Holtec's limited experience will be considered in the context of the weight given on various issues.

Applicant's Cask Stability Analyses.

268. The Holtec 2,000-year report describes, in part, Holtec's analysis using its proprietary computer program – DYNAMO – for the nonlinear cask stability analyses. Holtec modeled the cask as a two-body system - the storage overpack and the multipurpose canister ("MPC"). Singh/Soler Tstmy, Post Tr. 5750 at 17-18. The overpack is modeled with 6 degrees of freedom and the MPC is modeled with an additional 5 degrees of freedom. Id. The storage pad was modeled as a rigid body. Id. at A.59. The interface between the cask(s) and the pad are addressed using values for vertical and horizontal contact stiffness and the coefficient of friction. Id. at 17-18. Holtec used soil springs and soil damping coefficients to estimate the effects of the underlying soil and foundation to the cask and pad movement.[42] Id. at A29, A.32.

269. For its 2,000-year report, Holtec used a single set of time histories for a 2,000-year earthquake at PFS for 5% damping. Tr. (Singh) at 9671; (Soler) at 9675; State's Exh. 173 at 4. The 2,000-year report describes nine simulations. Singh/Soler Tstmy, Post Tr. 5750 at A.34. The simulations varied the number of casks from two, four, to eight. Id. at A.34; State Exh. 173 at 7, 8. The simulations also varied the soil properties referenced as "lower range," "upper range," and "best estimate" soil properties.[43] Singh/Soler Tstmy, Post Tr. 5750 at A.34; State's Exh. 173 at 8. Holtec assumed 5 percent damping between the cask and the pad to simulate energy loss due to impact. Tr. (Soler) at 5879; *see*

[42]Holtec relied on the methodology specified in ASCE 4-86, *Seismic Analysis of Safety related Nuclear Structures and Commentary*, Tables 3300-1 and 2, and Figure 3300-3. Tr. (Soler) at 5897; Singh/Soler Tstmy, Post Tr. 5750 at 21-22.

[43]Geomatrix provided to Holtec the upper range, lower range, and best estimate soil properties. Singh/Soler Tstmy, Post Tr. 5750 at A.32.

Singh/Soler Tstmy, Post Tr. 5750 at A.21. Holtec assumed the storage pad was rigid in all simulations. Tr. (Soler) at 5757.

270. In an attempt to thwart the State's criticisms of the Holtec 2,000-year report, the cask vendors performed sundry computer runs and animations not with DYNAMO but with a different computer code, VisualNastran 2001. Applicant Exh. 86 at 14, Tr. (Soler) at 9749. The analyses of eleven runs are described in *PFSF Beyond Design Basis Scoping Analysis* (April 19, 2002) (hereinafter referred to as "Holtec Beyond Design Basis report) (Applicant's Exh. 86).[44]

271. In the Holtec Beyond Design Basis report, the casks were modeled as a six degree-of-freedom, rigid single homogenous cylinder. Singh/Soler Tstmy, Post Tr. 5750 at A.117, 5757; Applicant's Exh. 86 at 15. Holtec also modeled the storage pad as a six degree-of-freedom, rigid body. Tr. (Soler) at 5757; Applicant Exh. 86 at 15. The soil foundation was modeled by six springs (three linear and three rotational) with dampers. Applicant's Exh. 86 at 16. Contact between the cask and the pad was modeled by compression only springs and damper springs. Id. at 11. The damping associated with these dampers was set at 40 percent. Tr. (Soler) at 6065. Holtec did not model the soil cement (or cement-treated soil) beneath the storage pad; however, Holtec claims the effects of soil cement are included in the "lower bound" soil parameters. Tr. (Soler) at 5776.

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[44]Holtec offered testimony concerning the results for it's previous report HI-2012780, *Dynamic Response of Free-Standing HI-STORM 100 Excited by 10,000 Year Return Earthquake at PFS* (November 2001) which was not entered as evidence into the record. Tr. (Soler) at 6002-6003, *see also* Singh/Soler Tstmy, Post Tr. 5750 at A.39. The simulations in the HI-2012780 Holtec report did not include soil structure interaction effects. Tr. (Soler) at 6002.

272. The Holtec Beyond Design Basis report, runs 1 and 2 analyzed a 2,000-year earthquake at the PFS site and runs 3 through 11 analyzed a 10,000-year earthquake at PFS. PFS Exh. 86c. The number of casks in the analyses varied between 1, 2, 4 or 8 casks. Id. Input values in Holtec's model include values for six soil dampers, six soil stiffnesses, coefficient of friction between the cask and pad, the masses and location of the pads, the contact stiffness between the cask and the pad. Tr. (Soler) at 5790. For the simulations (runs 2 through 10) where Holtec "tuned" the soil stiffness to a frequency of 5 hertz, Dr. Soler selected 5 hertz based on his understanding of "deposition testimony" where a State expert witness stated 5 hertz as a "frequency at which there was predominant earthquake energy being input into the motion" and where the State expert saw observable deflections in the pad in ICEC calculations. Id. at 6059.

Reliability and Uncertainty of Applicant's Cask Stability Analyses.

DYNAMO is a Small Deflection Code With Questionable Reliability at Sites With High Seismic Ground Motions.

273. Holtec modified a published "general lumped mass analysis" code to create the predecessor to DYNAMO, the code used to generate the result in the Holtec 2,000-year report. State Exh. 120 at 24-28. DYNAMO admittedly is a "small deformation code" that is not capable of processing "large" cask rotations. State Exh. 120 at 27.

274. Although not quantified, Dr. Soler opines that the maximum angle of rotation that DYNAMO is capable of accurately processing results is less than 15 degrees. State's Exh. 120 at 29-30, *see also* Tr. (Soler) at 5926. Dr. Soler's opinion is that "[a]s long as the deflection [ ] predict[ed] [by DYNAMO] are not too large," he is confident DYNAMO

is generating accurate results. Tr. (Soler) at 9930-31. In discussing a small deflection code such as DYNAMO, Dr. Soler opined that "if you attempt to take a code that is written for small deflections and blindly just apply it and get a result that would indicate large deflections, either your program will blow up on you or it will just give you ridiculously large results that have no physical meaning, or it will simply give you wrong results that you may think there's physical meaning to it." State's Exh. 120 at 43, *see also* Tr. at 9490-92. The Board finds no evidence to support Dr. Soler's confidence in DYNAMO producing accurate results in this case.

275. Dr. Soler agreed that the amount of cask tipping or rotation increases as the level of ground motion increases (zero period acceleration). Tr. (Soler) at 6032. Except for the PFS site, DYNAMO has not been used to analyze the stability of a free standing cask where the ground motions are equal to or greater than those for a 2,000-year earthquake at the PFS site (0.7 g). Tr. (Singh) at 5936; Khan/Ostadan Tstmy, Post Tr. 7123 at A.11 (*citing* State Exh. 120 at 19, 20, 29). The Licensing Board finds no evidence that the rotational limits of DYNAMO are not exceeded when evaluating ground motions equal to or greater than 0.7g, the 2,000-year earthquake at PFS.

276. To the contrary, using the same input parameters, DYNAMO failed to predict cask tip over, when in a Holtec nonlinear seismic analysis of its HI-STAR 100 cask using VisualNastran, Holtec determined the HI-STAR cask would in fact tip over at a zero period acceleration (ZPA) of 0.6 g. Tr. (Soler) at 9772-73, 9775, *see also* State Exh. 199. Although the HI-STAR cask has different features than the HI-STORM cask, both were analyzed as free standing casks. Additionally, the Holtec 2,000-year report (State Exh. 173)

references the methodology described in the HI-STAR technical paper (State Exh. 199) that discusses DYNAMO's failings as compared to VisualNastran. Tr. at 9782. In fact, Dr. Soler testified the reason, in part, for the technical paper comparison was to be cognizant that "you can't just say, because the computer program says it's so, that means it's so." Tr. (Soler) at 9775.

277. Holtec holds its DYNAMO code as proprietary information which has not been provided to the Staff or the State. Tr. (Singh) at 5923. This Licensing Board and the other parties have had no opportunity to test the reliability and limits of the DYNAMO code due to the proprietary claim held by Holtec. We note that "a trier of fact would be derelict in the discharge of its responsibilities were it to rest significant findings on expressions of expert opinion not susceptible of being tested on examination of the witness." Virginia Electric and Power Co. (North Anna Nuclear Power Station, Units 1 and 2), ALAB-555, 10 NRC 23, 26 (1979).

278. Additionally, Dr. Soler admitted that the contact spring stiffness computations used in State Exh. 173 are not all included in that report but referred to earlier documents that "set forth" the theory. Tr. (Soler) 9780. These "earlier documents" are not in evidence and therefore their reliability and the reliability of the contact spring stiffness computations have not been tested.

279. The Licensing Board finds that the question of whether DYNAMO, as a small deformation code, generated accurate results in the Holtec 2,000-year report is a "significant finding" in which the opportunity to test the witnesses on cross examination is limited, in part, by the unavailability of the DYNAMO code. There is also an incomplete

computation of input parameters in the record. As a result, we will consider the opposing parties ability to test witnesses on cross examination as a factor in weighing the evidence of the reliability of DYNAMO.

280. To support its use, Dr. Singh stated that DYNAMO has "been used in over a thousand discrete structures, qualifying them." Thus, he concluded, DYNAMO is a "well tested program." Tr. (Singh) at 6099-6100. The parties offered no evidence with respect to the type of "discrete structures" qualified by DYNAMO and how those DYNAMO analyses are relevant to this case given the unique and unprecedented design posed by PFS.

281. The Staff cites and accepts the results obtained with DYNAMO in the Holtec 2,000-year report. CSER at 5-30. However, the Staff does not specifically refer to the code used to obtain the Holtec results. *See generally id.* Holtec claims that the Staff also reviewed and accepted DYNAMO performed at other spent fuel storage sites. Singh/Soler Tstmy, Post Tr. 5750 at 14. The Licensing Board finds no evidence in the record concerning, a) the basis of the Staff's acceptance of Holtec's use of the DYNAMO code to accurately predict the dynamic behavior of unanchored casks under high seismic ground motions at the PFS site or sites with similar design characteristics, b) whether the Staff independently validated the results obtained with DYNAMO, and c) whether the Staff's previous acceptance of DYNAMO results have any direct bearing in this case where the Applicant has proposed to place free standing dry storage casks on a shallowly embedded foundation supported by cement-treated soil in a seismically active location. Notably, the Staff did not have access to the DYNAMO code for any purposes, including verifying the input parameters, the model, or results. Tr. (Singh) at 5923. As a result of the lack of

supporting evidence to demonstrate the basis of the Staff's acceptance of results generated by DYNAMO, the Licensing Board finds Holtec's reference to the Staff's previous acceptance of DYNAMO unpersuasive in this case.

282. During his testimony, Dr. Singh had with him DYNAMO's training manual in which he testified the manual contained over a dozen cases in which DYNAMO simulated a "wide variety of problems [such as] harmonic resonance, bifurcation, [and] . . . dynamic responses of nonlinear structures." Tr. (Singh) at 9679. Dr. Singh implies that the DYNAMO training manual represents that DYNAMO has been validated for both fuel rack and cask stability analyses. Tr. (Singh) at 9678-80. Dr. Singh professes that DYNAMO has been validated for dynamic responses of nonlinear structures. This Licensing Board's interest with respect to DYNAMO rests solely in any verification of its capability to accurately analyze the nonlinear seismic response of a free standing cask at the PFS site. We find it significant that the Applicant failed to proffer supporting documentation from the DYNAMO training manual if, in fact, Holtec has documented the scope and relevance of Dr. Singh's claims in this matter. Thus, this Licensing Board finds that not a scintilla of evidence has been offered by the Applicant that DYNAMO has been validated by the training manual.

283. Additionally, Holtec testified that DYNAMO results for "problems that had no simple analytical solutions were also evaluated [with DYNAMO] and shown to give good agreement with numerical solutions using finite element codes such as ANSYS." Singh/Soler Tstmy, Post Tr. 5750 at 20. However, Holtec also stated that ANSYS was not reliable, and in fact, Holtec found "in the case of a simulation of an earthquake on a

freestanding structure, [ANSYS] was [giving] unstable, actually incorrect results." Tr. (Singh) at 6099. In light of Dr. Singh's testimony as to the credibility of ANSYS to accurately model the seismic behavior of freestanding structures – the issues at the heart of this case – the Licensing Board finds that the comparison between DYNAMO and ANSYS unreliable.

284. Holtec testified that DYNAMO produced results in "good agreement" with known solutions for a "series of classical problems." Singh/Soler Tstmy, Post Tr. 5750 at 20. According to Holtec, the classical problems demonstrated DYNAMO features such as compression only behavior, friction resistance, etc. Id. No evidence was offered that demonstrates the relevance of the classical problems to the unique issues under consideration here. Thus, the Licensing Board finds that the capability of DYNAMO to reach "good agreement" with known classical solutions, albeit essentially unidentified known classical solutions, is inadequate to demonstrate the reliability of DYNAMO to accurately predict the seismic behavior of free standing casks under the 2,000-year earthquake at the PFS site.

