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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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

U. S. Nuclear Regulatory Commission
Sheraton Hotel, Wasatch Room
Salt Lake City, Utah 84101

On April 30, 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

A P P E A R A N C E S

FOR THE STATE OF UTAH:

Denise Chancellor, Esq.
Connie Nakahara, Esq.
James Soper, Esq.
ASSISTANT ATTORNEYS GENERAL
Office of the Attorney General
160 East 300 South, 5th Floor
P. O. Box 140873
Salt Lake City, Utah 84114

FOR PRIVATE FUEL STORAGE, LLC:

Paul Gaukler, Esq.
Mattias Travieso-Diaz, Esq.
Blake Nelson, Esq.
SHAW PITTMAN
Attorneys at Law
2300 N Street, N.W.
Washington, D.C. 20037

FOR THE U.S. NUCLEAR REGULATORY COMMISSION:

Sherwin E. Turk, Esq.
Martin O'Neill, Esq.
OFFICE OF THE GENERAL COUNSEL
Mail Stop - 0-15 B18
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

E X A M I N A T I O N

Witness Panel:	Page
Krishna P. Singh and Alan I. Soler	
Direct Examination by Mr. Gaukler	5746
Prefiled Testimony Admitted	5750
Cross Examination by Mr. Turk	5811
Cross Examination by Mr. Soper	5906
Tutorial testimony of:	
John Stamatakos	5812
Martin McCann	5820

E X H I B I T S

NO.		MRKD/ADMTD
APPLICANT'S EXHIBITS		
86	Report that goes with simulations	5850
87	Table by Dr. Soler	5870
NN	Letter from John Donnell to NRC dated 8-7-01, with attachments	5752 / 5753
OO	CD of visual simulation	5752
PP	Excerpts from the March 5, 2002 deposition of Dr. Mohsin Khan	5752 / 5753
QQ	Excerpts from article by J. Tou and P. M. Schultheiss - "Static and Sliding Friction in Feedback Systems"	5752 / 5753
RR	Excerpts from Holtec validation report	5752 / 5753
SS	Excerpts from the manual for ANSYS program	5752 / 5753
TT	Calculation done by Dr. Alan Soler	5752 / 5753
STAFF'S EXHIBITS		
CC	Section 3.7.2 of NUREG 0800	5744 / 5744
DD	Section 3.5.1 of NUREG 0800	5744 / 5744
STATE'S EXHIBITS		
173	Holtec's 2000-year seismic analysis (proprietary document)	5940

Tuesday, April 30, 2002 9:00 a.m.

P R O C E E D I N G S

JUDGE FARRAR: Let's come to order. It's Tuesday morning. Using some new ground rules yesterday, we got through one panel of witnesses in one day. We've got a challenge today. There's 96 pages of direct testimony as opposed to 32 yesterday, and even without a calculator, we can do the mathematics. So we've got to push forward hard today. If there are no preliminary matters --

MR. GAUKLER: Your Honor, I understand there's going to be an oral argument tomorrow morning at eight o'clock on SS, Mr. Silberg told me, and he is going to remind -- he'll be doing the argument for us, and so we will need a telephone conference hookup for that.

JUDGE FARRAR: At one point we had set that.

MS. CHANCELLOR: I heard it formally from Mr. Stewart that you had done that, but I don't know that that is required to be done.

JUDGE FARRAR: No. At one point we had said we would do that. That was when we had a different view of where the hearings might be. Our thought was to save the SS argument until a time in the next two weeks when you have a period when no witnesses are available. You know, if you have an hour and a half period where you can't get witnesses here and we have some dead time rather than do it at eight tomorrow morning. I thought we had said that, but if you each -- Mr. Silberg would do it for you?

MR. GAUKLER: Yes, he would.

MS. CHANCELLOR: Mr. Stewart.

JUDGE FARRAR: Mr. Turk, who's doing SS for you?

MR. TURK: I don't know, your Honor.

JUDGE FARRAR: That's an honest answer and leads to no confusion. If you each would talk to your people. We're not going to do SS tomorrow because that -- that to me is, without denigrating it as filler, we can arrange that. Particularly since it's different lawyers, we can arrange to do that by telephone at any point where there's a break in the action here rather than use it to create a break. So there will be no oral argument tomorrow morning at eight o'clock. But thank you, Mr. Gaukler, for reminding us.

Any other preliminary matters?

MR. TURK: One thing left over from yesterday, your Honor. I checked with counsel back in Washington this morning and was informed that the last Staff exhibit to have been offered and admitted was Staff Exhibit BB, which were the professional qualifications of Chet Poslusny.

JUDGE FARRAR: That was B as in boy, BB?

MR. TURK: BB as in boy. I was expecting to hear from the court reporter and I haven't, so I'm going to assume that that's the correct information I received from Washington. So with that, I'd like to formally offer into evidence the two documents that we discussed on the record yesterday, the two sections from NUREG 0800, and I would offer them as Staff Exhibits CC and DD.

JUDGE FARRAR: I take it to be no objection to that. That was the procedure we agreed on yesterday, so those documents will be admitted.

MR. TURK: Thank you, your Honor.

(STAFF EXHIBITS CC AND DD MARKED AND RECEIVED.)

JUDGE FARRAR: Mr. Gaukler, you may now put on your next panel.

MR. GAUKLER: I'd like to call to the stand Dr. Kris Singh and Dr. Alan Soler.

I've already given the court reporter three copies of the testimony with some small changes and corrections that Dr. Soler will go through. I have three copies here for the board members if they would like them.

JUDGE FARRAR: Okay. Remember for all of you, we need four, one for Will if you have one.

MR. TURK: Your Honor, just so I have a clear record. There were two exhibits, and just let me identify them for the record today. CC would be Section 3.7.2 of NUREG 0800, and Staff Exhibit DD would be Section 3.7.1 of that document.

JUDGE FARRAR: Right. Thank you, Mr. Turk.

MR. GAUKLER: Dr. Singh and Dr. Soler, do you have before you a copy of your testimony entitled "Testimony of Krishna P. Singh and Alan I. Soler on Unified Contention Utah L/QQ" dated April 1, 2002.

DR. SOLER: Yes, we do.

DR. SINGH: Yes, we do.

MR. GAUKLER: Do you have any changes or corrections -- oh.

MR. GAUKLER: Your Honor, you probably want to swear them in first.

KRISHNA P. SINGH and ALAN I. SOLER,
having been sworn to tell the truth, were examined
and testified as follows:

DIRECT EXAMINATION

BY MR. GAUKLER:

Q. Let's start again. First of all, would you please state your name for the record.

DR. SINGH: My name is Krishna P. Singh.

DR. SOLER: Alan I. Soler.

Q. And Dr. Singh and Dr. Soler, do you have before you a copy of your testimony entitled "Testimony of Krishna P. Singh and Alan I. Soler on Unified Contention Utah L/QQ"?

DR. SOLER: Yes.

Q. Do you have any changes or corrections to that testimony?

DR. SOLER: Yes.

Q. Would you please go through them?

DR. SOLER: Okay. On Question A17, page 7, the third line, remove the text "as shown in the figure below. Alan will attach a solid works rendering."

MR. SOPER: Could we have a moment to find that?

JUDGE FARRAR: You say page 7, answer 17?

DR. SOLER: Page 7.

MR. SOPER: The change again was what?

DR. SOLER: Put a period after "sealed" in the third line, and then remove all the text until the word "the."

The next change is on page 66, and it references answer 118, which starts on page 65. There are a number of changes to the table on page 66. Starting in item No. 4 under the column labeled "stiffness," instead of the word "casks" it should be "cask."

Item No. 1 under the column labeled "Remarks," there is a first line which consists of a bunch of letters and commas which should be removed. The entire first line, the remarks should simply say "demonstrate agreement with DYNAMO results."

For case 5 in that table under column marked "Stiffness," the word "casks" should be replaced by "cask"; and under the remarks column, instead of "check sliding" it should say "check real configuration."

In case 7, under the Stiffness column it should say "based on mass of eight casks," and under the Remarks column it should say "with high stiffness."

Those are the changes to that table.

The next changes go with answer -- question and answers to 119 and 120 on page 68. Answer 119, after the words "Windows Media Player," add the words "or Real Player." And the exhibit in the last sentence of answer 119 should be OO instead of MM.

Under answer 120 it should have the words "(KPS, AIS)" at the beginning of the question.

MR. TURK: I'm sorry. Can you repeat the last one, please?

DR. SOLER: At the beginning of answer 120, add the words "(KPS, AIS)."

And finally, on page 69, item No. 6 on that page, in the second line before the word "stiffness," add the words "soil spring." That completes the changes.

JUDGE FARRAR: That was what subsection?

DR. SOLER: Subsection 6 on page 69. The second line should say "tuning the soil spring stiffness." It currently just says "tuning the stiffness." That completes the changes.

Q. (By Mr. Gaukler) With these changes, do you adopt your testimony as true and correct and as your testimony in this proceeding?

DR. SOLER: Yes.

DR. SINGH: Yes, we do.

Q. And was this testimony prepared by you or under your supervision and direction?

DR. SOLER: Yes.

DR. SINGH: Yes.

MR. GAUKLER: Your Honor, I request that the testimony be included in the record.

JUDGE FARRAR: Any objection?

MR. SOPER: We're struggling with just one of the changes again. Could we ask for the change to answer 120 again, sir?

DR. SOLER: Which one? The last change? On page 69 --

MS. CHANCELLOR: 68.

MR. SOPER: No, page 68, I believe, answer 120.