285. Holtec further testified that DYNAMO was created and used to perform seismic analyses of spent fuel racks and was used in a number of free standing spent fuel rack analyses. Singh/Soler Tstmy, Post Tr. 5750 at 14-15. However, in the analysis of spent fuel racks, the racks are submerged in water and there are very small gaps between the racks; thus, Dr. Khan testified that the nonlinear stability analysis of a cask is "very different" from a free standing spent fuel rack. Tr. (Khan) at 7143. Moreover, the Board finds no evidence that the analyses of free standing spent fuel racks were conducted at ground motions equal or greater than a 2,000-year earthquake at the PFS site. The Board also finds no evidence of

any angles of rotation of free standing spent fuel racks in the confines of a spent fuel pool in comparison to free standing casks. Absent details substantiating the relationship between nonlinear analyses for free standing dry casks and free standing spent fuel racks, the Licensing Board finds unconvincing Holtec's testimony that prior acceptance of the DYNAMO code in spent fuel rack analyses is relevant in this case.

286. The Licensing Board finds that PFS has not produced evidence to demonstrate, (a) the capability of DYNAMO to produce accurate nonlinear seismic analyses of free standing casks under PFS site conditions, or (b) to support the comparison of DYNAMO results with known classical solutions, the comparison of DYNAMO results with results obtained with ANSYS, and the Staff's acceptance of DYNAMO results for both free standing casks and spent fuel racks.

287. The results generated by DYNAMO have not been benchmarked against full or bench scale data. State's Exh. 121 at 93-95. In the absence of validating physical data, the Licensing Board finds that the evidence discussed previously does not establish that the un-quantified rotational limitations of the small deflection code – DYNAMO – were not exceeded in the Holtec 2,000-year report. We now turn to the details of the various analyses proffered during the proceeding, including the reliability of the Holtec animations performed with VisualNastran.

Testability of Holtec VisualNastran Results

288. Many times throughout cross examination, Dr. Soler could not specify specific details or results of his various nonlinear analyses because he did not personally seek the requested results; he observed the data visually and did not record the results; he did not

know the inner workings of VisualNastran; or he needed additional time to locate the details. Tr. (Soler) at 5770-71, 5773-76, 5779, 5791-5803; 6021. For example, as documented in the transcript, untracked casks in Dr. Soler's animations appeared to move greater distances than the tracked cask. Id. at 5761. Dr. Soler did not have the ability to identify the actual deflection or angle of rotation of other casks. Id., *e.g.*, at 5779. Thus, although VisualNastran is a publically available code, the ability of parties, in particular the State, and the Licensing Board to test the reliability of Dr. Soler's testimony based in the nonlinear analyses was severely restricted.

289. Additionally, Dr. Soler admitted that no document in evidence lists every input value for each of his simulations. Tr. (Soler) at 5791; *see also* Tr. at 5796. Furthermore, Dr. Singh admitted that the Holtec Beyond Design Basis report does not list "each numerical value." Tr. (Singh) at 5796. Dr. Soler could not provide the critical damping used in his analyses of case 11 and relied upon "whatever ASCE 486 would ask you to use for the soil properties given to us, that is what we used." Tr. (Soler) at 5788-89. Furthermore, Dr. Soler was unaware of "the equations for equilibrium of rigid bodies [which] is built into the [VisualNastran] code." Tr. (Soler) at 5968.

290. During the hearing, the Licensing Board noted and now finds that the Holtec Design Basis report is no more informative, reliable or with foundation than the animation itself without the underpinning data. Tr. at 5853-54. As we assured the State when we admitted Holtec's animations over its objections, we now address, in general, the reliability of the animations. Tr. at 10552-54. As demonstrated by the State, the results of cask behavior could not be quantitatively determined from the animations alone. Without

supplemental documentation or narration, the animations merely represent one analyst's simulation of cask behavior. Given that Dr. Soler supplemented the record with actual input values and results, we find that the animations are not the best evidence. We also find that the visual animations themselves are dangerously prejudicial in that a trier of fact or future tribunal could in fact rely on the animations and not adequately weigh the facts in this case.

291. The Licensing Board finds the reliability of Holtec opinions which rely of the results generated using VisualNastran is a "significant finding" in which the opportunity to test the witnesses on cross examination is limited, in part, to the inability of the parties to test the VisualNastran results through cross examination. Similar to our finding with respect to DYNAMO, we will also consider the opposing parties' ability to test witnesses during the cross examination as a factor in weighing the evidence of the reliability of VisualNastran results.

292. Dr. Singh testified that the Staff's grant of a certificate of compliance for the Holtec's HI-STAR 100 shipping cask was supported in part by analyses generated with VisualNastran. Tr. (Singh) at 6112-13. The Licensing Board finds no evidence in the record concerning the basis of the Staff's acceptance of Holtec's use of the VisualNastran code; whether the Staff independently validated the results obtained with VisualNastran; and whether the Staff's previous acceptance of VisualNastran results have any direct bearing in this case where the Applicant has proposed to place free standing dry storage casks on a shallowly embedded foundation supported by cement-treated soil in a seismically active location. The Licensing Board finds no evidence that VisualNastran has been independently validated with test data for the sliding and uplift of free standing casks in an area with high

seismic ground motions. Based on the lack of supporting evidence, the Licensing Board finds the Staff's previous acceptance of VisualNastran with respect to the HI-STAR 100 cask unpersuasive in this case.

Non-Linear Analysis Input Parameters.

293. PFS witness, Dr. Wen Tseng, agreed with Dr. Ostadan that nonlinear analyses are sensitive to variation of input parameters. Tr. (Ostadan) at 7335, Tr. (Tseng) at 5695. According to Dr. Ostadan, small changes in input parameters may induce substantial changes in the results. Tr. (Ostadan) at 7352. PFS witness, Dr. Cornell confirmed that nonlinear dynamic analysis can be sensitive to some input parameters. Tr. (Cornell) at 8009. In light of no contradicting testimony, the Licensing Board finds that nonlinear analyses are sensitive to some input parameters.

294. No witness disagreed that the results of a finite element model such as a cask stability analysis are dependent upon the quality of input data. Tr. (Khan) at 7157; (Singh) at 6030; (Luk) at 11508. The Licensing Board finds that the acceptance of nonlinear cask stability results is dependent upon a showing that the data input into the models are reasonably conservative, accurate, and comprehensive to account for all effects to free standing cask movement under seismic ground motions.

Khan Report

295. At the request of the State, Dr. Mohsin Khan conducted a parametric study by modeling aspects of the seismic reaction of the HI-STORM 100 cask to evaluate Holtec's seismic analysis of free standing casks at the PFS site. Khan/Ostadan Tstmy, Post Tr. 7123

at A.18. For his parametric study, Dr. Khan utilized a finite element structural analysis code, SAP2000, to model a single HI-STORM 100 cask as beam elements in which the base of the cask is connected to the storage pad using nonlinear elements. Id. at A.21. Dr. Khan's methodology, analysis, results, and conclusions are described in *Analytical Study of HI-STORM 100 Cask System Under High Seismic Condition,* Technical Report No. 01141-TR-000, Revision 0 (December 2001) (State's Exh. 122) (hereinafter referred to as "Khan Parametric Study").

296. Dr. Khan performed case studies using three mathematical single cask models with varying degrees of complexity.[45] Khan Tstmy, Post Tr. 7123 at A.21. In the second and third case studies, Dr. Khan varied input parameters such as contact stiffness, the coefficient of friction, and the damping. Khan Tstmy, Post Tr. 7123 at A.21.

297. In the second case which discounted rocking effects, for a coefficient of friction of 0.8, the horizontal cask displacement varied from 42.74 inches to 0.057 inches with varying contact stiffness from 1×10^6 pounds per inch to 454×10^6 pounds per inch, respectively. *See* State's Exh. 122, Table 2 at 11. Similarly, in the three dimensional case, the horizontal and vertical displacement varied with the values of contact stiffness, coefficient of friction, and structural damping. Id., Table 3 at 13.

Contact Stiffness.

298. As a result of his study, Dr. Khan determined that nonlinear mathematical

[45]The first case study modeled horizontal sliding without any vertical excitation. Khan Tstmy, Post Tr. 7123 at A.21. The second case study modeled horizontal and vertical excitation absent rocking effects due to the cask height. Id. The third case study modeled a three-dimensional cask with vertical and horizontal beam elements. Id.

models are highly sensitive to the assumed contact stiffness between the cask and the storage pad. Id. at A.16. Dr. Khan explains that local contact stiffness is needed in a mathematical simulation before any sliding occurs. Id. at A.24. After sliding occurs, the horizontal displacement is a function of the intertial forces overcoming the coefficient of friction times the mass. Id. Thus, displacement of the cask from seismic ground motion should not be very sensitive to the contact stiffness values. Id.

299. Additionally, Dr. Khan maintains that in nonlinear analytical solutions, high contact stiffness values also absorb significant amounts of energy before sliding actually occurs by reducing instantaneous velocities for the next successive iteration in the nonlinear analysis. Id. As a result, high contact stiffness could underestimate vertical displacement of the cask. Id.

300. In its model, Holtec used contact stiffness to "define the stiffness of the vertical-only 'compression springs' at the interface of the cask and the pad." Singh, Soler Tstmy, Post Tr. 5750 at A.137. Holtec used a single vertical contact stiffness value for its simulations in the Holtec 2,000-year report. Id. at A.137, Tr. (Soler) at 6042. Notwithstanding the State's challenge to Holtec's contact stiffness value, Dr. Soler opined that "we got acceptable answers in the 2,000-year return earthquake, so there was no incentive for us there to lower the contact stiffness." Id. at 6043. In its simulations of the

10,000-year earthquake,[46] Holtec used a vertical contact stiffness of 18,864,480 lbs per inch.[47] Tr. (Soler) at 9575.

301. Prior to his parametric study, Dr. Khan had not had occasion to select a contact stiffness value for sliding or tipping. Tr. (Khan) at 7217. Similarly, neither Dr. Soler nor Dr. Singh have proffered evidence that they have prior experience selecting a contact stiffness value for a sliding or tipping analysis of a free standing cask where the ground motions equal to or exceed those for a 2,000-year earthquake at PFS. Tr. (Singh) at 6936. The Licensing Board finds that neither Dr. Khan nor the Holtec witnesses have proffered evidence that their recommended contact stiffness value has been validated or benchmarked by test data or other cask stability analysis with similar ground motions.

302. A vertical contact stiffness of 450 x 10^6 lbs per inch for unanchored casks is too high, opines Dr. Khan, because the contact stiffness makes the vertical frequency of the cask too rigid which underestimates the vertical displacement of the cask. Khan/Ostadan Tstmy, Post Tr. 7123 at A.28. Dr. Khan testified that "[o]nce [cask] sliding begins, the high [contact] stiffness values artificially treat the solution as linear [*e.g.*, as if the cask is anchored to the pad] without amplifying it in the upward direction and give non-unique or invalid results." Id. at A.28, A.31. A high contact stiffness corresponding to a high response

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[46]*See PFSF Beyond Design Basis Scoping Analysis*, HI-2022854; and *Dynamic Response of Free-Standing HI-STORM 100 Excited by 10,000 Year Return Earthquake at PFS*, HI-2012780, (November 2001).

[47]Dr. Singh and Dr. Soler's prefiled testimony erroneously states the 10,000-year earthquake analyses were conducted with a contact stiffness of 40,130,000 pounds per inch; however, Dr. Soler informed the Licensing Board and the parties that the contact stiffness was in fact 18,864,480 pounds per inch. Tr. (Soler) at 9561-75.

spectra frequency will never amplify the cask motion. Tr. (Khan) at 7231. Holtec notes its contact stiffness corresponds to a frequency in the rigid range of 111 hertz. Tr. (Singh) at 9634-35.

303. In the absence of test data, it is Dr. Khan's opinion that to conservatively capture the dynamic behavior of the cask, including cask rotation or rocking, the appropriate contact stiffness for unanchored casks must correlate with a frequency that falls within the amplified range of the response spectra curve. Khan/Ostadan Tstmy, Post Tr. 7123 at A.31; Tr. (Khan) at 9362, 9374, 9482. The rotational stiffness or rotational springs in the model will move the cask with a certain damping at an associated frequency. Id. at 9482. If the contact stiffness does not correlate with the frequency in the amplified region of the response spectra, then the mathematical code will treat the problem as linear as if the cask is anchored to the pad. Khan/Ostadan Tstmy, Post Tr. 7123 at A.31.

304. Paramount to Dr. Khan's opinion is that the Applicant has offered no test data to support its nonlinear cask stability results. If the real dynamic behavior of the structure is unknown, Dr. Khan is adamant that structural analysis design philosophy mandates that the structure's behavior is analyzed using the "peak of the spectra times the weight and other factors into consideration." Tr. (Khan) at 7236. Thus, for design purposes in the absence of test data, to estimate the dynamic response of the cask, a range of contact stiffness is selected that correlates with the rocking frequencies in the earthquake response spectra that give the maximum dynamic response. Id. at 7215, 7208.

305. Dr. Khan opined that contact stiffnesses in the range of 1×10^6 pounds per inch and 10×10^6 pounds per inch correspond to frequencies in the amplified spectral range

of the response spectra. Khan Tstmy, Post Tr. 7123 at A.32.

306. The Licensing Board notes that Dr. Singh testified that "[w]henever a problem cannot be physically modeled [such as with shake table testing], the engineer's only recourse is to make it conservative." Tr. (Singh) at 9685. Notwithstanding the need to make the model conservative, Dr. Singh disagreed with Dr. Khan's philosophy that in the absence of test data, the seismic response of the cask must be evaluated at a range of contact stiffness values corresponding to the natural frequency of the amplified region of the response spectra. Tr. (Singh) at 9617-18. Further, Dr. Singh testified that contact stiffness is not a parameter or a function of the earthquake, but that it is an "intrinsic property of the bodies that are subjected to the earthquake." Id. at 9618.

307. In a 1998 note by Max DeLong of Northern States Power regarding NRC Staff question 3-11 to Sierra Nuclear, the Staff states "[t]he response spectrum for the acceleration time history chosen for the nonlinear analysis or confirmatory testing must be enveloped by the response spectrum. . . . Furthermore the duration of the seismic event must be consistent with high acceleration levels. Large earthquakes that have high acceleration levels are associated with strong ground motion durations." Tr. (Khan) at 9792-93, State Exh. 197A.[48]

308. Fundamental to the conflicting testimony concerning the value of contact stiffness is Dr. Khan's steadfast opinion that absent test data to validate the results of a

[48]PFS discovery documents marked confidential; the confidentiality claim was removed per *Joint Report on Status of Utah Contention L/QQ Exh.s and Other Open Items from Hearing Concerning Utah Contention L/QQ* (July 31, 2002).

nonlinear analysis, typical design philosophy requires the designer to match the rocking frequencies in the amplified region of the response spectra. In contrast, without regard to the purpose of Dr. Khan's philosophy, Holtec adamantly professes that the dynamic contact stiffness value must render a "realistic" static deflection value.

309. Holtec testified that contact stiffness is the force applied at the interface points of contact between the cask and the storage pad that would be required to move either the cask or pad a unit distance[49]: K = W/d; where K is the contact stiffness, W is the weight of the cask, and d is the deformation by the pad under the cask. Id. Dr. Khan agrees that this formula would calculate the static, not dynamic, contact stiffness. Tr. (Khan) at 7211, 7237. In a dynamic response, the physical behavior changes as the cask moves; as a result, the load deflection characteristic on the pad would also change so the stiffness could vary with respect to time. Khan/Ostadan Tstmy, Post Tr. 7123 at A.31; Tr. (Khan) at 7243. Dr. Soler agreed, in part, that there is no contact stiffness when there is separation between the cask and pad. Tr. (Soler) at 6053, 9645. As represented in Holtec's model, the contact stiffness value at each contact point changes with time if the contact point on the cask is not physically on the pad due to rocking or uplift. Id. at 9645-47. However, Dr. Soler maintains that "contact stiffness should not be a function of the input motion." Id. at 6050.

310. Contrary to the Holtec witnesses, Dr. Khan's opinion is that a simple deflection calculation, K = W/d, cannot be used to determine a single unique contact stiffness value for a dynamic analysis where the cask can potentially rock, uplift, and slide.

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[49]Singh/Soler Tstmy, Post Tr. 5750 at A.136.

Khan/Ostadan Tstmy, Post Tr. 7123 at A.27, 31; Tr. (Khan) at 7235. A range of possible contact stiffnesses should be evaluated and validated with test results. Khan/Ostadan Tstmy, Post Tr. 7123 at A.32; Tr. (Khan) at 7235.

311. Dr. Singh testified that contact stiffness does not change in any significant manner whether the event is dynamic or static. Tr. (Singh) at 9628. However, Dr. Soler admitted that there is no contact stiffness when there is separation between the cask and pad during dynamic motion. Tr. (Soler) at 6053, 9645. Significantly, Holtec has not validated its contact stiffness results with actual test data, such as shake table data. Tr. (Soler) at 6054.

312. Absent test data, both Dr. Khan and Dr. Soler agree that there is no single correct contact stiffness value that is appropriate for the nonlinear analyses of the cask. Tr. (Soler) at 6049. The Licensing Board does not find a disagreement between the parties as to the definition of contact stiffness. However, the crux of the disagreement between Dr. Soler and Dr. Khan is whether Holtec's calculated stiffness can be used to accurately predict the sliding, uplift, and rocking of the cask under high seismic ground motions, and how to accurately incorporate design conservatism into a nonlinear analysis absent validating test data.

313. Holtec concluded "that Dr. Khan's work comes to erroneous conclusions because he has not achieved the correct, converged solution for many of his simulations, and has utilized unrealistic and unsupportable inputs for the simulations." Singh, Soler Tstmy, Post Tr. 5750 at A.124. Holtec claims that a contact stiffness of 1×10^6 pounds per inch is unrealistic because the simple deflection formula (K = W/d) results in a 0.36 inch static deflection of the pad. Tr. at 6043-44. Although disagreeing that a static deflection formula

is applicable to a dynamic model, Dr. Khan agreed that a 0.36 inch static deflection is not realistic. Tr. (Khan) at 7219.

314. To support his opinion that static contact stiffness is not applicable in a dynamic analysis, Dr. Khan testified that once the program is initiated, the boundary conditions are set so the static deflection prior to seismic excitation is not included in the results. Tr. (Khan) at 7210-11. In a dynamic analysis, the vertical contact stiffness is used to justify whether there is vertical amplification or rocking. Id. at 7212.

315. To support its position, Holtec points to an ANSYS training model which cautions that too high a value for contact stiffness "causes [computation] convergence difficulties," but "[m]inimum penetration gives best accuracy." Applicant Exh. SS at 3-3. ANSYS further recommends that "[d]etermining a good stiffness value usually requires some experimentation" and to start with a low contact stiffness value. Id. at 3-14. ANSYS suggests that as a check "if you can visually detect penetration . . . the penetration is probably excessive." Id. (emphasis added).

316. Dr. Soler agreed that ANSYS does not provide an example verification problem for either a real or artificial earthquake applied to either pure sliding, pure uplift or any combination of uplift and sliding, nor does ANSYS specify a contact stiffness value. Tr. (Soler) at 6051-52, 5900-01. Thus, it is unclear whether the ANSYS training manual can be properly applied to uplifting, rocking, and sliding simulations such as in this case. However, without determining the applicability of the training manual in this case, we find that the ANSYS training manual does not nullify Dr. Khan's contact stiffness value of 1×10^6 because: first, Dr. Soler testified that "no one" contact stiffness value is necessarily correct

(Tr. (Soler) at 6049); second, Dr. Soler testified that whether there is visual penetration is subjective (id. at 6037-38); third, ANSYS also advises that finding a "good" stiffness value usually requires "some experimentation," which we find similar to evaluating a range of stiffness values such as in the Khan Parametric Study; and finally, ANSYS qualifies its advice that if visible penetration is detected then penetration is "probably" but not conclusively excessive.

317. Dr. Soler opined that a contact stiffness value that resulted in a deflection of ".0 something" or ".00 something" inch would be sufficient for the cask stability analysis. Id. at 6038. Dr. Soler did not offer a technical basis for his opinion that ".0 something" or ".00 something" is acceptable deflection in estimating contact stiffness. Dr. Khan also opined that a contact stiffness of 10×10^6 pounds per inch is within the recommended spectral range. Khan/Ostadan Tstmy, Post Tr. 7123 at A.32. While noting that the values have not been validated with test data and that the experts acknowledge more than one contact stiffness value is acceptable, the static deflection of a cask corresponding to a contact stiffness of 10×10^6 pounds per inch is equal to 0.036 inches, which is within what Dr. Soler deemed acceptable.

318. Holtec further postulated that in some of the Khan Parametric Study cases, Dr. Khan exceeded the rotational limits of SAP2000. Tr. (Soler) at 9603-04. SAP2000 is a small deflection structural code that is capable of predicting accurate results if the angles of rotation are not large. Tr. (Khan) at 7174-75, 7183. SAP2000 will "blow up" or stop working if the rotational capability is exceeded. Id. at 7187. In SAP2000, "all nonlinearity is restricted to Nllink elements." Tr. (Khan) at 9346. The SAP2000 Nllink element limitation

occurs when a significant amount of rigid body rotation (*e.g.*, cask rotation) is introduced into the analysis. Id. at 9353, 9355. Dr. Khan testified that SAP2000 has no sliding displacement limitations or vertical uplift limitations if the center of gravity remains within acceptable limits. Id. Dr. Khan did not evaluate whether SAP2000 had exceeded the rotational limits. Id. at 9360.

319. The parametric study runs did not exceed the rotational capabilities of SAP2000, opined Dr. Khan, because the analyses ran to completion and did not blow up. Tr. (Khan) at 7187. Although admittedly not a user of SAP2000, Dr. Soler opined that SAP2000 could run to completion and not stop even if the program had "blown up." Tr. (Soler) at 9615-16, 9604.

320. Dr. Khan agreed that as the coefficient of friction increases, the cask would lift and increase the potential for tipping. Tr. (Khan) at 9513. However, Dr. Khan disagreed that the cask would only tip and not slide in a simulation where the coefficient of friction is 0.8, because once the cask starts rocking, the response cannot be predicted where a coefficient of friction of 0.7 may be more sensitive to tipping than 0.8 Id. at 9513

321. Dr. Soler "presumed" Dr. Khan properly represented the cask by beam elements in his model. Tr. (Soler) at 9914-15. Although he questioned the accuracy of Dr. Khan's parametric study results, Dr. Soler admitted he was not a user of SAP2000 and could not comment "to any degree to certainty" why SAP2000 generated "erroneous" results. Tr. (Soler) at 9604. Notwithstanding Holtec's claims, Dr. Khan checked the time histories of his runs to verify that the cask did experience large rotations. Tr. (Khan) at 7187. The Licensing Board finds insufficient evidence to conclude that any of the Khan Parametric

Study runs "blew up" or gave inaccurate results based on exceeding the rotational limitations of the program.

322. Dr. Soler testified that Holtec ran an 8 cask simulation for a 2,000-year earthquake with a contact stiffness of approximately one eighth of 4×10^6 pounds per inch, which resulted in a maximum deflection of cask no 1 of about half an inch to an inch. Tr. (Soler) at 6050-51. Holtec did not offer supporting documentation for this simulation or the values of all input parameters. Based on the lack of simulation details, the Licensing Board finds Holtec's reference to this simulation unreliable.

323. Holtec also ran nine simulations where it "tuned" the soil stiffness so that the mass of the cask(s) and pad resonate at 5 hertz.[50] Tr. (Soler) at 5767, *see* Applicant's Exh. 86c at 17 (Holtec Beyond Design Basis report). The damping in these simulations was 1 or 5 percent. Applicant's Exh. 86c. The coefficient of friction was 0.2, 0.8, or randomly applied in a range between 0.2 and 0.8. Id. Holtec conducted one of the nine runs at a 2,000-year earthquake and the remaining simulations at the 10,000-year earthquake. Id.

324. Dr. Khan agreed that Holtec's "tuning"the soil stiffness to 5 hertz is a comparable approach to evaluating the cask response at rocking frequencies. However, Dr. Khan emphasized that Holtec did not evaluate a higher or lower frequency than 5 hertz where the dynamic response of the cask may be higher. Tr. (Khan) at 9482. To illustrate his point, Dr. Khan referred to the response spectra for 1 percent damping which shows peak acceleration of 4 g at 4 hertz, whereas at 5 hertz the acceleration is 2.7 g and then at 6 hertz

[50]The simulations are described in the *Holtec Beyond Design Basis Scoping* report, Applicant's Exh. 86c.

the acceleration goes back up to 3.6 g. Tr. (Khan) at 9499-00, State Exh. 195. Moreover, based on Dr. Luk's results, soil structure interaction will filter some of the frequencies but still significantly amplify the accelerations when compared to free field acclerations. Tr. (Khan) at 9511, 9539; (Luk) at 6934-36. Thus, the actual acceleration at the top of the pad will be higher than the free field accelerations shown in the response spectra curves generated by Dr. Khan. Tr. (Khan) at 9511.

325. As shown in State Exh. 195, accelerations at 5 hertz are exceeded at frequencies above and below 5 hertz. The Licensing Board finds, absent test data, the Holtec simulations with "tuned" soil stiffness at 5 hertz do not reasonably show that all potential cask rocking and uplift are encompassed in the analyses. The Licensing Board further finds that the additional simulations in the *Beyond Design Basis Scoping* report do not validate Holtec's contact stiffness of 464 x 10^6 pounds per inch in the Holtec 2,000-year report or 18.8 x 10^6 pounds per inch in Holtec 10,000-year analyses.

326. Additionally, Dr. Soler testified that he simulated Dr. Khan's "exact problem" for case 3, Study run 3 of the Khan report using VisualNastran.[51] Tr. (Soler) 9603, Applicant's Exh. 225 at 15. The sole purpose of Dr. Soler's simulation was to demonstrate that case 3, study run 3 of the Khan Parametric Study is erroneous. Tr. (Soler) at 9613.

327. Holtec simulated the seismic response of a single cask with a 1 x 10^6 pounds per inch contact stiffness at about 5.2 hertz applied at 8 contact points, and 1 percent damping for a 2,000-year earthquake. Tr. (Soler) at 9605, 9611, Applicant's Exh. 225 at 15.

[51]The analyses are describe in Applicant's Exh. 225, HI-2022878, *Additional Cask Analyses for the PFSF* (June 7, 2002).

The simulation did not consider the effects of soil structure interaction. Applicant's Exh. 225 ("Holtec Additional Analyses"). To simulate the SAP2000 model, Dr. Soler embedded 8 spheres rigidly attached to the cask. Id. at 16. Dr. Soler admitted that he did not model his cask system exactly the same as Dr. Khan but used the same number of contact elements and locations and used a different representation of the cask. Tr. (Soler) 9750-51. Moreover, Dr. Soler admitted that "presumably" had he run the same model as Dr. Khan with SAP2000, Dr. Soler would have obtained the same results as Dr. Khan. Id. at 9755-56, 9757.