DR. SOLER: Okay. The only thing that's

being inserted is basically the words that indicate that this question was answered by both of us, so it's KPS, AIS.

MR. SOPER: I see. Thank you.

JUDGE FARRAR: For all the future witnesses, when we come to something like this, if you'll make sure we have the right place, give everybody five seconds to find that place and then give us the change, we can avoid the necessity to repeat.

With now the changes that are in order, does the State have any objection?

MR. SOPER: No objections, your Honor.

JUDGE FARRAR: Then the testimony will be bound into the record at this point as if read.

(PREFILED TESTIMONY OF DRS. SINGH AND SOLER FOLLOWS.)

April 1, 2002

UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
PRIVATE FUEL STORAGE L.L.C.	)	Docket No. 72-22
	)	
(Private Fuel Storage Facility)	)	ASLBP No. 97-732-02-ISFSI

TESTIMONY OF KRISHNA P. SINGH AND ALAN I. SOLER ON UNIFIED CONTENTION UTAH L/QQ

I. BACKGROUND – WITNESSES

A. Krishna P. Singh ("KPS")

Q1. Please state your full name.

A1. Krishna P. Singh.

Q2. By whom are you employed and what is your position?

A2. (KPS) I am President and CEO of Holtec International ("Holtec"). In that position, I bear the ultimate corporate responsibility for the accuracy and correctness of the company's spent fuel storage systems engineered for dry storage under certification by the U.S. Nuclear Regulatory Commission ("NRC").

Q3. Please summarize your educational and professional qualifications.

A3. (KPS) My professional and educational experience is described in the *curriculum vitae* attached as to this testimony. I have a Ph. D in Mechanical Engineering, which I received from the University of Pennsylvania in 1972. I have extensive experience in the design and licensing of nuclear spent fuel systems which extends back to 1979. Over the past twenty-three years, I have personally led the design and licensing of spent fuel storage systems for over forty nuclear power plants, and for Holtec's HI-STAR 100 System and HI-STORM 100 Storage Cask System ("HI-STORM System"). I am also the inventor of the honeycomb basket design utilized in the HI-STAR 100/HI-STORM Systems (Patent Number 5,898,747) and the METCON™ construction used in the HI-STORM System overpack (Patent No. 6,064,710). The internal thermosiphon feature of the HI-STORM System multi-purpose canisters, widely recognized as a seminal contribution to dry storage technology, was conceptualized and implemented under my technical leadership. My professional work in the field of applied heat transfer and structural mechanics, to which this testimony in part pertains, consists of over 500 industry reports, over fifty published papers in the refereed technical literature, and academic courses taught at the University of Pennsylvania. I have served as AN expert witness in three prior Atomic Safety and Licensing Board hearings dealing with wet storage of spent nuclear fuel.

Q4. What knowledge do you have of American Society of Mechanical Engineers Boiler and Pressure Vessel Code standards?

A4. (KPS) I have designed hundreds of pressure vessels to the ASME Boiler and Pressure Vessel codes. over 40 nuclear plants have pressure vessels designed by me, or under my supervision, in use throughout the world.

Q5. What is your experience with nuclear facilities and the requirements of the NRC for the design and licensing of dry cask storage systems?

A5. (KPS) My company, Holtec International, has three dockets with the NRC on dry storage systems (72-1014, 72-1008, and 71-9261) for the HI-STORM System, the HI-STAR 100 Cask Storage System and the HI-STAR 100 Cask Transport System, respectively. Each docket has obtained a Certificate of Compliance ("CoC"), all of which have been secured under my technical direction and leadership.

Q6. Are you familiar with the Private Fuel Storage Facility ("PFSF") and the activities that will take place there?

A6. Yes.

Q7. What is the basis of your familiarity with the PFSF?

A7. (KPS) I have provided consultation and technical oversight to the analysts involved in evaluating the effects of seismic excitations on the HI-STORM System which is to be deployed at the PFSF Independent Spent Fuel Storage Installation ("ISFSI"). I have personally visited the proposed dry storage facility in Skull Valley. I have been directly involved with PFS's technical management from the inception of the Skull Valley project, because PFS had selected the HI-STORM technology even before the selection of the most eligible site was made. I have also reviewed Unified Contention Utah L/QQ ("the Unified Contention"), in which the State of Utah raises various challenges to the seismic analysis of the HI-STORM System for the PFSF site, and related materials.

Q8. What is the purpose of your testimony?

A8. (KPS) The purpose of my testimony is to respond to allegations raised by the State of Utah in the Unified Contention concerning the seismic analysis of the HI-STORM 100 System to be deployed at the PFSF. In response to these allegations, Dr. Soler and I will: (1) summarize the design of the HI-STORM System; (2) describe the features of and conservatisms incorporated in the design of the HI-STORM System that enhance the ability of the casks and the fuel canisters inside the casks to withstand the forces imparted on them during a severe seismic event; (3) report the results of the analyses performed on the casks' response to a 2,000-year return period earthquake at the PFSF and other, more severe seismic events; (4) respond to claims raised by the State of Utah in Section C.3(e) and portions of Section D of the Unified Contention; (5) respond to claims concerning the modeling of the stability of the HI-STORM System under earthquake forces raised by the State's witness, Dr. Moshin Khan; and (6) address the capability of the HI-STORM System to withstand earthquake forces significantly beyond those imparted by the 2,000-year return period design basis earthquake for the PFSF, including the forces due to the 10,000-year return period earthquake for the site.

B. **Alan I. Soler ("AIS")**

Q9. Please state your full name.

A9. Alan I. Soler.

Q10. By whom are you employed and what is your position?

A10. (AIS) I am Executive Vice President and Vice President of Engineering for Holtec International. In that capacity, I am responsible for all corporate engineering activities by the company, including overseeing the analyses performed to establish the stability of the HI-STORM System under postulated seismic events. I am the lead structural discipline expert responsible for the design of the HI-STORM System, including supporting analyses, and have acted in this capacity since the design was conceptualized in the early 1990s. In particular, I have either performed or reviewed all HI-STORM System seismic analyses conducted in support of deployment of the HI-STORM System at the PFSF.

Q11. Please summarize your educational and professional qualifications.

A11. (AIS) My professional and educational experience is described in the *Curriculum Vitae* attached to this testimony. Prior to my current employment with Holtec International, I was a tenured Professor of Mechanical Engineering and Applied Mechanics at the University of Pennsylvania for over 26 years. During my academic career at the University of Pennsylvania, I taught graduate and undergraduate courses in mechanical engineering, engaged in funded research, and was an active consultant to the nuclear industry on various mechanical engineering matters, including spent fuel storage equipment. Through my professional and educational background and work experience, I am qualified to address matters pertaining to the effects of seismic and structural loadings on the HI-STORM System.

Q12. What knowledge do you have of American Society of Mechanical Engineers Boiler and Pressure Vessel Code standards?

A12. (AIS) In the course of my activities in seismic and structural analysis at Holtec International, I use Section VIII, Divisions 1 and 2, Section II, and Section III, Subsections NB-NG, extensively. I have also served for over ten years as a member of an ASME Working Group to develop Section VIII, Division I of the ASME code. These provisions of the code pertain to the design methodologies and fabrication of Nuclear and Non-Nuclear pressure vessels and pressure bearing components. Included, among other items I am familiar with in the various sections of the Code, are tables of allowable stresses for various materials of construction, classification of loads, and formulas for determining the state of stress in some common constructions.

Q13. What is your experience with nuclear facilities and the NRC's requirements for the design and licensing of dry cask storage systems?

A13. (AIS) I led the structural and seismic effort for obtaining the CoC for the HI-STAR and HI-STORM Systems, and in so doing I became familiar with the applicable sections of the NRC guidance documents for the design and licensing of dry cask storage and transport systems. I have also been responsible for the seismic and structural analysis of spent fuel racks for numerous nuclear plants. Over 40 nuclear plants have spent fuel storage devices that were designed using the analysis methodology that I developed. In addition to Holtec's dry storage systems, I have also performed seismic stability evaluations for other casks such as the TN -12 and 1F-300. The analysis I performed for the latter served as the basis for defueling the Shoreham Nuclear Plant in the early nineties.

Q14. Are you familiar with the PFSF and the activities that will take place there?

A14. (AIS) Yes.

Q15. What is the basis of your familiarity with the PFSF?

A15. (AIS) I performed the seismic analyses for the HI-STORM System to be deployed at the PFSF ISFSI. I developed the original model of 1-8 spent fuel dry storage casks on the ISFSI pad resting on a soil foundation using the Holtec validated computer code for dynamic simulation. I performed the original analysis for PFSF using a deterministic earthquake and directed and reviewed the follow-on efforts utilizing various probabilistic seismic events. Most recently, I developed and performed the large motion dynamic simulation of the HI-STORM System, subject to the beyond-design-basis 10,000-year return seismic event. I also directed and reviewed the drop and tip-over analyses of the storage cask that are required to demonstrate that the enclosed spent fuel will not experience excessive deceleration levels in the event of a handling accident or a non-mechanistic tip-over. Based on my experience with the PFSF project over the past several years, I am familiar with the site-specific characteristics of the site's subsoil and the design features of the concrete pad on which the casks will rest, and understand how the subsoil characteristics affect the seismic analyses performed on the HI-STORM System at the PFSF ISFSI. I have also reviewed the Unified Contention, in which the State of Utah raises various challenges to the seismic analysis of the HI-STORM System for the PFSF site, and related materials.

Q16. What is the purpose of your testimony?