328. Also described in the Holtec Additional Analyses, Dr. Soler ran another simulation of the seismic response of a cask with a 1 x 10^6 pounds per inch contact stiffness applied at 16 points and 1 percent critical damping for a 2,000-year earthquake. Tr. (Soler) at 9613-14.

329. We note that no evidence was offered to demonstrate that Dr. Soler correctly remodeled and simulated the Khan model. We further note that Dr. Soler did not compare his results using the same parameters with his VisualNastran model used in Holtec Design Basis report. Thus, the Licensing Board finds there is insufficient evidence that the Holtec replication of the Khan Parametric Study, Case 3, Study run 3 is accurate or reliable. Although criticizing Dr. Khan's results, Dr. Soler attempted to replicate only one out of twenty runs performed in Dr. Khan's parametric study, case 3, study run 3. Tr. (Soler) at 9758-61, 9929. Thus, we find the Holtec simulations are not relevant to the reliability of the Khan Parametric Study.

330. In its comparison of stiffness and damping values, Holtec created an 8 cask

animation on a pad with a 40 million pound per inch contact stiffness, 40 percent damping, lower bound soil springs, for a 2,000-year earthquake. Tr. (Soler) at 9673, Applicant's Exh. 225. Another animation of 8 casks on a pad used a 5 million pound per inch contact stiffness, 40 percent critical damping, lower bound soil springs, for a 2,000-year earthquake. Id. As a result of these three animations, Dr. Soler concludes that by "varying damping or stiffness or both" the difference in results are in the order of inches not feet. Tr. (Soler) at 9676.

331. In State's Exh. 195, Dr. Khan plotted the free field response spectrum in the vertical and two horizontal directions for 1, 3, 5, and 40 percent damping for the 2,000-year return period earthquake at PFS. Tr. (Khan) at 9495, 9498, 9502. In each direction for an associated damping, Dr. Khan plotted the frequency from 0 to 34 hertz against the acceleration to generate response spectrums using the same single standard degree-of-freedom model. Id. at 9495, 9499.

332. The points generated by Dr. Khan along the response spectra curve for 5% damping showed essentially identical correlation when compared to the 5 percent damping response spectra curve prepared by Geomatrix on behalf of PFS. Id. at 9543-47; *see e.g.* State Exh. 196. In the absence of contradicting evidence and the correlation between Dr. Khan's and the Geomatrix response spectra for 5 percent damping, we find Dr. Khan's response specta for 1, 3, 5, and 40 percent damping (State's Exh. 195) reliable.

333. The 40 percent damping response spectra curves are relatively flat and all acceleration is below 1 g between 0 and 33 hertz. Dr. Khan opined that if the acceleration stays below 1g, then the cask will behave in a rigid manner without dynamic amplification.

Tr. (Khan) at 9499-9500; State Exh. 195. Recognizing Dr. Khan's curves are free field response curves and do not account for increased accelerations due to soil structure interaction, the Licensing Board finds that at 40 percent damping the cask would not uplift and behave as if anchored to the pad.

334. Dr. Soler also testified the damping value changes because critical damping is a function of stiffness. Tr. (Soler) at 9674. The Licensing Board notes that Holtec did not proffer an animation where it simultaneously lowered both damping and stiffness; hence, Dr. Soler's conclusion with respect to "both" has no basis. Additionally, in challenging Dr. Khan's results, Holtec did not run a simulation at a contact stiffness of 1×10^6 pounds per inch. Thus, the Licensing Board finds that the effects on the cask behavior as a result of the stiffness value used are also a function of the damping value used. Consequently, considering that associated damping is a function of stiffness and the cask behavior during a seismic event is nonlinear, we find that the additional Holtec animations varying either damping or contact stiffness are insufficient to show that the cask behavior is not sensitive at both lower damping and lower contact stiffness, than used in Holtec simulations (*e.g.*, 40 percent damping and 18.8×10^6 pounds per inch contact stiffness).

335. Furthermore, since the actual value for the coefficient of friction is unknown, Holtec attempted to bound its analysis by evaluating the two values of the coefficient of friction. *See* State Exh. 173. The Licensing Board notes that Dr. Khan's design philosophy is similar in that it conservatively evaluates a range in the absence of test data.

336. At this point, we reflect back to our concern early on, which was confirmed by Dr. Cornell, that we should not become "too enamored" with the computer models and

make sure the models are anchored in reality. Tr. (Cornell) at 8024. In addition, Dr. Ostadan cautioned us that the safety during a seismic event rests solely in the accuracy of Holtec's nonlinear predictions of cask response because of the lack of past experience with PFS's unique and unconservative design, the lack of redundancy in PFS's design, and the lack of test data to validate the nonlinear seismic analyses of the freestanding cask. Tr. (Ostadan) at 7312, 7335-36, 7340-41. We also feel that it is appropriate to balance Dr. Singh's and Dr. Soler's exuberant confidence in their own analyses with substantial financial interest in our acceptance of their analyses and their limited experience in performing nonlinear seismic analyses for free standing casks at ground motion equal to or greater 0.7 g, such as in this case.

337. The Licensing Board finds the evidence is severely wanting with respect to the key dispute between the parties – whether a static contact stiffness is appropriate in a nonlinear dynamic seismic analysis of free standing casks. Consequently, the Licensing Board finds that in the absence of test data, it accepts Dr. Khan's design philosophy that to account for potential rocking, uplift, and sliding of the cask, the contact stiffness values must correspond to the amplified region of the response spectra.

<u>Holtec Used High Damping Values that Underestimate Cask Movement</u>

338. In the Holtec 2,000-year report, Holtec incorporated an impact damping of 5 percent. Tr. (Soler) at 6095-96. However, for the 10,000-year simulations, Holtec used a 40 percent of critical damping value to represent the loss of energy at the pad and cask interface. Tr. (Soler) at 6065, 6097.

339. Dr. Singh testified that Holtec changed the damping from the 5 percent used

in the 2,000-year earthquake DYNAMO runs to 40 percent with the VisualNastran runs because of the increase in ground motion. Tr. (Singh) at 9671. According to Dr. Singh, the impact damping increases with the increase in ground motion. Id. at 9670. The Licensing Board finds no evidence beyond Dr. Singh's single statement to support a finding that the impact damping increases with increase in ground motion.

340. Dr. Khan raised his concern that the dynamic response may be underestimated in a nonlinear horizontal sliding analysis where the assumption is that all the energy is dissipated if energy is also absorbed by using a high damping value. Tr. (Khan) at 9393-99. Dr. Ostadan concurred that the damping has been overestimated which resulted in reducing seismic loads in the dynamic analyses. Tr. (Ostadan) at 10389.

341. Dr. Singh claims that impact damping would be higher than 40 percent because Holtec calculated greater than 50 percent impact damping for a metal cask on a "thick, very thick concrete foundation" from a simple simulation where a cask was dropped and the amount of rebound was measured. Tr. (Singh) at 6098. The Applicant did not proffer supporting calculations for the impact damping of the metal cask nor did the Applicant explain the details of its assumptions or its relevance to the impact damping for the HI-STORM 100. Notwithstanding Dr. Singh's testimony, later during the hearing, Dr. Soler, agreed that the impact damping of a cask "might not be 40 percent, but it is extremely unlikely that [it] would be as low as 1 percent." Tr. (Soler) at 9912.

342. Additionally, Dr. Singh later referred to NRC sponsored impact experiments where steel "billets" were dropped on a concrete pad in which he claimed "our version of the program" was correlated with the test data. Tr. (Singh) at 9660-61. Holtec used the LS-

Dyna code for its tip over and drop analyses. Tr. (Soler) at 9761. However, Dr. Singh was unaware of the actual impact damping results in the LS-Dyna tip over and drop analysis. Id. at 9761-62. Again, neither the Applicant nor the Staff offers any supporting documentation concerning the impact tests, which Holtec program was correlated with NRC data, or how the NRC impact tests relate to damping of HI-STORM casks during a seismic event. As we have stated throughout this opinion, our findings must be supported by sufficient facts in the record. Accordingly, this Licensing Board finds insufficient evidence in the record to rely on the "metal cask" test data showing greater than 50 percent damping or the NRC "billet" impact experiment.

343. Dr. Soler proffered an animation of three spheres dropped from a height of 18 inches where each sphere had either 1, 5, or 40 percent damping. Tr. (Soler) at 9662 , Applicant's Exh. 225 (Holtec Additional Analyses). The 40 percent damping sphere came to rest after two bounces, the 5 percent damping sphere stopped after approximately 14 bounces, and the 1 percent damping sphere stopped after more than 73 bounces. Id. at 9665.

344. In another animation, Dr. Soler replaced the sphere image with a cylinder representing a cask where he dropped the cylinders from a height of 18 inches and each cylinder had either 1, 5, or 40 percent damping. Id. at 9665-66. In this case the cylinders with 40 percent damping and the 1 percent damping bounced three times and more than 73 times, respectively, before stopping. Id. at 9666-67.

345. In a reactionary flurry during the hearing, Holtec generated a number of additional animations, including an 8 cask animation with a 40 million pound per inch

contact stiffness, 5 percent damping, lower bound soil springs, for a 2,000-year earthquake. Tr. (Soler) at 9673, Applicant's Exh. 225. Another 8 cask animation used a 40 million pound per inch contact stiffness, 5 percent critical damping, lower bound soil springs, for a 2,000-year earthquake. Id.

346. The response spectra curves, generated by Dr. Khan in State's Exh. 195, demonstrate that the acceleration is sensitive to the frequency of the system. State Exh. 195, Tr. (Khan) at 9496, 9501. For the reasons cited earlier, we again find Dr. Khan's response spectra for 1, 3, 5, and 40 percent damping (State's Exh. 195) reliable. For the 1 percent damping curve, and to a lesser extent the 3 and 5 percent damping curves, the response spectra curves show acceleration varies with respect to frequency. State's Exh. 195. Additionally, the response spectra curve for 40 percent damping shows relatively no amplification which means the analysis treats the cask as a rigid or anchored system. Tr. (Khan) at 9496.

347. The 40 percent damping response spectra curves are relatively flat and the acceleration is below 1 g from 0 to 33 hertz. Recognizing Dr. Khan's curves are free field response curves and do not account for increased accelerations due to soil structure interaction, the Licensing Board finds that at 40 percent damping the cask would not uplift and behave as if anchored to the pad.

348. At 1, 3, and 5 percent damping, the response spectra curves show higher acceleration in excess of 1g at various frequencies which will result in cask uplift. Id. at 9496-97, State Exh. 195. The response spectra curves at various damping also show that if the contact stiffness is tuned to 33 hertz, there is relatively no increase in acceleration on any

curve. Tr. (Khan) at 9502, State Exh. 195.

349. Holtec testified that at a static contact stiffness of 454 million pounds per inch and assuming the cask were connected to the pad, the natural frequency of the cask is 111 hertz and thus, outside of the frequency of an earthquake. Tr. (Singh, Soler) at 9635-36. A contact stiffness of 454 million pounds per inch treats the cask as if it were connected to the pad. Id. The calculated natural frequency assuming the cask is connected to the pad is known as the "rigid range." Tr. (Singh) at 9636. Dr. Singh further professed that to reduce the stiffness to correspond with the amplified region of the response spectra, such as at 5 hertz and 1 percent damping, will give results that "bear no semblance to [ ] reality." Id. at 9637.

350. Dr. Soler also testified that the damping value changes because critical damping is a function of stiffness. Tr. (Soler) at 9674. The Licensing Board notes that Holtec did not proffer an animation where it simultaneously lowered both damping and stiffness; hence, Dr. Soler's conclusion with respect to "both" has no basis. In association with our earlier finding, the Licensing Board also finds that the effects on cask behavior as a result of the damping value used are also a function of the stiffness value used. Thus, we re-emphasize our earlier finding that considering that the associated damping is a function of stiffness and the cask behavior during a seismic event is nonlinear, we find that the additional Holtec animations varying either damping or contact stiffness are insufficient to show the cask behavior is not sensitive at both lower damping and lower contact stiffness, than used in Holtec simulations (*e.g.*, 40 percent damping and 18.8 x 10^6 pounds per inch contact stiffness).

351. With respect to the Holtec dropping sphere animation, Dr. Khan disagreed that a dropped sphere would be similar to the impact damping between the cask and a pad because the earthquake motion is moving the cask up and down. Tr. (Khan) at 9400-01. Dr. Soler admitted that he expected a cask would not simply bounce vertically up and down but uplift and rock from side to side, depending upon the earthquake. Tr. (Soler) at 9932. Dr. Soler also agreed that during an earthquake, the frequency and peak intensity would change with time. Id. Given that both Drs. Khan and Soler agree that the seismic behavior of a cask would not simply bounce in a pure vertical direction, but potentially also rock from side to side, we find that the bouncing sphere animation and bouncing cask animation are inconclusive to define the damping experienced by a HI-STORM cask during a seismic event.

352. Additionally, Dr. Soler implies that the ball representing 1 % damping that bounces more than 73 times is unrealistic. While the Licensing Board agrees that a 360,000 lb HI-STORM 100 cask would not likely bounce 73 times if dropped from a height of 18 inches, we must have sufficient evidence to support a finding; hence, we find no evidence was presented that the bouncing ball or bouncing cask animations would, in fact, simulate cask impact during seismic ground motions. Significantly, no evidence was proffered that the ball or cask representing 40% impact damping would better simulate the cask impact damping under seismic ground motion. The Licensing Board finds that the bouncing ball or bouncing cask animations are inconclusive as to which damping ratio best represents the HI-STORM cask impact damping when subject to seismic ground motion.

353. Thus, the Licensing Board finds insufficient evidence that impact damping

between the HI-STORM 100 cask and the concrete storage pad of 5 percent for a 2,000-year earthquake or 40 percent for a 10,000-year earthquake is reasonable.

Acceptable Angle of Rotation.

354. Without consideration of the effects from soil structure interaction, Holtec predicted a maximum angle of rotation for a single cask of approximately 10 degrees for a coefficient of friction of 0.8 and a 10,000-year earthquake. Tr. (Soler) at 6031. The HI-STORM 100 cask will "theoretically" tip over if the cask tipped at an angle of approximately 29 degrees from vertical. Tr. (Soler) at 6033-34. However, Dr. Singh agreed that the cask could tip over if there is residual momentum when the cask reaches approximately 29 degrees (point where the center of gravity is over the corner of the cask). Tr. (Singh) at 6110.

355. In a paper presentation, Drs. Soler and Singh state that "[a]fter a certain threshold value, the response (viz. maximum tilting of the cask axis) increases rapidly with increase in the [zero period acceleration] level."[52] State's Exh. 174, *Seismic Response Characteristics of HI-STAR 100 Cask System on Storage Pads* (January 1998) at 15-16. During cross examination in this case, Dr. Soler disagreed with the quote from his publication in that he did not agree that after a certain point, the maximum tilting would "rapidly" increase as the zero period acceleration increased. Tr. (Soler) at 6032. Additionally in the HI-STAR publication, Drs. Soler and Singh recommend that the maximum rotation of the cask be set to 25 percent of the ultimate cask tip over value. Id. However, in this case, the Applicant

[52]The paper was authored jointly by Dr. Soler, Dr. Singh, and Martin G. Smith.

did not offer evidence concerning the "ultimate" cask tip over value. The Licensing Board notes that 25 percent of the "theoretical" tip over value of 29 degrees is 7.25 degrees. We note that Dr. Singh testified that the HI-STAR cask is more likely to tip over than the HI-STORM cask because of the HI-STAR's lower height to diameter ratio.

356. For the HI-STORM 100 cask, to ensure an adequate safety factor to prevent cask tip over, Dr. Soler opined that the maximum excursion of the top of the cask should not exceed half the radius (33.16 inches). Id. at 6034-35. When considering the maximum excursion of the top of the cask of 33.16 inches with a cask height of 231.25 inches, the Licensing Board finds that to ensure an adequate margin of safety a maximum allowable rotation angle is 8.15 degrees from vertical.

357. In two reports, Holtec estimated maximum cask rotation angles of approximately 10 degrees for a 10,000-year earthquake and a coefficient of friction of 0.8 which exceeds the maximum rotation angle of 8.15 degrees suggested by Dr. Soler. Tr. (Soler) at 6031, Applicant's Exh. 86d at 13. In Applicant's Exh. 86d, the rotation angle from vertical was calculated based on "50 percent of peak-to-peak excursion instead of the maximum excursion of the top of the cask from the location at the start of the run. Applicant' Exh. 86d. We note that 50 percent of the maximum peak-to-peak excursion is lower than the maximum excursion recorded at the top of the cask. Thus, the Licensing Board finds that the rotation angle calculated in Applicant's Exh. 86d may not reflect the maximum angle of rotation that occurred during the simulations.

358. Additionally, Dr. Soler admitted, based solely on the animation, that in some runs, casks (*e.g.*, cask 5) other than cask 1, in which he only quantified cask 1's movement,

appear to move more than the cask 1. Tr. (Soler) at 5762. In an additional 8 cask simulation for a 2,000-year earthquake, Dr. Soler actually quantified the movement for cask 1 and cask 5 where he showed the maximum excursion of the top of the cask for cask 1 was 3.4 inches and for cask 5 was 10.5 inches. Applicant's Exh. 225 at 18.

359. Dr. Singh claims that the "actual" maximum angle of rotation for the cask would be "much less" due to the "huge conservatisms" built into Holtec's model. Tr. (Singh) at 6035. We find, notwithstanding any actual conservatisms, the record is devoid of any evidence quantifying the "huge conservatisms" claimed by Dr. Singh, consequently, we find any claimed conservatism in the Holtec nonlinear analyses unreliable.

360. Based on the Applicant's existing analyses, the Licensing Board finds that the Applicant has not demonstrated that the HI-STORM 100 cask will not exceed the tip over angle of rotation with a margin of safety of 8.15 degrees from vertical.

Non-linear Analysis Should Be Validated With Shake Table Data.

361. Dr. Khan opines that the only way to validate Holtec's seismic analysis is to benchmark the cask displacement with actual shake table test data. Khan/Ostadan Tstmy, Post Tr. 7123 at A.34. Consistent with his opinion with respect to the Holtec results that the analyses must be validated with test data, Dr. Khan testified that he could also not claim his parametric study results were correct without first validating his results with test data and calibrating his damping, stiffness, and rocking values. Tr. (Khan) at 7178-79. Moreover, Dr. Khan opined that the nonlinear cask seismic analyses should be validated with test data regardless of the analyst's confidence in his solution. Id. at 9425.

362. As an example of the NRC philosophy supporting the need to validate

nonlinear seismic analysis with test data, Dr. Khan referred to NRC Reg. Guide 1.100, which endorses IEEE 344-1987 requirement.[53] Khan/Ostadan Tstmy, Post Tr. 7123 at 13-14. IEEE, section 6 states that "[t]he analysis method is not recommended for complex equipment that cannot be modeled to adequately predict its response. Analysis without testing may be acceptable only if structural integrity alone can ensure the design-intended function." Id. IEEE provides "good guidelines" for nonlinear seismic analysis which have been applied in the qualification of structures. Tr. (Khan) at 9431-32. IEEE requires test data validation for Class 1E electrical equipment defined as "electrical equipment and system that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or are otherwise essential in preventing a significant release of radioactivity to the environment." Id. at 9428-29, Applicant's Exh. 222.

363. Dr. Khan testified that IEEE's provision that "analysis without testing may be acceptable only if structural integrity alone can ensure the design intended function" is not applicable to cask analysis because a designer cannot rely on its judgment that its design is adequate. Tr. (Khan) at 9137-42. In this case, shake table data would validate the cask dynamic response or whether the cask tips over under various ground motions.

364. To rebut Dr. Khan's suggestion that IEEE provides reasonable guidance in this case, Dr. Singh testified that the intended class of components (Class 1E) is not very large and can be placed on a shake table and that "some" electrical and mechanical equipment have small tolerances which alter their functionality. Tr. (Singh) at 9680-81. The

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[53]Institute of Electrical and Electronic Engineers, Inc., *Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations.*

Licensing Board finds in light of Dr. Luk's testimony concerning the availability of a large shake table facility which could accommodate a full scale cask (Tr. (Luk) at 15569-72), Dr. Singh's opinion with respect to the size of components no longer has merit. The Licensing Board further finds that absent verification test data, the nonlinear seismic analysis of the cask system and any implied tolerances of the cask system are uncertain.

365. Holtec also points to its cask tip over analyses to demonstrate that the canister will not be breached. Singh/Soler Tstmy, Post Tr. 5750 at 29. The Applicant did not offer the Holtec cask tip over analyses into the record. Additionally, Holtec assumed an initial angular velocity of zero in its non-mechanistic tip over analysis. Tr. (Bartlett) at 12870-71. Accordingly, if the cask tips over due to seismic excitation, Dr. Steve Bartlett opines, then the angular velocity could be greater than zero and thus, invalidate Holtec's cask tip over analyses and conclusions that the canister would not breach. Id. at 12913-17. Concurring with Dr. Bartlett, in response to a question if in fact, the cask tips over as a result of a seismic event what would be the initial angular velocity, Dr. Cornell stated, if "that's an interesting question physically, actually. The initial velocity would probably clearly have to be something greater than zero or it would not be moving in that direction, that is tipping over." Tr. (Cornell) at 7978. The Licensing Board finds whether the canister is breached as a result of cask tip over is dependent upon whether the cask in fact tips over during a seismic event. Hence, the Licensing Board finds it is circular reasoning to justify not validating the nonlinear cask analyses based on the structural integrity of the cask system which is itself grounded in the assumption that the nonlinear cask stability analysis shows no tip over. Thus, the Licensing Board further finds Holtec's drop tip over analyses cannot be

used to ensure the structural integrity of the cask absent testing.

366. The Licensing Board finds the philosophy encompassed in Reg. Guide 1.100 and IEEE persuasive in that it imposes test validation of nonlinear analyses for "equipment essential in preventing a significant release of radioactivity to the environment." The Licensing Board finds that the HI-STORM cask system is essential in preventing a significant release of radioactivity to the environment. The Licensing Board further finds that to prevent a significant release of radioactivity to the environment the Applicant must demonstrate that the HI-STORM 100 cask will not tip over.

367. Because of uncertainties in the analysis, Dr. Luk confirmed he and the individuals in "his group" view shake table testing as "useful" in confirming his analysis. Tr. (Luk) at 11569, 11572. In fact, during the June 2002 hearings, Dr. Luk updated his previous testimony that he expected a "true state-of-the-art" shake table test facility that could accommodate a full scale cask would be available at the University of California at San Diego next spring due to a recent grant from the National Science Foundation. Id. at 15569-72. Additionally, the Staff plans to request funding for shake table tests. Id. at 11570. Dr. Luk testified that he could "almost assure [that] the cask will not be damage or destroyed on the shake table." Tr. (Luk) at 7111. Through its funding, the National Science Foundation endorse large scale shake table testing for some purposes. Although there is no direct testimony in the record, the Staff itself must find a benefit to cask shake table tests given its intent to seek funding. Notably, if Dr. Luk misrepresented the Staff's intention, the Staff did not proffer any witnesses to correct Dr. Luk's testimony.

368. Dr. Cornell opined that a scaled down shake table test may introduce

uncertainties. Tr. (Cornell) at 8025. Furthermore, Dr. Cornell disagreed that shake table testing was necessary to verify input parameters - "we do lots of nonlinear analyses in advanced earthquake engineering. We have done some shake table testing, and the shake table testing is used to verify the general nature of those models. But it's not used for each and every application." Tr. (Cornell) at 7975.

369. Notwithstanding Dr. Cornell testimony, he agreed that physical test data would reduce the amount of uncertainty in a seismic assessment. Tr. (Cornell) at 7979.

370. In sharp contrast to other expert opinions expressed in this case concerning the need or desire for shake table tests, Dr. Singh emphatically stated "is [shake table tests] necessary . . . absolutely no." Tr. (Singh) at 9682. He further disagreed that shake table tests have any value in verifying cask seismic analyses and that "it is absolutely impossible to run a shake table test [to simulate the seismic response of a cask] and get a [sic] meaningful data." Id. at 9682, 9684. Furthermore, contradicting other witnesses, Dr. Singh assured the Licensing Board that shake table tests would "confer no new knowledge" or information because shake table testing is "simply not feasible" based on the size of the cask and that the coefficient of friction varies with time. Id. at 9682-84, 9728. Dr. Singh opined that a shake table test would not provide any information because "the condition of a pad on a simulated cask with a scale model or even full size" cannot be replicated on a shake table. Id. at 9728-29. Contrary to other witnesses, Dr. Singh offered that "any engineer trained in basic mechanics would not need the shake table to come up – to get any new information" and shake table tests would serve no useful purpose "whatsoever" in this case. Id. at 9729, 9731-32. Dr. Singh submits that "I know to absolute technical certainty, as long as the laws of

nature don't change on us, this cask will not tip over under the earthquakes postulated for the PFS site. There's absolutely no doubt." Tr. (Singh) at 9750.

371. However, Dr. Singh did acknowledge that shake table tests are necessary "when you have some ambiguities and some concerns, some possible uncertainty with respect to performance," albeit he believes there is no uncertainty with Holtec's analysis. Id. at 9731. Moreover, although both Dr. Singh and Dr. Soler initially denied ever discussing performing shake table tests with PFS (Tr. at 9732), in November 1997, Dr. Singh sought funding from PFS to verify their analytical work by conducting scale model tests on a shake table (id. at 9738-39.). *See* State Exh. 197. Dr. Singh testified that because the Staff relied upon a "simpleminded static limit," NRC requested that Holtec conduct scale model shake table tests to support the HI-STORM 100 application for a certificate of compliance at high earthquake levels. Id. at 9739. Notwithstanding the November 1997 Holtec letter (State Exh. 193) which stated "NRC endorsed the Holtec proposal to experimentally confirm the seismic analysis approach," Dr. Singh denied ever recommending shake table tests to PFS, claiming instead the letter was "politically correct" and a result of "the guy who has the gold makes the rule," implying that NRC, not Holtec, desired the shake table tests. Id. at 9745-48 (*emphasis* added).

372. Although, Dr. Singh does not define "high earthquake levels," it appears Holtec sought funding from PFS and Pacific Gas and Electric. Id. at 9742. Dr. Soler testified that ground motions at the PG&E, Diablo Canyon facility are 0.9 g. Tr. (Soler) at 5932. The peak horizontal ground accelerations at the PFS site are estimated as 1.15 for deterministic, and 0.711 g for a 2,000-year event. Con-SER at 2-34.

373. Moreover, the March 1998 Holtec letter to PFS states "if PFS elects not to support [shake table testing], then we can provide all high seismic material stripped from Rev. 1 of the HI-STORM [topical safety evaluation report] for direct incorporation in the Skull Valley site-specific submittal, and we will proceed with only anchored cask certification on this new docket." Tr. (Singh) at 9744; State Exh. 197 (*emphasis added*).