A16. (AIS) The purpose of my testimony is to respond to allegations raised by the State of Utah in the Unified Contention concerning the seismic analysis of the HI-STORM System to be deployed at the PFSF. Dr. Singh and I will (1) summarize the design of the HI-STORM System; (2) describe the features and conservatisms in the design of the HI-STORM System that enhance the ability of the casks and the fuel canisters inside the casks to withstand the forces imparted on them during a severe seismic event; (3) report the results of the analyses performed of the casks' response to a 2,000-year return period earthquake at the PFSF and other, more severe, seismic events; (4) respond to claims raised by the State of Utah in Section C.3(e) and portions of Section D of the Unified Contention; (5) respond to claims concerning the modeling of the stability of the HI-STORM System under earthquake forces raised by the State's witness, Dr. Moshin Khan; and (6) address the capability of the HI-STORM System to withstand earthquake forces significantly beyond those imparted by the 2,000-year return period design basis earthquake for the PFSF, including the forces due to the 10,000-year return period earthquake for the site.

II. DESIGN FEATURES OF THE HI-STORM SYSTEM CASKS AND CANISTERS THAT ENABLE THEM TO WITHSTAND SEISMIC FORCES

Q17. Please describe the general design of the HI-STORM System to be used at the PFSF ISFSI.

A17. (KPS) The HI-STORM System features a massive cylindrical steel and concrete storage cask surrounding a multi-purpose stainless steel canister in which the spent nuclear fuel is sealed. ~~as shown in the figure below: [Alan will attach a solidworks rendering]~~ The casks are almost 20 feet tall (239.5 inches) and approximately 11 feet in diameter (132.5 inches). When loaded with a spent fuel canister, the casks will weigh approximately 180 tons. The steel and concrete cylindrical walls of the cask form a heavy steel weldment, consisting of an inner and outer steel shell within which shielding concrete is installed. These walls are approximately 30 inches thick. The multi-purpose canister ("MPC") in which the spent fuel is sealed is stored vertically within the storage cask. Loaded HI-STORM System casks are placed on concrete storage pads using a specially designed transporter.

The storage cask has four air inlets at the bottom and four air outlets at the top to allow air to circulate naturally through the annular cavity to cool the MPC inside the cask. The inner shell of the storage cask has channels attached to its interior surface to guide the MPC during insertion and removal. These channels would also provide a flexible medium to absorb impact loads under postulated, non-mechanistic tip-over events, while allowing cooling air to freely circulate through the cask.

The cask is engineered to minimize local area radiation doses and to provide a robust structural enclosure for the MPC located within it. Specifically, the storage cask is designed to withstand extreme natural phenomena, including strong earthquakes. The loaded HI-STORM System storage cask exhibits excellent resistance to overturning under seismic events. This high resistance to overturning is partly due to its low height-to-diameter ratio (239.5 inches to 132.5 inches, a height-to-diameter ratio of 1.8). Its seismic resistance is further enhanced by the energy absorbing internal channels mentioned above, by the state of internal dissonance produced by the vibrating of the MPC within the cask and by the individual fuel assemblies in their respective storage locations.

Q18. How will the storage casks be stored at the PFSF site?

A18. (AIS) As described in Section 4.2.1.5.2 of the PFSF Safety Analysis Report ("SAR"), the HI-STORM System storage casks will be placed on a regular array of concrete pads arranged to provide a lateral (edge to edge) spacing of 35 feet between adjacent pads. Each pad will be sized to accommodate a 2 x 4 array of casks with a 15 ft pitch (the distance between the casks center points) in the width direction and 16 ft in the length direction. As described in Section 4.2.3.1 of the PFSF SAR, the cask storage pads will be independent structural units constructed of reinforced concrete, each pad being 30 ft wide, 67 ft long and 3 ft thick. Each pad will be capable of supporting eight loaded storage casks. For a graphical representation of the cask storage arrangement, see Figure 4.2-7 in the PSFS SAR.

Q19. Please describe the codes and standards to which the HI-STORM System is designed and manufactured.

A19. (KPS) The array of codes and standards used in the design of the HI-STORM System are listed in the HI-STORM FSAR. In particular, the HI-STORM System is designed and constructed in accordance, as applicable, with Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code ("the Code"). The Code governs the design of pressure vessels for safety-related applications at nuclear power plants. The manner of compliance with the Code is described in the HI-STORM System FSAR. The multi-purpose canister is engineered in accordance with Subsection NB of the Code, which governs the construction of Class 1 nuclear components. Class 1 nuclear components include such items as reactor pressure vessels and primary coolant system piping. Use of

Subsection NB for the construction of the MPC is highly conservative since the MPC design pressure is much lower than the design pressure for a typical reactor coolant system (i.e., 100 psig versus 2,500 psig or higher) and there is no significant cycling of the stress state in the service condition of the MPC, eliminating fatigue as a concern. The internal fuel basket is designed to Subsection NG of the Code, which governs the construction of nuclear component core support structures. The HI-STORM System storage cask is designed in accordance with Subsection NF of the Code, which governs the construction of nuclear component supports, such as spent fuel racks and reactor coolant piping supports. Thus, the MPC and the storage casks are designed and built to the same standards, as applicable, as safety-related components used in nuclear power plants. In addition, the HI-STORM System components are designed in accordance with the standards specified in the governing NRC Standard Review Plan, NUREG-1536, "Standard Review Plan for Dry Cask Storage Systems", January 1997.

Q20. How do the standards specified in NUREG-1536 for dry storage cask systems compare to the standards specified in the NRC's Standard Review Plan for nuclear power plants set forth in NUREG-0800?

A20. (KPS, AIS) NUREG 1536 provides guidance to NRC reviewers of Dry Cask Storage Systems ("DCSS"). From the standpoint of seismic/structural considerations, NUREG-1536 for dry storage incorporates the lessons learned from the evolutionary development of its counterpart NUREG-0800 for reactor systems. The differences in the two NUREGs principally lie in the difference in their technical missions. For example, whereas NUREG-0800 does not dwell on the structural consequences of tornado-borne missiles on a spent fuel storage rack in the plant's fuel pool (the pools being completely enclosed, reinforced concrete monoliths), the ability of the storage cask, situated outdoors, to withstand impactive and impulsive tornado loads is treated as an important consideration in NUREG-1536. Likewise, the amplification of the earthquake by the interplay between the flexibility of the fuel storage buildings and the free field seismic motion is a matter of considerable attention in NUREG-0800. Because vertical ventilated casks (particularly HI-STORM) are essentially rigid structures to a seismic input, the focus of consideration in NUREG-1536 is directed towards evaluating the effects of free-standing massive rigid bodies under seismic events.

In summary, NUREG-1536 calls for application of the same codes, standards and design procedures as does NUREG-0800. The difference in the details of the guidance are almost entirely due to the differences in the type, nature, relative significance and relevance of the anticipated loadings between dry storage casks and reactor installations.

Q21. Please describe in greater detail the design of the HI-STORM System storage casks.

A21. (KPS) As required by NUREG-1536 and other applicable codes and standards, the design of the HI-STORM System storage cask has significant built-in conservatisms and design margins that assure its ability to perform in accordance with design basis requirements and to withstand events well beyond its design basis. The HI-STORM System storage casks are stubby steel weldments with homogeneous concrete (without rebars or other potential sources of crack propagation), designed to tolerate very large earthquake-induced forces without tipping over. To assure utmost structural ruggedness, the HI-STORM System storage cask has been designed as a buttressed ASME Section III, Class 3, Subsection NF cylindrical structure. The 1¼ -inch thick inner steel shell and ¾ inch thick outer steel shell are both welded to a 2 inch thick baseplate, and are joined by four full-length inter-shell radial support plates, each ¾ -inch thick and welded to the inner and outer shells. The cask provides an internal cylindrical cavity, 191½ inches in height and 73½ inches in diameter, for housing the MPCs. The top steel closure plate is also a steel weldment with confined concrete. Finally, a steel pedestal with enclosed concrete is provided for shielding, missile penetration, canister drop, and cooling flow considerations. As stated earlier, steel channels are located on the interior surface of the inner shell to minimize g-loadings imparted to the MPC under a hypothetical cask tip-over scenario.

Q22. Please describe in greater detail the design of the multi-purpose canister.

A22. (KPS) The multi-purpose canister is the component in which the spent fuel is placed. After the spent fuel is loaded into the MPC, the MPC is filled with an inert gas (helium) and welded shut for long-term storage at a site or ready transport off-site. The MPC consists of (i) the stainless steel enclosure vessel; and (ii) the fuel basket. The enclosure vessel is a cylindrical container with flat ends designed to meet the applicable provisions of Subsection NB of the Code. The fuel basket is a stainless steel, continuously welded, stiff honeycomb structure that is designed to meet Subsection NG of the Code, as applicable, and serves to position the fuel in the MPC enclosure vessel. The MPC has the same relative design margins as those imposed by Subsection NB of the Code for reactor operation service, even though the MPC is not subject to the stresses that result from an operating reactor environment. Further, the MPC is designed for transportation as well as storage, giving it a ruggedness that allows it to resist very large earthquake induced forces. Thus, similar to the storage casks, the MPC has significant built-in conservatisms and design margins that assure its ability to perform in accordance with its design basis requirements and to withstand events well beyond its design basis.

Q23. Has Holtec performed any analyses that demonstrate the beyond-design basis conservatisms and capabilities of the MPC?