374. In almost stark contrast to their views with respect to shake table tests or "experimental tests," Drs. Singh and Soler testified that "[t]o properly validate a friction model for a free standing structure, it is necessary to check the model you propose against a known analytical solution or against experimental results" to demonstrate the code can produce well known problems. Singh/Soler Tstmy, Post Tr. 5750 at A.132.

375. When weighing the panoply of testimony concerning the advantages, disadvantage, and need for shake table testing, the Licensing Board finds that the testimony in favor of shake table testing is more compelling. Moreover, the Licensing Board finds the testimony proffered by Dr. Singh, and to a lesser extent Dr. Soler, inconsistent and unreliable. Further, given Drs. Singh and Soler's financial interest in the outcome of this case, we note that any finding that results in the need to conduct shake table testing negatively impact Holtec's financial interest. Accordingly, we further find the testimony of Drs. Singh and Soler unreliable with respect to shake table tests.

376. No expert disagreed that the results of nonlinear analyses could only be validated with test data. The experts disagreed to various degrees of the actual need for shake table data. Accordingly, the Licensing Board finds that breadth of the testimony agrees that the nonlinear analyses can only be validated with actual test data. Moreover,

given that Dr. Luk anticipates a shake table test facility able to conduct full scale tests will be available in the spring, Dr. Luk's assurances that a cask would not be damaged by shake table tests, and the lack of evidence which convinces this Licensing Board of the accuracy and reliability of the Holtec 2,000-year report, we cannot find that the Applicant has met its burden to demonstrate that free standing HI-STORM 100 casks will not tip over under at 2,000-year earthquake at the PFS facility.

The NRC Sponsored Luk Report Does Not Verify the Holtec Seismic Analyses.

377. Commencing in March 1999, the NRC commissioned a generic study to evaluate dry spent fuel cask storage. Tr. (Luk) at 6763. The purpose of the generic study was to see how casks perform under seismic conditions and to provide guidance concerning freestanding casks.[54], [55] Tr. (Guttmann) at 6835-36. At first the generic study did not include any site specific inputs but later included conditions at Hatch and San Onofre. Tr. at 6763-67, 11614. The Southern Company Hatch plant uses free standing Holtec casks but unlike the PFS site, the Hatch site has very low ground motions – 0.15 g (vertical) and 0.1 g (horizontal). Tr. (Luk) at 6914-15. The San Onofre ISFSI does not use free standing Holtec casks; it uses horizontal modules tied together into one unit. Tr. (Luk) at 6915.

[54]Although Mr. Guttmann maintained that the Standard Review Plans are still applicable to the entire country, Dr. Luk testified that the generic study was initiated because "[t]he current Standard Review Plan is [ ] adequate to go through the licensing efforts in regions with low seismic loading" but with relatively higher seismic loading in the west, "there is a concern to whether the current Standard Review Plan is adequate to support the . . . licensing review process." Tr. (Luk, Guttmann) at 6838-39.

[55]Sandia National Laboratories was contracted to "establish criteria and review guidelines for the seismic behavior of dry cask storage systems." Staff Exh. P at 3.

378. The Luk confirmatory analysis specific to the PFS site grew out of the generic cask study and results from the confirmatory PFS site specific analysis will eventually be included in the generic study.[56] Tr. (Luk) 7023-24. For the period March 1999 to November 2002, NRC has financed the generic and PFS site specific studies to the tune of one million dollars – $200,000 of which relates specifically to the PFS site-specific confirmatory analysis. Tr. (Luk) at 6854-56; *see also* Tr. (Turk) at 6884.

379. Under contract with the Staff, Vincent Luk developed a three dimensional coupled finite element model to evaluate the seismic stability of the HI-STORM 100 casks at the PFS site. Luk/Guttmann Tstmy, Post Tr. 6760 at A3(b), A.6. Mr. Guttmann testified that he requested a cask stability analysis for the PFS site to "assist the State in understanding the complexities of the [cask stability] analyses." Tr. (Guttmann) at 6843, *see also* 6846-47, 6849. Mr. Guttmann did not affirm that the Luk analysis would also assist the Staff because the Staff "expected" the Luk analysis to be confirmatory. Tr. (Guttmann) at 6847.

380. Dr. Luk summarized his evaluation in *Seismic Analysis Report on HI-STORM 100 Casks at Private Fuel Storage (PFS) Facility*, Rev. 1 (March 31, 2002) ("Luk report").[57]

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[56]The State objected to the admission of the Luk report based on the late notice and its availability. Although, the we denied the State's motion to strike the Luk report (Tr. at 6901-03), the Licensing Board notes it is disturbed by the Staff's untimeliness in providing the results to the parties in light of Mr. Guttmann's testimony that he initiated the analysis to "assist the State in understanding the complexities of the analysis" (Tr. at 6843, 6846-47, 6874) and that the 2,000-year DBE status report, including results, was completed at the end of October 2001 (Tr. at 6861, 6877-79).

[57]The other parties in the proceeding received the Luk report on April 2, 2002, the day after the deadline for filing prefiled testimony.

Luk/Guttmann Tstmy, Post Tr. 6760 at A.3(b). Using the ABAQUS/Explicit code, a single elastic cask was modeled on a flexible concrete pad with soil cement[58] adjacent and beneath the pad, and a soil layer beneath the soil cement. Staff Exh. P at 5-6; Luk/Guttmann Tstmy, Post Tr. 6760 at A.7. ABAQUS is a general purpose nonlinear finite element code. Tr. (Luk) at 6768. Contact elements were modeled at three interfaces - 1) the cask/pad interface, 2) the pad/soil cement interface, and 3) the soil cement/soil interface. Staff Exh. P at 5-6. The model considered six horizontal layers in the soil foundation to a depth of 140 feet from the surface. Luk/Guttmann Tstmy, Post Tr. 6760 at A.12. Dr. Luk used contact elements to model the interface between the cask and the pad. Tr. (Luk) at 6809. Dr. Luk evaluated a 2,000-year and a 10,000-year earthquake for the PFS site.[59] Id. at 6760; Luk/Guttmann Tstmy, Post Tr. 6760 at A.6.

381. Dr. Luk varied three input parameters (the seismic ground motion, the coefficient of friction in the interfaces, and soil parameters) in running 13 simulations of a single cask on a pad with the surrounding soil cement and soil foundation. Staff Exh. P at 30-32. An additional simulation ("Model Type 2") simply modeled a single cask on a pad with no soil foundation for a 2,000-year earthquake. Id. at 30. At the direction of the Staff, Dr. Luk also ran one simulation of Model Type 3, a single cask with the "dead" loads of

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[58]Note the term "soil cement" beneath the storage pad in the testimony of Vincent Luk and his ***Seismic Analysis Report on HI-STORM 100 Casks at Private Fuel Storage (PFS) Facility***, Rev. 1 has typically been referred to as "cement-treated soil" in other portions of the hearing. *See e.g.,* Tr. at 6921-23. Soil cement adjacent to the storage pad was also modeled. Id.

[59]The ground motion associated with the 1971 San Fernando Earthquake (Pacoima Dam) was also evaluated. Luk Tstmy, Post Tr. 6760 at A.6.

seven adjacent casks on the pad and 4 adjacent pads each with a "deal" load of 8 casks for a 2,000-year earthquake. Id.; Tr. (Luk) at 7004, 7025.

382. The Staff supplied Dr. Luk with the input values to be used in the PFS analysis (*e.g.*, single set of time histories for a 2,000-year and 10,000-year earthquake, cask and pad design, material properties of the cask and pad, "upper bound," "lower bound," and "best estimate" soil profiles, and the coefficient of frictions values). Luk/Guttmann Tstmy, Post Tr. 6760 at A.6; Tr. (Luk) at 6771, 6824, 6919-23. Dr. Luk did not independently verify any of the input values. Tr. (Luk) at 6923-24. The Luk model accounted for the mass proportional Rayleigh damping, but not the stiffness proportional damping. Staff Exh. P at 9; Tr. (Luk) at 6793-94. The stiffness proportional damping was ignored to reduce the computational time for each simulation. Tr. (Luk) at 6794. Although excluding the stiffness proportional damping would result in high frequency response effects, the high frequency response effects would not have much impact on the structural response of the cask. Id. at 6794-95.

Potential Conflict of Interest.

383. A review panel consisting of three NRC Staff and four industry representatives provided technical advice and input to the generic and site specific cask stability studies conducted by Dr. Luk and his associates. Tr. (Luk) at 6994-6996, 7052-54. The hearing testimony revealed that industry representatives include representatives from Southern Company, San Onofre Nuclear Generation Station, the Electric Power Research Institute, and a private consultant, Dr. Robert Kennedy. Id. at 6995. Southern Company and Southern California Edison, owner of San Onofre, are members of PFS. FEIS (Staff

Exh. E) at Fig. 1.3; Con-SER at 17-1. The role of the industry panel members was to provide recommendations concerning the analysis methodology and range of input parameters used by Dr. Luk. Tr. (Luk) at 7054. The advisory panel, including industry representatives, reviewed the generic Luk finite element model and provided their comments and recommendations. Id. at 7076. Dr. Luk met with the advisory panel on three occasions, including November 2001, to discuss the details of the PFS model. Id. at 7077-78. The panel provided comments on the completed 2,000-year analysis for PFS at the November 2001 advisory panel meeting. Id. at 7082-83. The advisory panel meetings were not open to the public. Id. 7083.

384. Although Dr. Luk testified that he had no knowledge that any of the industry representatives were associated with PFS (Tr. (Luk) at 6995-96), the Licensing Board presumes the Staff was aware that representative from PFS member companies were on the advisory panel. Tr. (Luk) at 7053-54; 7081-86. However, we note that "fundamental fairness" to the conduct of a licensing proceeding mandates the "disclosure of all potential conflicts of interest," whether or not a party believes them to be material and relevant to a licensing proceeding. Long Island Lighting Company (Shoreham Nuclear Power Station Unit 1), LBP-82-73, 16 NRC 974, 979 (1982). Disclosure is necessary to enable the Licensing Board to determine the materiality of the potential conflict of interest. Id. Due to the lack of disclosure of potential conflicts of interest of the industry representatives on Dr. Luk's advisory panel, compounded by the lateness of the availability of the Luk report to the State, the State has had little or no opportunity to probe the backgrounds of the advisory panel and its influence on the Luk methodology and analysis during discovery. Because of

the constraints placed on the State to probe the issue and potential inability to raise it themselves, notwithstanding Dr. Luk's testimony that the advisory panel had not inappropriately interfered with his PFS site work, the Licensing Board cannot find that at least two industry representatives on Dr. Luk's advisory panel have no conflict of interest with the outcome of the Dr. Luk's cask stability analysis for the PFS site. Thus, the Licensing Board finds that it must weigh the potential conflict of interest from PFS member companies in its assessment of the Luk report.

Experience in Modeling the Seismic Response of Free Standing Dry Storage Casks.

385. Dr. Luk's sole experience in modeling the free standing dry storage casks includes the site specific analysis for PFS, Hatch, and San Onofre. Tr. (Luk) at 6764, 6914-16, 7051. The site conditions for Hatch and San Onofre are not similar to those at the proposed PFS site. Although Dr. Luk modeled ground motions in excess of those estimated for Hatch, the Hatch ground motions are approximately 0.15 g horizontal and 0.1 g vertical. Tr. (Luk) at 6915-16. The Hatch site store 12 casks on a concrete pad in a 2 x 6 array, however, Dr. Luk modeled a square pad with a 2 x 2 array. Id. at 6993. The casks proposed for San Onofre are 3 unanchored, rectangular, horizontal casks tied together, unlike the individual cylindrical HI-STORM 100 casks. Tr. (Luk) at 6915, 7054-56. Dr. Luk acknowledged that the seismic response of the horizontal casks at San Onofre is "very different" when compared to the cylindrical cask proposed for PFS. Id. at 7056. The Licensing Board finds that the Hatch site conditions are different from those proposed for PFS. We further find that the San Onofre site conditions and the facility design are substantially different from those proposed for PFS. Therefore, Hatch and San Onofre do

not provide relevant modeling experience for the PFS design or site conditions.

386. Robert Dameron, Anatech Corporation, and Po Lam, Earth Mechanics, are co-authors of the Luk report. *See* Staff Exh. P. Mr. Dameron is an engineer with finite element experience. Tr. (Luk) at 6765-66. Mr. Lam, a trained seismologist (id. at 6765-66), developed the soil foundation model. Id. at 7037.

387. Dr. Luk testified that the most important "state-of-the-art" features in his model are, 1) the interface between the substructures and 2) the modeling of soil structure interaction. Tr. (Luk) at 6979.

388. Dr. Luk has no expertise in soil dynamics – an area that directly relates to two critical areas featured in his model. Tr. (Luk) at 6917; 7036. Without input from Mr. Lam, Dr. Luk developed the soil structure interaction model. Id. at 7037. Later in the hearing, Dr. Luk corrected his earlier testimony that he relied on co-authors of the Luk report for soil structure interaction expertise. Id. at 6917.

389. Initially Dr. Luk testified that he has no expertise in soil structure interaction but later recanted his testimony to claim he has such expertise. Id. Dr. Luk claims the evaluation of soil structure interaction effects is nothing more than the systematic evaluation to address the dynamic coupling between a structure and soil. Id. at 6917, 7036. We previously described the concept of soil structure interaction in Contention Part D, Dynamic Analysis.