A23. (KPS, AIS) Yes. Holtec performed an analysis to determine whether the confinement boundary of the MPC would be breached in the hypothetical, postulated case of a crane failure or other malfunction that causes a drop of an MPC that is in the process of being loaded into a cask. At the PFSF, a loaded MPC will be transferred from the transportation cask in which it is shipped to the site to the HI-STORM System storage cask in the Canister Transfer Building. To perform this transfer, the HI-TRAC transfer cask is placed on top of the transportation cask, the MPC is lifted up into the transfer cask, the loaded transfer cask is moved by a crane over to the storage cask, and the MPC is placed inside the storage cask. (This process is described in the testimony of Donald Wayne Lewis being filed simultaneously with this testimony.)

In the analysis performed by Holtec, the MPC is assumed to free-fall over a distance of 25 feet, representing the height of the storage cask cavity plus an allowance for the thickness of the transfer cask bottom lid. The target surface is assumed to be essentially unyielding and is modeled as a 22 ft thick concrete slab of compressive strength 6,000 psi. The computed strain in the confinement boundary material as a result of this hypothetical drop is only 41% of the failure strain limits for the material. Therefore, the MPC confinement boundary integrity is maintained and radioactive material is not released into the environment even under this severe, hypothetical drop accident. This hypothetical drop accident is far more severe than either the drop accident analysis or hypothetical tip-over performed as part of the design basis of the HI-STORM System. It demonstrates the huge margins provided by the Code and design criteria that enable the MPC to withstand forces much greater than the design basis forces and still perform its safety function.

III. ABILITY OF THE HI-STORM SYSTEM STORAGE CASKS AND CANISTERS TO WITHSTAND SEISMIC EVENTS POSTULATED FOR THE PFSF

A. General Background

Q24. Please describe the regulatory requirements for the seismic performance of dry cask storage systems, such as the HI-STORM System.

A24. (KPS, AIS) The regulatory requirements for the seismic performance of Dry Cask Storage Systems are stated in 10 C.F.R. § 72.122(b)(2) and translated into guidance to the NRC Staff in NUREG-1536. 10 C.F.R. § 72.122(b)(2) states that "structures, systems, and components important to safety must be designed to withstand the effects of natural phenomena such as earthquakes,.without impairing their capability to perform safety functions. The design bases for these structures, systems, and components must reflect: (i) Appropriate consideration of the most severe of the natural phenomena reported for the site and surrounding area, with appropriate margins to take into account the limitations of the data and the period of time in which the data have accumulated, and (ii) Appropriate combinations of the effects of normal and accident conditions and the effects of natural phenomena." NUREG-1536 addresses these requirements in Section V.1.d.(i)(3), subparagraph (g) and requires that … "Cask designs must satisfy the load combinations that encompass earthquake, including those for sliding and overturning in ANSI/ANS-57.9, Section 6.17.4.1. The applicant should demonstrate that no tip-over or drop will result from an earthquake. In addition, impacts between casks should either be precluded, or should be considered an accident event for which the cask must be shown to be structurally adequate."

Q25. In general, how does one demonstrate that these requirements are satisfied?

A25. (KPS, AIS) To demonstrate that the above requirements are satisfied, a comprehensive dynamic model of the casks, the supporting pad, and the soil foundation is constructed and a series of dynamic simulations performed with the input loading being the specified three-dimensional seismic acceleration time histories for the design basis earthquake. Because the storage casks are free-standing (not anchored) on the pad, and since each storage cask contains a large free standing body (the MPC) inside, the dynamic simulation requires a non-linear analysis. A non-linear analysis recognizes that the relationships between load and deformation are not linear and that changes in orientation may be large enough to require a re-formulation of the governing equations of equilibrium at each instant in time. Classical solution methods, such as modal analysis in the time or frequency domain, are inapplicable to such a problem and the only recourse to ensure an accurate representation of the response is to use a direct solution of the differential equations of motion in the time domain. The modeled system is subject to the earthquake induced forces, and the solution over the event duration is obtained. At each instant in time, the position and orientation of each cask in the model is determined in order to draw conclusions concerning cask stability and cask-to-cask impact. In order to encompass the wide variety of configurations and the potential for sliding and/or overturning of one or more casks, multiple simulations are performed with upper and lower bound cask-to-pad coefficients of friction, and for varying numbers of casks on the pad.

Q26. Has Holtec developed a computer code to perform this dynamic analysis of the cask system?

A26. Yes. Holtec has developed a specialized computer code, referred to as DYNAMO, for modeling spent fuel systems to demonstrate their compliance with NRC seismic requirements. This code has been validated and has been reviewed and accepted by the NRC for the licensing of spent fuel storage systems.

Q27. Please describe the various seismic analyses that Holtec has performed for the HI-STORM System.

A27. (KPS, AIS) Holtec has performed general seismic analyses in its Safety Analysis Report for the HI-STORM System which supports the Certificate of Compliance ("CoC") that the NRC has issued for the HI-STORM System under 10 C.F.R. Part 72. Under the CoC, nuclear power plant licensees may use the HI-STORM System at their sites under the general license provision of 10 C.F.R. § 72.210 as long as they meet the conditions of both 10 C.F.R. § 72.212 and the CoC. Holtec has also performed seismic analyses for ISFSIs that do not fall under the general license provisions of 10 C.F.R. Part 72. In addition to the seismic analyses for the PFSF, Holtec has performed site-specific seismic analyses using DYNAMO for the HI-STORM System for Pacific Gas & Electric (Diablo Canyon), Exelon (Dresden), Energy Northwest (Columbia Generating Station), Entergy Nuclear Northeast (J.A. Fitzpatrick) and Tennessee Valley Authority (Sequoyah). These analyses were performed using DYNAMO to demonstrate that the HI-STORM System would perform satisfactorily under seismic conditions at all these sites.

Q28. Does Holtec have other relevant experience performing seismic analyses for spent fuel storage systems?

A28. (KPS, AIS) Yes. In addition to the work in dry storage system seismic analysis, Holtec has extensive experience in the seismic qualification of spent fuel racks used inside nuclear plants. The spent fuel racks are large rectangular structures of honeycomb construction that are free standing in the spent fuel pool. These racks are square or rectangular, are supported by four or more stubby legs, and rest on the spent fuel pool floor slab. During a seismic event, the racks may slide, tip, and rotate with respect to the spent fuel pool in a manner similar to the potential motions of a spent fuel cask on a concrete storage pad. The same non-linear phenomena (sliding and tip-over) are modeled with the additional feature that fluid coupling between racks, and between racks and walls, is also considered. The same computer code is used to model the spent fuel rack behavior that is used to model the behavior of one or more spent fuel casks on an ISFSI pad. No changes to the code were required in order to simulate the behavior of the casks; the input data for a particular site reflects the differences between simulating submerged spent fuel racks and simulating dry casks.

Holtec has employed its wet storage seismic simulation methodology at many nuclear sites, both in the U.S. and abroad. The list below provides a partial list of U.S. and foreign sites where Holtec has performed seismic analyses for spent fuel rack systems that were licensed by the applicable regulatory authority. In all such activities, Holtec's QA validated computer code DYNAMO was employed.

PLANT	DOCKET NUMBER(s)	YEAR
Enrico Fermi Unit 2	USNRC 50-341	1980
Quad Cities 1 & 2	USNRC 50-254, 50-265	1981
Rancho Seco	USNRC 50-312	1982
Grand Gulf Unit 1	USNRC 50-416	1984
Oyster Creek	USNRC 50-219	1984
Pilgrim	USNRC 50-293	1985
V.C. Summer	USNRC 50-395	1984
Diablo Canyon Units 1 & 2	USNRC 50-275, 50-323	1986
Byron Units 1 & 2	USNRC 50-454, 50-455	1987
Braidwood Units 1 & 2	USNRC 50-456, 50-457	1987
Vogtle Unit 2	USNRC 50-425	1988
St. Lucie Unit 1	USNRC 50-335	1987

Millstone Point Unit 1	USNRC 50-245	1989
Chinshan	Taiwan Power Company	1988
D.C. Cook Units 1 & 2	USNRC 50-315, 50-316	1992
Indian Point Unit 2	USNRC 50-247	1990
Three Mile Island Unit 1	USNRC 50-289	1991
James A. FitzPatrick	USNRC 50-333	1990
Shearon Harris Unit 2	USNRC 50-401	1991
Hope Creek	USNRC 50-354	1990
Kuosheng Units 1 & 2	Taiwan Power Company	1990