390. Dr. Luk professes to be an expert in soil structure interaction based on his work over the "past few years" in evaluating coupling between components in a nuclear power plant. Id. at 7038. Dr. Luk's own soil structure interaction experience is limited to

"the past few years" which would encompass the analyses he performed for the Hatch and San Onofre ISFSIs. We find that the record bare in its support that Dr. Luk alone is qualified to model soil structure interaction effects.

391. The Licensing Board finds insufficient evidence to find that Dr. Luk's associates in his analyses are qualified to accurately model the soil dynamics or the soil structure interaction effects.

392. The Licensing Board also finds that Dr. Luk's experience in the nonlinear modeling of the seismic behavior of cylindrical, free standing casks is limited to his generic study and the Hatch analyses. We therefore find that Dr. Luk does not have experience in the nonlinear modeling of the seismic behavior of cylindrical free standing casks supported by cement-treated soil and a relative soft clay foundation at ground motions equal to or greater than the 2,000-year earthquake at PFS.

393. Mr. Guttmann admitted he has no experience in performing the seismic analysis of free standing casks. Tr. (Guttmann) at 6917. The Licensing Board finds Mr. Guttmann is not qualified as an expert in technical or scientific matters concerning the nonlinear modeling of the seismic behavior of free standing casks.

The Luk Report Does Not Confirm Holtec's Analyses.

394. The Holtec witnesses agreed that the Luk report did not confirm Holtec's methodology but similarly concluded that the cask would not tip over. Tr. (Singh, Soler) at 6122-23, Tr. (Soler) at 6077, 9755. Dr. Soler testified that the Staff's analyses "studies a different problem than [Holtec] simulated either with DYNAMO or VisualNastran." Tr. (Soler) at 5898. Dr. Soler further testified that the Staff analysis "models certain features of

the problem in a different manner than [Holtec]." Id. Dr. Soler did not know why there was a difference in the results between his analysis and the Staff analysis for a 10,000-year earthquake with a coefficient of friction 0.8. Id. at 5898-99. Although Dr. Soler claims the Luk report magnitude of excursions are in the same order with those determined by Holtec (Tr. (Soler) at 5998), Dr. Luk testified that the Holtec and Luk results cannot be compared. Tr. (Luk) at 6949-51.

395. Dr. Luk testified that his and Holtec's methodology are "entirely different" and some of the other important input parameters are "critically different." Tr. (Luk) at 6950. Dr. Luk opines that his and Holtec's results should not be directly compared due to the different methodologies employed and the different input parameters. Tr. (Luk) at 6950-51.

396. Additionally, Dr. Luk did not compare his soil structure interaction effects for a 2,000-year or 10,000-year earthquake with those predicted by PFS. Id. at 6940-41. Similarly, Dr. Luk did not compare his deconvoluted time histories for a 2,000-year or 10,000-year earthquake with those predicted by PFS at similar depths. Id. at 6941.

397. Like Holtec's analyses results, the Luk report results have not been benchmarked or compared with any physical data, such as shake table tests. Id. at 6958.

398. When probed about his confidence in the results from a "very complicated model" with large amounts of data, Dr. Luk further testified that the results are dependent on the input parameter. Tr. (Luk) at 6987. The Luk model has 4,124 elements - 864 elements model the cask, 384 elements model the storage pad, 848 elements model the soil cement adjacent and beneath the pad, and 2,000 elements model the soil foundation. Id. at

7027. Given the complexity of Dr. Luk's model, at this juncture we think it appropriate to heed Dr. Cornell's affirmation not to be too enamored with the computer program itself. Tr. (Cornell) at 8024. Furthermore, Dr. Luk acknowledges the value in validating nonlinear results with test data. Tr. (Luk) at 11571-72.

399. Due to the lack of test data to validate his results, Dr. Luk relies on sensitivity analyses and the experience he has gained in his NRC related study to substantiate his model. Id. at 6987-88. In an effort to show his model is accurate, Dr. Luk points to his seismic analysis at Hatch where the ground motion was increased to demonstrate that his model could show cask tip over. Id. at 6988. Although Dr. Luk relies on the Hatch analysis to support the accuracy of his PFS model, he also testified that the PFS model was modified to simulate the soil cement layer at the PFS site. Tr. (Luk) at 7026. Moreover, Dr. Luk admitted that the soil cement (cement-treated soil) layer, with interfaces both above and beneath the layer, "actually caused quite a bit of difficulties in the simulation portion." Id. at 7028.

400. As a result of the additional interface layer in the PFS model, the Licensing Board finds that no documentation has been proffered to show that simulations with the Hatch model provide assurance that the results obtained from the Luk-PFS model are reasonably accurate. Moreover, the record contains no evidence that the results generated from the Hatch model, in fact, accurately predict the seismic behavior of the cask, storage pad, and foundation. Notwithstanding the fact that no party presented documentation to support Dr. Luk's testimony that his model would show cask tip over, the Licensing Board finds that the Hatch model may in fact show cask tip over at higher ground motions, but

based on the apparent complexity of the model, the differences in the PFS and the Hatch model, and the lack of test data to validate any results, there is insufficient evidence to conclude the PFS model developed by Dr. Luk accurately or conservatively estimates cask response, including displacement, angle of rotation, and tip over.

401. Furthermore, Dr. Luk's cumulative experience in modeling and predicting the seismic behavior of free standing casks is limited to the three site specific cases analyzed under contract with NRC - PFS, Hatch, and San Onofre. Tr. (Luk) at 6764, 6914-16, 7051. Dr. Luk testified that he modified the generic model for PFS. Id. at 7026. The record is absent a showing that the experience gained from modeling horizontal, rectangular casks at San Onofre is transferable to modeling vertical free standing casks at PFS. *See* ¶ __ LUK LIMITED EXPERIENCE *supra.* Thus, the Licensing Board finds that Dr. Luk's limited experience in performing seismic cask stability is insufficient to find the Luk model accurately or conservatively estimates cask response, including displacement, angle of rotation, and tip over

402. In the Model Type 1 simulations, Dr. Luk opined that modeling a single cask on a pad is adequate because cask rotations will be larger if the cask's movement is in phase and independent of other casks. Tr. (Luk) at 6774. Dr. Luk verified his assumption with a single simulation (Model Type 3) where he modeled a single cask on a pad with the dead loads of 7 adjacent casks and 4 adjacent pads with the dead loads of 8 casks per pad. Id. at 6776. Dr. Luk did not model 8 casks on a pad because of additional computer time and memory needed for an 8 cask model. Id. at 6779-81, 6956-57. Dr. Luk assumed that all 8 casks on a pad actually behave independently of other casks on the pad. Id. at 6779-80.

However, Dr. Luk did not confirm his assumptions by running a model with 8 casks moving. Id. at 7066.

403. Dr. Luk testified that based on a generic study without casks, he concluded that the storage pads are dynamically independent of one another. Tr. (Luk) at 7030. The Staff offered no documentation to support Dr. Luk's testimony, but claim the sensitivity study consisting of a single simulation with Model Type 3 confirmed Dr. Luk's earlier conclusion that the storage pads are independent of other pads. Id. at 7031.

404. Based on a sensitivity analysis for a 2,000-year earthquake, Dr. Luk claims that the results are indifferent to the location of the single cask in his analysis. Tr. (Luk) at 6956. There was no similar sensitivity analysis for a 10,000-year earthquake. Id. Contrary to Dr. Luk's assumption, in a 10,000-year simulation, cask #5 moved significantly more than cask #1 – 10.5 inches versus 3.4 inches, respectively. *See* Applicant Exh. 225 at 29. The Licensing Board finds that the cask stability results may be dependent upon the specific location of the cask on the pad.

Luk Report Shows Significant Soil Structure Interaction Effects.

405. Dr. Luk concluded a "presence of significant [soil structure interaction] effects, as shown in Figures 17 through 19" in the Luk report. Luk Tstmy, Post Tr. 6760 at A.20; 6930. Dr. Luk testified that soil structure interaction is a "key feature" in his model. Id. at 6770. Figure 17 is raw data analysis results which compare the ground motion acceleration for a single node on a storage pad with the free field[60] ground motion

[60]Dr. Luk testified that free field acceleration is not influenced by the presence of the concrete pad or the edge of the soil foundation. Tr. (Luk) at 7012.

acceleration. Tr. (Luk) at 6803-04. Figure 17 shows increased accelerations due to soil structure interaction compared to the free field ground motion. Id. at 6935-36. Dr. Luk concluded that the presence of a structure increases the ground motion acceleration compared to the free field acceleration. Id. at 7012.

Modeling PFS Foundation Soils

406. The Staff directed Dr. Luk to use a coefficient of friction of 0.31 at the pad and soil cement beneath the pad (cement-treated soil). Tr. (Luk) at 6924-25.

407. Dr. Luk initially contemplated how to incorporate the plastic behavior of soil into his model but, in part, because of the two to three fold increase in computer time this would entail, he instead used an elastic body to simulate foundation soils. Tr. (Luk) at 11548.

408. As part of the PFS site-specific confirmatory analysis, Dr. Luk also had an eye on developing a practical analytical model that could be used by the nuclear industry:

> [P]eople, of course, can argue within the technical arena there's no such behavior as elastic, but we are very much concerned with eventually it is one of our tasks to develop [an] applicable [sic, appletical] analysis model that can be used by people in the industry. By modeling the plastic behavior in the model, we are going to talk about — we're going to change the order of magnitude of the size of the model, maybe by a factor of at least two to three.

Tr. (Luk) at 11549.

409. In the PFS site-specific confirmatory analysis, Dr. Luk treats the interface layers under the storage pad as granular material and models the interface nodes as a frictional material, such as a sand. Tr (Bartlett) at 10530; Luk Report at Table 8. As understood in the geotechnical engineering profession, frictional materials are those without

any cohesion — generally sands and gravel that do not have a large component of clay or maybe silts in them. Tr. (Bartlett) at 11402.

410. In Table 8, column 2, of the Luk Report, $\mu 1$ is the interface coefficient of friction between the casks and the storage pad; $\mu 2$ represents the coefficient of friction at two different interfaces: between the bottom of the pad and the top of the cement-treated soil; and between the bottom of the cement-treated soil and the top of the upper Bonneville clays. Tr. (Bartlett) at 10348.

411. To model the interfaces, including interfaces above and below the cement-treated soil ($\mu 2$), Dr. Luk used what he referred to as Coulomb's law of friction, $F = \mu n$, where F is the frictional resistance, μ is the coefficient of friction, and n is the normal stress. Tr. (Luk) at 11510; Tr. (Bartlett) 11407. Dr. Luk observed that "the so-called coefficient of friction at the interface between two bodies is an estimate of the friction in the systems of one body in motion with respect to the other, basically, fitting Coulomb's Law of Friction." Tr (Luk) at 11509-10. In particular, Dr. Luk testified that "Coulomb's Law of Friction is a description of the frictional resistance at the interface, as material properties at the interface." Tr. at 11510.

412. By treating the interface conditions as frictional material, the State is adamant that Dr. Luk's model does not represent the actual PFS design or the PFS site soils. Tr (Bartlett) at 10375-77. Of particular concern to the State is the way in which Dr. Luk has modeled the interface conditions, $\mu 2$, and also the way in which Dr. Luk's model does not account for the post-yield behavior of the upper Bonneville clays. Tr. (Bartlett) at 11481-82.

413. The actual design of the storage pad system at the PFS site is undisputed: a

one to two foot thick cement-treated soil layer, the top of which is bonded to the underside of the concrete storage pads and the bottom of which is bonded to the top of the native soil layer (*i.e.*, upper Bonneville clay). Applicant Exh. JJJ; Trudeau/Wissa Tstmy, Post Tr. 10834 at 24-25; Bartlett Tstmy (Soils), Post Tr. 11822 at 4; Con-SER at 2-59. Unlike structural fill, which derives its resistance to seismic forces from friction, cement-treated soil derives its resistance to seismic forces from cohesion. Tr. (Trudeau) at 10839-40.

414. PFS's design intent to withstand seismic forces from the design basis earthquake is to rely on cohesion from bonding at the interface layers (the upper Bonneville clays interface with the laminated cement-treated soil lifts; and the cement-treated soil with the underside of concrete pad) to transfer the horizontal earthquake forces downward from the storage pad to the underlying clay soils. Trudeau/Wissa Tstmy post Tr. XX at 23; Tr. (Bartlett) at 10375-76).

415. The soils characterization at the PFS site was conducted by Stone & Webster but these soil properties are not used in the Luk model. In addition, Geomatrix developed dynamic soil properties – upper bound, best estimate, and lower bound for the PFS site. In his model, Dr. Luk uses the dynamic soil properties developed by Geomatrix. Tr. (Bartlett) 11502; Luk Report, Table 8.

416. Clays are not a granular material – they are a relatively soft plastic material. Tr. (Bartlett) at 10377. The clays that PFS is relying upon to transfer earthquake forces – the upper Bonneville clays – derive their strength from cohesion (i.e., the undrained shear strength) not from friction. Id.

417. Cohesion is a material property – it is the shear strength or resistance to

sliding within the material. Tr. at 11687. Dr. Luk admitted that his model does not incorporate cohesive strength of the soils. Tr. (Luk) at 6787.

418. Cohesion is generally not thought of as a dynamic property – it is a shear strength property that is measured by a static test. Tr. at 11706. Cohesion is also an interface property – it is the strength of the bond at the interface between two layers.[61] Tr. at 11688.