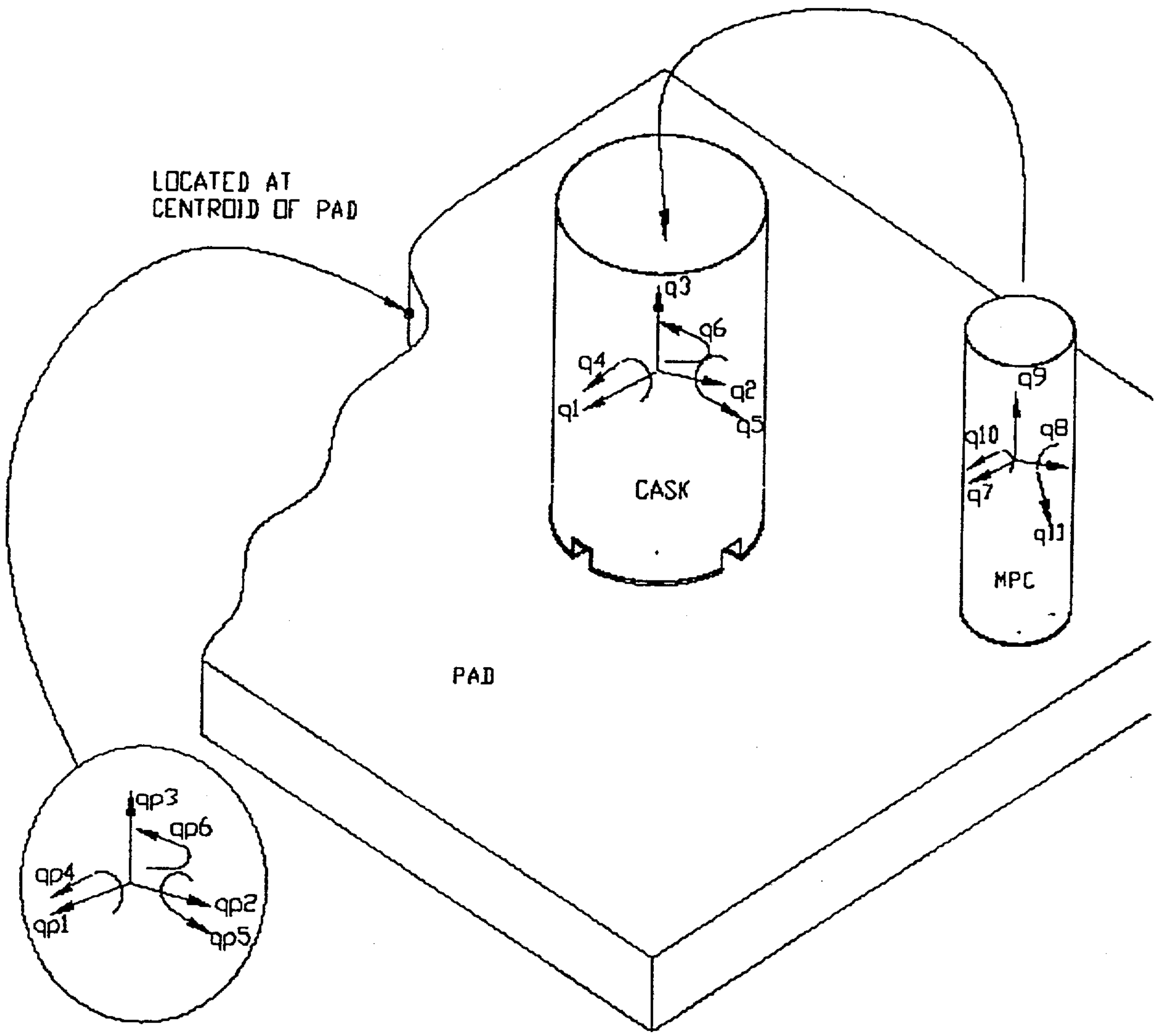
PLANT	DOCKET NUMBER(s)	YEAR
Ulchin Unit 2	Korea Electric Power Co.	1990
Laguna Verde Units 1 & 2	Comision Federal de Electricidad	1991
Zion Station Units 1 & 2	USNRC 50-295, 50-304	1992
Sequoyah	USNRC 50-327, 50-328	1992
LaSalle Unit 1	USNRC 50-373	1992
Duane Arnold Energy Center	USNRC 50-331	1992
Fort Calhoun	USNRC 50-285	1992
Nine Mile Point Unit 1	USNRC 50-220	1993
Beaver Valley Unit 1	USNRC 50-334	1992
Salem Units 1 & 2	USNRC 50-272, 50-311	1993
Limerick	USNRC 50-352, 50-353	1994
Ulchin Unit 1	KINS	1995
Yonggwang Units 1 & 2	KINS	1996
Kori-4	KINS	1996

Connecticut Yankee	USNRC 50-213	1996
Angra Unit 1	Brazil	1996
Sizewell B	United Kingdom	1996
Waterford 3	USNRC 50-382	1997
J.A. Fitzpatrick	USNRC 50-333	1998
Callaway	USNRC 50-483	1998
Nine Mile Unit 1	USNRC 50-220	1998
Chin Shan	Taiwan Power Company	1998
Byron/Braidwood	USNRC 50-454, 50-455, 50-567, 50-457	1999
Wolf Creek	USNRC 50-482	1999
Plant Hatch Units 1 & 2	USNRC 50-321, 50-366	1999
Harris Pools C and D	USNRC 50-401	1999

Q29. Please generally describe the model used by Holtec for analyzing spent fuel storage systems.

A29. (AIS) The model used by Holtec for analyzing spent fuel storage systems (either casks for dry storage outside the plant structures on a separate pad, or racks for wet storage inside the plant facility) models the cask (or rack) as a multi-degree of freedom system. The contents of the cask or rack are modeled as a separate internal body that is free to contact the cask (or rack). The support on the floor is modeled by sets of compression-only contact elements with associated lateral resistance by friction elements. In the case of racks, the contact locations are beneath the support legs and the pool liner (generally located near the four corners of the structure), while in the case of casks, contact is defined to occur at a finite number of locations around the cask's circular perimeter. For the case of casks, a more detailed description of the model is provided below:

Each HI-STORM System cask is modeled as a two-body system. Each storage overpack is described by six degrees of freedom which capture the rigid body motion of the overpack in inertial space. Within each overpack, the internal MPC is modeled by an additional five degrees of freedom sufficient to capture all but the rotational motion of the MPC about its own longitudinal axis. There is no loss of generality in this five degree of freedom system since there is no interest in the omitted rotational degree of freedom. Six degrees of freedom establish the rigid body motion of the ISFSI pad relative to inertial space. The complete system (multiple casks on a pad) is characterized by the aforementioned degrees of freedom (a set for each cask), by the mass and inertia properties of the component parts, and by the stiffness elements (linear and non-linear) that are used to characterize contact and friction between components and to characterize underlying pad and soil properties. The pad is subject to seismic movements at the base of soil springs, which represent the resistance of the soil foundation to pad translations and rotations. By changing the value for variables, the problem can be re-formulated as one in which the base of the soil springs is fixed, and three components of ground acceleration time histories of the earthquake, multiplied by the mass of the component are applied as specified inertia forces at the mass center of each moving body. The model simulates the application of earthquake forces with the pad, cask and canister are free to respond to the earthquake forces in any of the directional degrees of freedom described above. The figure below graphically illustrates the modeling concept.



HI-STORM 100 DYNAMIC
MODEL (DYMAMO)

Q30. You stated that your model has been validated and accepted by the NRC for the licensing of spent fuel storage systems. Please describe this validation process.

A30. (KPS, AIS) In order for DYNAMO to be approved by the NRC for use in licensing analyses, the code had to be validated to demonstrate that it produces acceptable results for the class of problems where it could be used. A series of classical problems having known solutions were modeled using the code and were shown to give results in good agreement with the analytical results. The problems were chosen to exercise all of the features that are built into DYNAMO (compression only behavior, friction resistance, etc.). In addition, problems that had no simple analytical solutions were also evaluated and shown to give good agreement with numerical solutions using finite element codes such as ANSYS. Finally, some features of DYNAMO were validated by comparing results from experiments designed to be capable of simulation using DYNAMO. During the course of certain wet storage license submittals, DYNAMO was subjected to additional validation at the request of NRC's reviewers. In every case, the DYNAMO code proved capable of providing acceptable resolutions to the problem. As noted above, on numerous dockets, the NRC has accepted the results from DYNAMO as the basis for NRC licensing action. In summary, DYNAMO has been extensively benchmarked to confirm its veracity as a non-linear dynamics code.

B. Cask Stability Seismic Analyses of the HI-STORM System for Use at the PFSF

Q31. Please describe generally the seismic analyses that Holtec performed for the HI-STORM System to be used at the PFSF.

A31. (AIS) Holtec performed seismic analyses for the HI-STORM System to be used at the PFSF using the general design parameters for the HI-STORM System together with the site-specific earthquake ground motions for the PFSF site and other relevant site-specific parameters. Over the time period that Holtec has participated in the Project, a number of time history analyses were performed using different seismic events. The simulation model, however, was consistent through all of the analyses; namely, the casks, along with their loaded internals, were modeled as rigid bodies, the pad was modeled as a rigid rectangular slab, and the effect of the soil/soil cement foundation was modeled by appropriate springs and dampers characterizing the soil resistance in deflection and rotation. The casks were modeled as free-standing structures with compression-only contact and with friction elements modeling the interfaces between casks and the pad. Seismic design input (acceleration time histories and soil properties to characterize the soil springs and dampers) were provided as design input by Geomatrix Consults, Inc. ("Geomatrix").

Q32. What were the PFSF site-specific ground motions and related information used by Holtec in its seismic analysis of the HI-STORM System for the PFSF?

A32. (AIS) The ground motions for the 2,000-year return period design basis seismic event were provided to Holtec by Geomatrix in the form of three acceleration time histories for 5% damping entitled "Fault Normal", Fault Parallel", and "Vertical". It is our understanding that these seismic ground motions were developed from response spectra having the following zero period acceleration ("ZPA"), also known as the Peak Ground Acceleration ("PGA") values:

Fault Normal – 0.711 g

Fault Parallel – 0.711 g

Vertical – 0.695 g

The actual time histories used in the dynamic analyses were developed in accordance with the requirements of Standard Review Plan 3.7.1 and had the following peak acceleration amplitudes:

Fault Normal – 0.73 g

Fault Parallel – 0.71 g

Vertical – 0.73 g

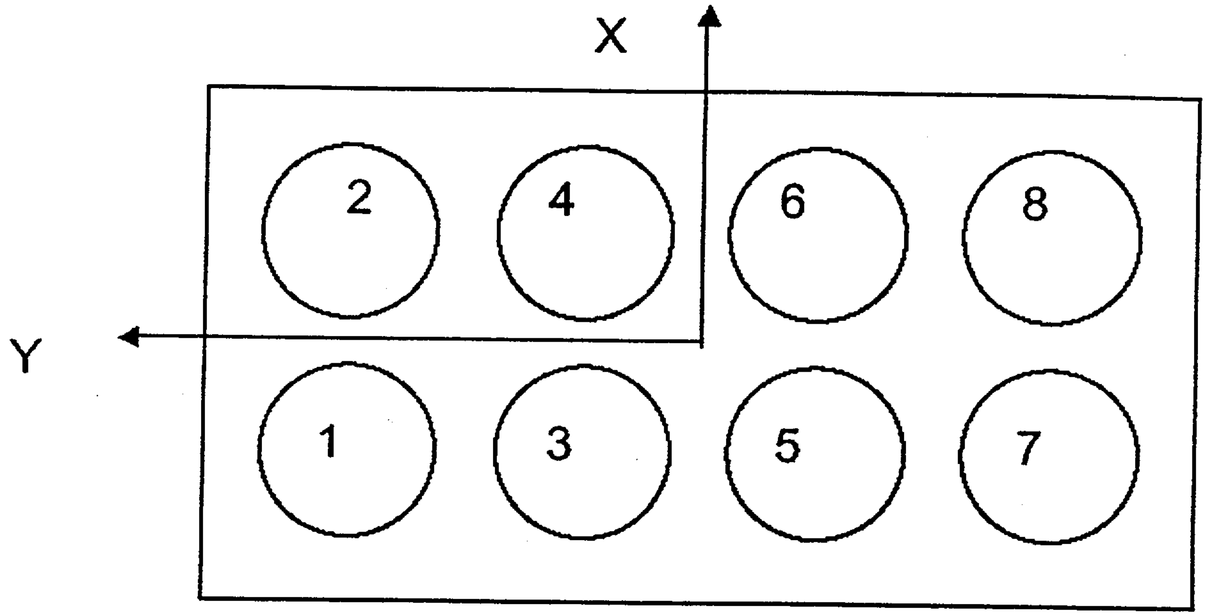
Along with the time histories, Geomatrix provided Holtec with the property values for the soil under the pad, including the effect of soil cement, as applicable. The "Best Estimate," "Lower Range," and "Upper Range" soil properties provided by Geomatrix are summarized in the table below:

RANGE OF SOIL PROPERTY VALUES 2000 Yr. Seismic Event			
	Young's Modulus, ksf	Shear Modulus, ksf	Poisson's Ratio
Lower Range	2,546	955	0.333
Best Estimate	5,194	2,027	0.281
Upper Range	12,234	5,015	0.220

The terminology "Lower Range" and "Upper Range" refers to the magnitude of the spring constants arising from the stated soil properties. The smaller values of Young's Modulus and Shear Modulus coupled with the larger value of Poisson's Ratio give rise to lower values for soil spring constants. The larger values of Young's Modulus and Shear Modulus coupled with the smaller values of Poisson's Ratio give rise to higher values for soil spring constants. The values of the spring constants and damping coefficients were computed by Holtec using the soil property values supplied by Geomatrix and applying the formulas provided in ASCE Standard 4-86, "Seismic Analysis of Safety Related Nuclear Structures and Commentary", Tables 3300-1 and 2, and Figure 3300-3.

Q33. What other PFSF site-specific design features were incorporated into Holtec's seismic analysis of the HI-STORM System for the PFSF?

A33. (AIS) The seismic analysis incorporated the PFSF site-specific dimensions for each storage pad of 67' x 30' x 3', with the casks arrayed, as shown in the figure below, as well as other relevant pad design information:



A single pad was modeled with the effect of the underlying soil foundation included by virtue of the six soil spring/dampers, calculated by Holtec based on soil properties provided by Geomatrix, located at the origin of the X-Y coordinate system at the base of the pad. The effect of soil cement under the pads was included in the modulii values used to model the springs. An effective soil mass or inertia was also included by Holtec in the model for each pad degree of freedom in accordance with formulas provided in Levy and Wilkerson, The Component Element Method in Dynamics..., McGraw-Hill, 1976.

Q34. Using this input information, what seismic analyses did Holtec perform?

A34. (AIS) Various configurations of one (1) to eight (8) casks were modeled using the lower bound, best estimate and upper range soil properties and an upper bound coefficient of friction of 0.8 at the cask/pad interface to emphasize the possibility of cask tipping, and a lower bound coefficient of friction of 0.2 to emphasize the possibility of sliding. The analyses are summarized in Section 8.2.1.2 of the PFSF SAR.

Nine cases were run for the upper bound coefficient of friction of 0.8, and one case was run for a lower-bound coefficient of friction of 0.2 for the configuration that gave the limiting results from the above table to identify the range of potential sliding. Only one configuration was evaluated at the 0.2 coefficient of friction based upon the results of previous cask stability analyses that Holtec had performed for the PFSF for different earthquakes, which showed that the bounding solution for cask displacement (as measured at the top of the casks) was for a coefficient of friction of 0.8.

Q35. What were the results of your analyses?

A35. (AIS) The analyses showed that under design basis earthquake conditions for the PFSF the loaded HI-STORM System casks have large safety margins against overturning or sliding. In no case do the analyses predict that there will be any cask tip-over or cask-to-cask impacts. Further, the maximum accelerations experienced by the casks (less than 8 g) are well below the design basis limits (of 45 g) specified by the HI-STORM System FSAR. These results confirm that the forces experienced by the cask and its internals in a design-basis earthquake do not produce stresses that exceed the allowable limits.

Q36. Please describe further the large margin against cask tip-over as shown by your analysis.

A36. (AIS) The following table summarizes the results from the nine Holtec analyses using a coefficient of friction of 0.8. The first column identifies the cases evaluated; the second and third columns show the maximum displacements in the X and Y directions as measured at the top of the casks; the fourth column shows the angle of tilt of the cask, which is measured by the net maximum displacement of the top of the cask in the horizontal X-Y plane (representing the net excursion of the cask from the vertical plane) and the height of the cask. The net maximum displacement in the X-Y plane is computed by a Square-Root-of Sum-of Squares ("SRSS") procedure using the extremes from each direction, which conservatively assumes that the maximum excursions in the two horizontal directions occur at the same time.

SUMMARY OF CASK SIMULATIONS (COEFFICIENT OF FRICTION=0.8)			
Simulation	Max. X-Displacement (absolute value), in.	Max. Y-Displacement (absolute value), in.	Angle of Tip (degrees – based on net top-of-cask displacement and height to top of cask body)
Casks in Position 1 and 2, Best Estimate Properties	2.06	3.24	0.950
Casks in Position 1 and 2, Lower Bound Properties	2.16	3.09	0.934
Casks in Position 1 and 2, Upper Bound Properties	2.58	3.24	1.026
Casks in Position 1to 4 Best Estimate Properties	2.14	3.16	0.945
Casks in Position 1 to 4, Lower Bound Properties	2.08	3.02	0.908
Casks in Position 1 to 4, Upper Bound Properties	2.17	3.23	0.964
Casks in Position 1 to 8, Best Estimate Properties	2.21	2.96	0.915
Casks in Position 1 to 8, Lower Bound Properties	2.04	2.51	0.801
Casks in Position 1 to 8, Upper Bound Properties	1.89	3.18	0.916

The case that produced the maximum displacement (identified by the largest angle of tip) was also evaluated for a coefficient of friction = 0.2. This evaluation produced maximum displacement of 1.69 inches in the X direction and 1.94 inches in the Y direction.

As can be seen, the maximum angle of tilt indicated by the analysis for the 2,000-year design basis earthquake for the upper bound coefficient of friction of 0.8 is 1.026 degrees. This can be compared to the angle of tilt at which a cask would tip from the movement of its own weight. Using simple geometry and values for the cask diameter and the height of the cask center of mass above the top surface of the pad, the angle of inclination of the cask where the cask has its center-of-gravity directly over a corner of the cask (with the cask tipped up to such an angle) at which the cask would tip over from its own moment with no other force applied is 29.3 degrees. Defining a safety factor against exceeding the so-called "center-of-gravity-over-corner" location by the ratio of c.g-over corner angle to calculated angle of rotation from the vertical, which could signal the possibility of a continued rotation to a tipped-over horizontal position, it is shown that the minimum safety factor for the HI-STORM System for the PFSF design basis earthquake is 28.6, computed as follows:

Safety Factor (overturning) =29.3/1.026 = 28.6

Q37. Please describe further the large margin against cask-to-cask impact as shown by your analysis.

A37. (AIS) Since the maximum excursion predicted at the top of the cask is below 3.25 inches (and this is larger than that predicted for any case where the coefficient of friction is 0.2), a conservative safety factor against cask-to-cask sliding impact may be defined as the ratio of 50% of the cask-to-cask spacing divided by the computed net displacement. The result shows a safety factor of 5.79, computed as follow:

Safety Factor (cask-to-cask impact) = 24"/4.142" = 5.79

Q38. Did Holtec perform other seismic analyses of the HI-STORM System using earthquakes with the PGAs for the PFSF?

A38. (AIS) Yes. Holtec has performed a variety of seismic analyses for various earthquakes. In 1997 Holtec performed a seismic cask stability analysis for the HI-STORM System based on the seismic characterization for the PFSF site in the PFS June 1997 License Application, based on an earthquake with a vertical PGA of 0.69 and a horizontal PGA of 0.67. Then, in 1999, Holtec performed two other seismic cask stability analyses. The first was based on an 1,000-year return period earthquake with vertical and horizontal PGAs of 0.391 and 0.404, respectively, and the second was based on an initial 2,000-year return period earthquake with vertical and horizontal PGAs of 0.55. The results of these earlier analyses showed similarly large safety margins against overturning or sliding and impacting.