419. Cohesion was not an inherent property included in the dynamic soil properties that were developed by Geomatrix for the PFS site. Tr. (Bartlett) at 10409; 11691. The dynamic soil properties given to him by the Staff and apparently developed by Geomatrix are: maximum shear modulus, soil density, Poisson's ratio, an estimation of shear modulus degradation and damping degradation as a function of strain. Tr. (Bartlett) at 11710. The State's soils expert testified that he knows of no theory of obtaining cohesion of the upper Bonneville clays from dynamic soil properties developed by Geomatrix. Tr. (Bartlett) 1711.

420. Here, the Board gives particular deference to Dr. Bartlett. His expertise in soils is unquestioned. Dr. Luk, on the other hand, admits that he has no expertise in soils and that he relied on a seismologist for the soil input to the numerical model. Further Dr. Luk admits that shear strength (i.e., cohesion) is not represented in his model. The Board, therefore, finds that the Luk model does not incorporate cohesion through the use of the

[61]Strictly speaking the term "adhesion" refers to the condition between two dissimilar materials; "cohesion" is the failure within the material itself. Tr. (Bartlett) at 11417.

dynamic soils properties developed by Geomatrix.

421. Frictional materials like sand or gravel derive their strength from grain to grain contact and, in general, derive their resistance to sliding from the normal force. Such materials act differently from clays under non-seismic and seismic loads. Tr. 10377. In the Luk model, when the horizontal forces are large enough then sliding occurs. But as the following illustrates this model does not describe the conditions at the PFS site.

422. In the case of frictional material, and taking first the simple case of gravity loads from the cask-pad system at PFS, the casks and pad impose a normal stress of about 2 kips per square foot (ksf). For a μ2 value of .31 in Luk Report, Table 8, this would result in a sliding resistance of about 0.6 ksf; for μ 2 equal to 1.0, the sliding force would be about 2 ksf. Looking at frictional materials in the dynamic case, the situation is more complex because of the cyclic nature of the earthquake forces. Tr. (Bartlett) 105312. When accelerations are acting downward there is an effective force acting upward and this decreases the normal stress and sliding initiates earlier than in the gravity case. Conversely, when the acceleration forces are acting upward, there is an effective force acting downward, this increases the normal force and sliding would initiate later than in the gravity case. Tr. at 10532.

423. To illustrate the difference between the Luk Model and the actual materials at the interface at the PFS site, it is instructive to examine the μ2 value of 0.31 for a cohesive material such as cement-treated soil and for a frictional material at the interfaces under the pad. The shear resistance to sliding of the upper bond strength of the cement-treated soil at PFS is about 7.2 ksf. Tr. (Bartlett) at 11421-22. By contrast, the resistance to

sliding in the Luk model, using frictional material, and using the mu2 value of 0.31, is about 0.6 ksf. Id. From this simple example, it is clear that the Luk model overestimates sliding by allowing sliding to occur at a much lower horizontal dynamic force than would occur in a model with cement-treated soil and cohesion at the interface

424. Also, clays act much differently than sand or other frictional material during an earthquake. As stresses develop in clay there is a linear relationship between stress and strain, expressed by shear modulus, until a peak is reached. Once reaching a peak, the clay has no more capacity, it yields, goes into post yield behavior, acts nonlinearly and deforms considerably. Tr. (Bartlett) at 10412. The soil model (*i.e.*, constitutive relation) used by Luk is unable to represent the post-yield behavior of the clay. Tr. (Bartlett) at 11482. Further, Dr. Luk recognized this issue but testified that he had not chosen to use a plastic model for soils. Tr. (Luk) at 11549.

425. The Board finds that the Luk Report does not model the design PFS intends to employ at the site; does not model the actual interface conditions at the PFS site; and by using a frictional material to represent the behavior of the two $\mu 2$ interfaces employs an inappropriate constitutive relationship to use in the numerical model.

426. In sum, the properties ascribed in the Luk Model at the interfaces designated as $\mu 2$ do not properly represent the strengths of those interfaces, and therefore, the Luk Model overemphasizes sliding and this potentially could dampen out seismic energy that is delivered to the cask.

Young's Modulus

427. The Luk Report uses a 270,000 psi Young's modulus for the cement-treated

soil under the pads. Table 4, Luk Report, NRC Exh. P.

428. None of the parties disagree that Holtec has constrained the Young's modulus of cement-treated soil to less than 75,000 psi. Moreover, meeting a Young's modulus of 75,000 psi is an integral part of PFS's soil cement testing that PFS has yet to conduct. *See e.g.,* PFS Exh. JJJ.

429. Dr. Luk testified he obtained the 270,000 psi from NRC Staff person, Mr. Mahandra Shah. Tr. (Luk) at 11625. There is nothing in the record to describe Mr. Shah's technical background, qualifications or experience. Counsel for the Staff represented that Mr. Shah conducted a literature review in which 270,000 psi was referenced for soil cement and he decided to use that value. Tr. at 11629.

430. The Board is puzzled why a value of 270,000 psi was used in the Luk model when the actual value is known for the cement-treated soil at the PFS site. Further, Young's modulus for cement-treated soil is not some obscure technical reference – it is part of a heated dispute between the State and PFS in Contention, Part C.

431. The question arises as to the effect of misrepresenting Young's modulus for cement-treated soil in the Luk Model. The State's expert testified that nonlinear models are extremely sensitive to input parameters and was unwilling to hazard a guess at the effect. Morever, the issues of changes of input parameters to nonlinear modeling is at the heart of the dispute between the State and PFS in Holtec's cask stability analysis.

432. The Board finds that even though the correct value of Young's modulus was readily available, Dr. Luk used a value that differs three to four fold from that of cement-treated soil at the PFS site. As such, the Board finds this to be an additional error in the Luk

model which adds uncertainty to the accuracy of its results.

Pacoima Dam earthquake time histories

433. Dr. Luk obtained the Pacoima Dam earthquake time histories, used in his model, form NRC Staff person, Mahandra Shah. Tr. (Luk) 6923. Dr. Luk, however, did not independently review the input time history. Id.

434. The acceleration time histories for Pacoima dam are 0.61 horizontal and 0.433 vertical. Tr. (Bartlett) at 10536.

435. Further, Dr. Luk testified that he does not know the location of the earthquake epicenter compared with the observation point or compared with the earthquake time history for PFS site. Tr. (Luk) 7005-09.

436. Significantly, the Pacoima dam time histories were not matched to a target spectrum and as such are not representative of an evaluation earthquake for the PFS site. Tr. (Bartlett) 11702. (SB)

437. For nonlinear analysis ASCE 4-98[62] recommend the use of multiple time histories. § 3.2.2.3 (2)(d) states: "In general, more than one set of acceleration time histories, meeting the requirements of Section 2.3, should be used, and the results of the analyses shall be averaged." State Exh. 118; *see also* ASCE 4-86 PFS Exh. XX. One of the requirements of ASCE Section 2.3 is that earthquake time histories shall be selected or developed so that they reasonable represent the duration of strong shaking conditions expected for the site. PFS Exh. XX.

[62]American Society of Civil Engineers, Seismic Analysis of Safety-Related Nuclear Structures and Commentary.

438. The Board finds that the Pacoima dam earthquake record is not representative of the expected seismic conditions at the PFS site and does not satisfy using multiple time histories as provided in ASCE 4-98.

439. The Licensing Board finds that the Luk cask stability analyses did not model the appropriate site conditions at the PFS site, thus, the Licensing Board finds the Luk cask stability analyses is not persuasive in demonstrating the HI-STORM 100 cask will not tip over under either a 2,000-year or 10,000-year earthquake at the PFS site.

440. Mr. Guttmann opines that the Luk report "[g]enerally shows that the Applicant's calculations are conservative." Tr. (Guttmann) at 6826. In response to whether " no stone has been left unturned," Mr. Guttmann testified that "as the state came up with concern, we reviewed every one of their concerns" and "addressed everyone of the state's concerns." Tr. (Guttmann) at 7062-64. Given that Mr. Guttmann a) admitted he had not reviewed the Holtec 2,000-year report (Tr. at 6844), b) is not familiar with the issues raised in this matter (Utah Contention L and L part B) and c) that we earlier found he has no expertise in modeling seismic behavior of free standing casks, the Licensing Board affords no weight to Mr. Guttmann's opinion concerning the Applicant's calculations and whether the State's concerns in this contention have been addressed.

Comparison of the Holtec-Luk Results.

441. The proponents of the Holtec and Luk models each claim that their model accurately evaluates the seismic response of casks at the PFS site at a 2,000-year or 10,000-year earthquake. Yet, Dr. Luk submits that the results from his analysis and Holtec's analyses "should not be directly compared." Tr. (Luk) at 6952. The Licensing Board

recognizes the Luk and Holtec models are vastly different. Notwithstanding the vastly different nonlinear models, Holtec and Luk both purportedly modeled a HI-STORM 100 storage cask, on a 30 foot x 67 foot x 3 foot concrete storage pad, supported by cement-treated soil and dynamic soil properties developed by Geomatrix subject to single sets of time histories for a 2,000-year and 10,000-year earthquakes (initially developed by Geomatrix). Applicant's Exh. 86c at 13; Staff Exh. P at 7. The Licensing Board finds it difficult to reconcile that Holtec's and Luk's results cannot be directly compared yet the Applicant and Staff both claim they confirmed no cask tip over.

442. Holtec claims its Beyond Design Basis, case 1, confirms its DYNAMO results in its 2,000-year report. Applicant's Exh. 86c at 20-21. The Beyond Design Basis case 1, was an 8 cask simulation run on VisualNastran at a lower bound soil, coefficient of friction of 0.8 for a 2,000-year earthquake. Applicant's Exh. at 86d at 1. The VisualNastran showed a net displacement at the top of the cask of 3.7 inches with a maximum angle of rotation of 0.916 whereas DYNAMO generated a net displacement at the top of the cask of 3.08 inches with a maximum angle of rotation of 0.741. Applicant Exh. 86c at 20.

443. As described in its Additional Analyses (Applicant's Exh. 225), Holtec also ran another 8 cask simulation run on VisualNastran with a contact stiffness of 38,194,576 pounds per inch, 4.9 percent damping, and coefficient of friction of 0.8 for a 2,000-year earthquake. Applicant's Exh. 225 at 18 (referencing 12). A contact stiffness of 464 x 10^6 pounds per inch and 5 percent damping was used in the DYNAMO runs where as a contact stiffness of 18.8 pounds per inch and 27.5 percent damping was used in Beyond Design Basis VisualNastran, case 1. Applicant's Exh. 86d at 2, A-1, Tr. (Soler) at 9672. The

Additional Analyses, VisualNastran simulation produced cask #1 results of 3.4 inches maximum excursion of top of cask. Applicant's Exh. 225 at 29. Notwithstanding the results for cask #1, cask #5 of the same simulation showed a 10.5 inch maximum excursion of the top of the cask. Dr. Soler testified that in the highly nonlinear calculation, "we cannot just say one set of results is double the other. When you change something, you have a factor." Tr. (Soler) at 11676. Contrary to Holtec's claims, while we recognize the behavior is nonlinear, the Licensing Board still finds inconsistencies in the various Holtec results. We further find that Holtec's additional simulations at a 10,000-year earthquake raise additional uncertainties and do not support the Holtec 2,000-year earthquake analyses.

444. The Luk analyses for a 10,000-year earthquake at a $\mu 1$ of 0.8, $\mu 2$ of 1.0 resulted in a maximum rotational angle of 1.16 degrees and maximum horizontal sliding of 7.2 inches and 7.39 inches in the u1 and u2 direction, respectively. Staff Exh. P at 32. In comparison, also for a 10,000-year earthquake with a coefficient of friction of 0.8, 5 percent damping, and the soil tuned to 5 hertz, Holtec predicted a maximum excursion of the top of the cask of 56 inches and a rotational angle of 5.37 degrees. Applicant's Exh. 86d at 13. Additionally, for a 10,000-year earthquake, in case 8, Holtec estimated a rotational angle of 10.13 degrees compared to Luk's maximum angle of rotation at 1.16 degrees. Applicant's Exh. 86d at 13, Staff Exh. P at 32. While the we are cognizant that Holtec and Luk developed different models, the Licensing Board finds that the results generated by the Luk analyses provide no assurances that Holtec obtained accurate results.

<u>Summary</u>

445. The Licensing Board finds that barring actual test data to validate the results

obtained by the cask vendors themselves, it is impossible to quantify the uncertainties in the nonlinear computer analyses. Additionally, the Applicant has not met its burden that Holtec's nonlinear finite element cask stability results for both the 2,000-year and 10-,000-year earthquakes are not substantially altered based on our preceding findings that a) there is no engineering precedence or seismic performance data, b) the Applicant has not credibly demonstrated the dynamic properties and behavior of the storage pad, c) there is ample evidence to suggest that the acceleration of the pads may be greater than that estimated by PFS d) there is insufficient evidence to show that all the pads will settle uniformly and e) Holtec analysis for a simple two pad system demonstrates that there can be significant forces transferred from pad-to-pad. The Licensing Board further finds uncertainty in the calculated maximum angle of rotation for the VisualNastran simulations conducted for 10,000-year and 2,000-year earthquakes. Thus, the Licensing Board finds that there is not sufficient probative and relevant evidence to show that the Applicant has met its burden that the HI-STORM 100 casks will not tip over under a 2,000-year DBE or a 10,000-year earthquake at the PFS site.