Q39. Did Holtec perform any analyses of the HI-STORM System at the PFSF for ground accelerations greater than those for the 2,000-year design basis earthquake?

A39. (AIS) Yes. Holtec performed an analysis of a loaded HI-STORM storage cask subject to accelerations from a postulated, beyond-design basis 10,000-year return period earthquake for the PFSF site. The earthquake had a vertical PGA of 1.33g and horizontal PGAs of 1.25g and 1.23g. This analysis used a conservative estimate of the coefficient of friction between the base of the cask and the top surface of the pad of 0.8, in order to maximize the possibility of tipping by the cask. The earthquake motion was assumed to be applied directly to the base of the pad so that soil springs were not included in the simulation. Since the rotations were expected to increase to a level where the orientation of the cask could significantly affect the equilibrium equations, a computer algorithm capable of including finite rotations was used for this analysis. Although the loaded cask exhibited larger rotations relative to the pad (approximately 10.89 degrees from the vertical) than seen in the earlier analyses using lower earthquake levels, the results of this analysis still showed the existence of significant margins against tip-over. Using the same definition of safety factor against cask overturning as before, the safety factor against overturning was 2.69, computed as follows:

Safety Factor (overturning) = 29.3/10.89 = 2.69

Thus, even at the 10,000-year earthquake ground motion level, large margins of safety against cask tip-over still exist.

Q40. In addition to these previously performed analyses, have you performed any further analyses of cask tipping and sliding at the PFSF?

A40. (AIS) Yes. In conjunction with the preparation of this testimony, we ran additional simulations to test alleged deficiencies that the State's experts claimed might affect our previous analyses by re-running our analyses using different assumptions than those used in the above described analyses. These additional simulations were done at both the 2,000 and 10,000-year return period earthquakes. The new analyses were run under unrealistic, worst case assumptions, yet all showed that the casks would remain upright and not tip over during a seismic event.

Q41. Based on the seismic analyses that you have performed, what is your conclusion regarding the capability of the HI-STORM System to withstand earthquake events at the PFSF site?

A41. (KPS, AIS) Based on the totality of the analyses performed for this Project by Holtec, which encompassed the entire range of friction coefficients likely at the interface between the casks and pad, and which also encompassed the expected range of cask positioning and number of casks present on the pad, we conclude that under the design-basis 2,000-year return period seismic event, the casks will remain vertical and not tip over, and will not impact each other. Moreover, a very large margin exists such that the HI-STORM System at the PFSF can withstand earthquakes with return periods significantly greater than the 2,000-year design basis earthquake, including earthquakes with 10,000-year return period ground motion, and not tip over.

Q42. Do any independent seismic analyses confirm your conclusions?

A42. (KPS, AIS) Yes. The NRC commissioned Sandia Laboratories to perform a confirmatory analysis of the behavior of the Holtec cask under the design-basis 2,000-year return period seismic event and under the beyond-design basis 10,000-year return period seismic event. The Sandia analysis considered a single cask on the pad and included pad flexibility. Instead of using soil springs, the Sandia model used a finite element representation of the soil cement/soil foundation and extended the foundation boundary well beyond the pad boundary. Sandia's results that have been made available to us are for the 2,000-year return period earthquake for both 0.8 and 0.2 coefficients of friction, and for the 10,000-year return period event for the 0.2 coefficient of friction. All of the Sandia analyses we received confirmed that the casks will not tip over and will not impact one another during the postulated events. Moreover, the results obtained by Sandia are in the same general range as those that we have obtained (showing, at most, several inches of displacement for the 2,000-year design-basis ground motions), thus independently confirming the results of our analyses.

C. Cask Drop and Non-Mechanistic Tip-over Analyses for the PFSF

Q43. Did Holtec perform any analyses for PFS concerning either the dropping or postulated tip-over of a loaded HI-STORM System cask?

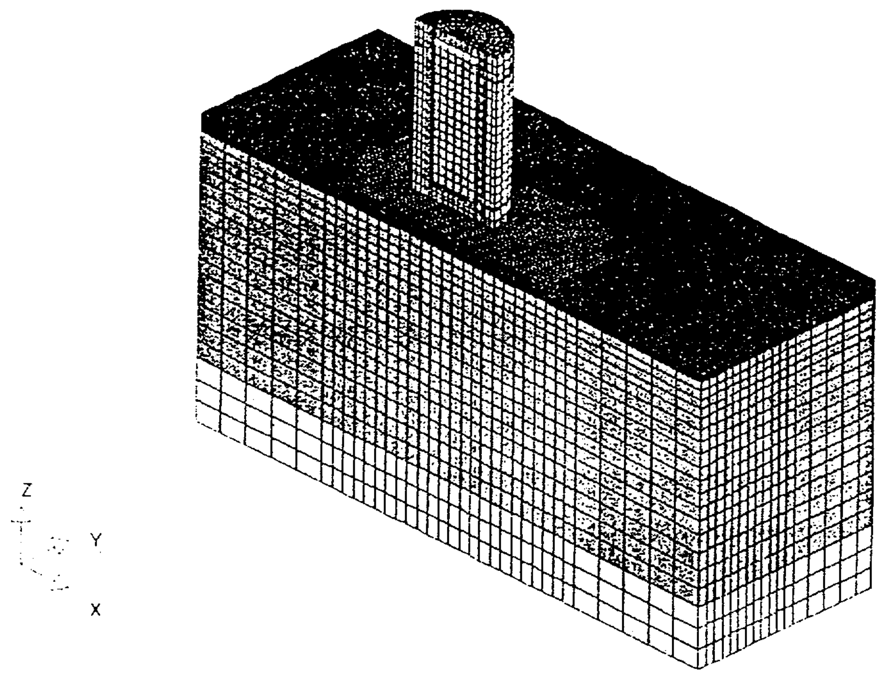
A43. (AIS) Yes. In accordance with the guidance in NUREG-1536, Holtec performed both cask drop and non-mechanistic postulated cask tip-over analyses of a loaded HI-STORM System cask at the PFSF site. The purpose of the analyses was to demonstrate that the deceleration experienced by the stored fuel in the HI-STORM System cask during each of the postulated vertical drop and tip-over accidents remains below the design basis deceleration of 45 g limit as specified in the HI-STORM System CoC. The pad thickness at PFSF site is 36 inches, which equals the reference pad thickness criteria in the HI-STORM FSAR. The soil foundation, beginning 2 feet below the pad, has an effective soil Young's Modulus no greater than 28,000 psi, which meets the reference Young's Modulus criteria in the HI-STORM FSAR. The first two feet of foundation directly below the pad concrete consist of cement-treated soil having an effective Young's Modulus no greater than 75,000 psi. To ensure that the design basis deceleration limit is met for the specific conditions at the PFSF site, Holtec performed transient finite element analyses to simulate postulated accidents involving the vertical drop and the non-mechanistic tip-over of a loaded HI-STORM System cask using the same methodology and computer codes used in the HI-STORM System FSAR. Holtec used the same methodology and computer codes for these cases as was used in its other analyses.

Q44. Please briefly describe the cask drop analysis that Holtec performed for the PFSF.

A44. (AIS) A loaded HI-STORM System cask was assumed to drop from a specified height, with its longitudinal axis in the vertical orientation, such that its bottom plate hit the pad; two different drop heights were evaluated. The cask steel components were modeled using elastic-plastic material shell and solid elements, the concrete in the cask and in the pad was modeled using a non-linear concrete material model that has been accepted by the NRC, and the soil layers (including the soil cement) were modeled conservatively by linear elastic materials with no permanent energy absorption capability. The parameters of the cask storage pad at the PFSF and the underlying soil layers are summarized below:

Item	Concrete Pad	Soil Cement	Soil Layer 1	Soil Layer 2
Thickness (ft)	3	2	26	7
Compressive Strength (psi)	4,200	---	---	---
Young's Modulus (psi)	---	75,000	6,000	12,000
Poisson's Ratio	0.22	0.2	0.3	0.3
Density (pcf)	140	105	91	115

The finite element model for the drop (only half the structure is modeled by virtue of symmetry) is shown in the figure below:



The calculated deceleration results from the two drop analyses (from a height of 6.5" and 10") were:

Drop height = 10" - longitudinal deceleration experienced by fuel = 45.15 g.

Drop height = 6.5" - longitudinal deceleration experienced by fuel = 36.15 g.

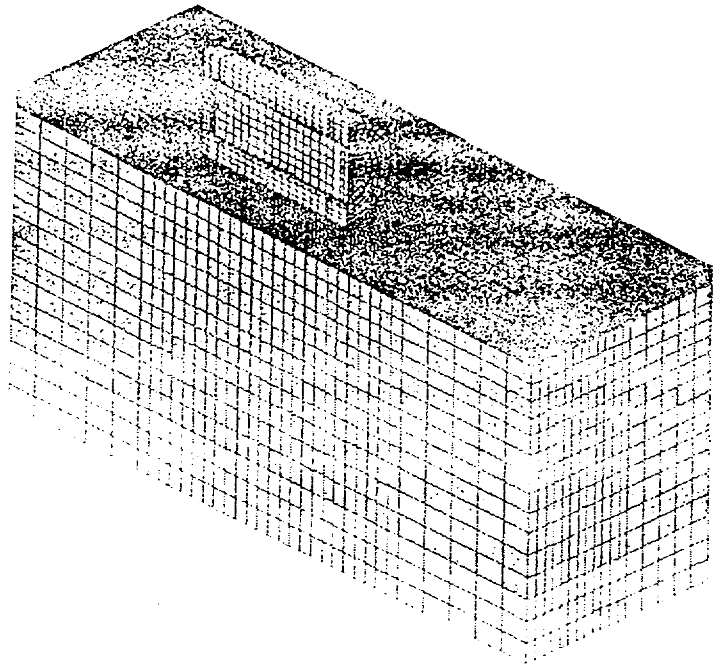
The predicted decelerations are consistent with the design basis decelerations in the Holtec CoC, although the deceleration for a 10" drop is slightly above the 45 g design limit. These decelerations translate into even larger margins of safety against the release of radioactivity, in that to actually breach a canister requires deceleration levels far in excess of those predicted by these analyses.

Q45. How were the drop heights selected?

A45. (AIS) The drop heights were selected at random, with the intent of determining the maximum height from which a cask could possibly drop. We understand that PFS is implementing design and procedural measures to limit the maximum height above the ground that a HI-STORM System cask will be lifted by a transporter to 9 inches. Therefore, the 10 inch drop test represents a conservative upper limit to the potential accelerations to which a cask will be subjected in the event of a drop.

Q46. Please briefly describe the non-mechanistic, hypothetical cask tip-over analysis that Holtec performed for the PFSF.

A46. (AIS) Although it has been demonstrated that casks will not tip over under either the design-basis 2,000-year return period earthquake or a beyond-design basis, 10,000-year return period seismic event, a further "defense-in-depth" analysis has been performed to evaluate the results of a hypothetical cask tip-over event with the attendant impact of the cask on the pad. This analysis is summarized in the PFSF SAR Section 8.2.6. The HI-STORM System storage cask and a representative portion of the pad, soil-cement, and soil substrate were modeled to the extent required to accurately predict the post-impact system response. The primary objective of the hypothetical tip-over analysis was to demonstrate that the decelerations experienced by the fuel contained in the MPC are bounded by the design basis limits for fuel stated in the FSAR. This tip-over analysis showed that the maximum fuel deceleration is below the 45g. The tip-over finite element model used is shown below:



[illegible] results from [illegible] tip-over analyses [illegible] three different cask [illegible] [illegible] [illegible] [illegible] [illegible] potential [illegible]

Q47. How [illegible] these analyses [illegible] stability analysis [illegible] Holtec for the PFSF?

A47. (MS) There is no direct relationship between these hypothetical, postulated [illegible] and the design basis stability analysis, which shows that the casks will [illegible] stable and will not tip over even [illegible] well beyond those [illegible] the 2,000-year design basis [illegible] the PFSF. However, these mechanistic tip-over analyses [illegible] availability of "defense in depth" margin with regard to the HI-STORM system to be used at the PFSF. [illegible] that, if for any unspecified reason [illegible] were to tip over, the cask contents would retain its integrity and no release of radioactivity would occur.

IV. RESPONSE TO THE STATE OF UTAH'S CLAIMS IN SECTIONS C AND D OF THE UNIFIED CONTENTION

Q48. The State of Utah has raised various claims in Sections C and D of the Unified Contention concerning the adequacy of Holtec's cask stability, drop and tip-over analyses. Have you reviewed and analyzed the claimed deficiencies raised by the State in those sections of the Unified Contention?

A48. (KPS, AIS) Yes.

Q49. What claims raised by the State in Sections C and D of the Unified Contention will you be addressing in your testimony?

A49. (KPS, AIS) With respect to Section C, the only claim that we will be addressing is the claim in Section C.3.e concerning the Young's modulus that Holtec used in the cask drop and non-mechanistic tip-over analyses. In Section D, the various issues raised in Section D.1, "Seismic Analysis of the Storage Pads, Casks and Their Foundation Soils," either directly or indirectly relate in whole or in part to the cask stability analyses that Holtec performed for PFS. Accordingly, we will address each of the claims raised in Section D.1, although for certain of the claims (such as the claims in Sections D.1.a and D.1.d concerning non-vertically propagating waves), we rely upon the conclusions expressed in the testimony of Dr. Robert Youngs and Dr. Wen Tseng being filed simultaneously with this testimony.

Q50. What conclusion have you reached regarding the claims made by the State.

A50. (KPS, AIS) In Section C.3.e, the State has claimed that the cask drop and tip-over analyses that Holtec performed for the PFSF are not conservative since, in the State's opinion, the model used an unreasonably low soil modulus to characterize the soil stiffness. Contrary to the State's claim, Holtec used the correct modulus appropriate to a large strain condition in the soil foundation, in accordance with the NRC-approved methodology that has been benchmarked against test data. With regard to the State's contentions in Section D.1 that the stability analyses performed by Holtec are deficient, we will respond to those claims by demonstrating the inherent conservatisms in our model, and provide a point-by-point refutation of the issues raised by the State.

A. Claim Raised by the State in Section C.3.e of the Unified Contention Concerning the Holtec Cask Drop and Hypothetical Cask Tip-over

Q51. Please describe the claims raised by the State in Section C.3.e of the Unified Contention concerning Holtec's cask drop and non-mechanistic tip-over analyses performed for the PFSF.

A51. (KPS, AIS) The State claims that PFS underestimated the dynamic Young's modulus of the cement-treated soil at the PFSF when subjected to impact during a cask drop or tip-over. Such underestimation, the State claims, significantly understates the impact forces on the cask and canister in those analyses.

Q52. What is the Young's modulus?

A52. (AIS) The Young's modulus is an elastic property of a material that is defined by a simple extension test; it is the ratio of the stress to which the material is subjected to the strain (deformation) that the material experiences as a result of the applied stress. The Young's modulus of a metal is a function of the properties of the metal, but is insensitive to strain level as long as no yielding occurs. The Young's modulus of a non-metallic material may, in addition, be dependent on the level of strain applied.

Q53. What is the significance of the Young's modulus to the cask drop and cask tip-over analyses?

A53. (AIS) As a HI-STORM System cask is dropped (or tips over) onto the concrete storage cask pad, some of the energy caused by the impact will be absorbed by the cement-treated soil and the underlying soil as strain (deformation). Because of the large magnitude of the forces (stress) caused by the impact, the level of strain that will be experienced by the cement-treated soil and the soil will be relatively large, and will depend on the value of the Young's modulus of the cement-treated soil and the soil at the point of impact.

Q54. The State's contention refers to a "dynamic Young's modulus." What does the term mean?

A54. (AIS) The term "dynamic Young's modulus" is somewhat of a misnomer. It really refers to the manner in which the Young's modulus is measured in a test, rather than to whether it represents a "dynamic" condition. A dynamic Young's modulus is one determined by a particular type of test in which a small amount of strain in the soil results from the passage of a wave front generated from a rather large stress (the setting off of explosives). On the other hand, a "static Young's modulus" is one measured in a test in which the type of test performed, such as moving a boring device some distance into the soil, requires relatively little force (stress) but produces a large deformation (strain) on the soil.

Q55. What is the relevance of the "dynamic" Young's modulus that the State claims should be used to the Holtec cask drop and tip-over analyses?

A55. (AIS) None. The proper concepts to apply in those analyses are those of "large strain" and "small strain" Young's modulus. Because the impact of the dropping or tipped-over cask on the underlying cement-treated soil will produce a large strain on the soil directly under the impact location (that strain is calculated in our drop and tip-over analyses as 1.93%), our analysis requires that a "large strain" Young's modulus be used. Such a large strain Young's modulus correlates well with the empirically-determined stress/strain relationships obtained in static tests. Therefore, it is appropriate for the Holtec analyses to be based on large-strain (i.e., "static") values of Young's modulus as opposed to small-strain (i.e., "dynamic") values.

It is important to note that an evaluation conducted for the NRC (NUREG/CR-6608, "Summary and Evaluation of Low Velocity Impact Testing of Solid Steel Billets Onto Concrete Pad", February 1998) used "static" Young's modulus relationships and showed good correlations between those relationships and the results of actual drop tests of steel specimens on concrete pads on top of soil.

In short, the nature of the cask drop and tip-over analyses conducted by Holtec makes the use of a small strain "dynamic" Young's modulus inappropriate; instead, a large-strain, "static" modulus should appropriately be used. This is what Holtec did and what the independent evaluations conducted for the NRC have confirmed to be correct.

B. Claims Raised by the State in Section D.1 of the Unified Contention Concerning the Holtec Seismic Cask Stability Analyses for the PFSF

1. Claims Raised in Section D.1.a of Unified Contention – Non-Vertically Propagating Seismic Waves

Q56. Please describe the claim raised by the State in Section D.1.a of the Unified Contention.

A56. (AIS) In Section D.1.a of the Unified Contention, the State claims that "Applicant's calculations unconservatively assume that only vertically propagating in-phase waves will strike the pads, casks and foundations, and fail to account for horizontal variation of ground motion that will cause additional rocking and torsional motion in the casks, pads and foundations."

Q57. Do you know whether the seismic waves arriving at the foundations of the pads could arrive at an angle rather than vertically propagating, and if so, what effect, if any, that would have on the movement of the pad and casks?

A57. (AIS) Based on the testimony of Dr. Robert Youngs and Dr. Wen Tseng, we understand that the angles at which seismic waves would impinge the PFSF site are, for all practical purposes, vertical and that the rocking and torsional motion caused by the small angle of incidence from vertical of the waves arriving at the PFSF site would be insignificant. We also note that many of Holtec's analyses of cask stability consider cask arrays which, by design, provide an eccentric loading to the pad. One accepted methodology for bounding the effects of non-vertical seismic waves is, in fact, to deliberately induce a 5% loading eccentricity into the model to account for rocking and torsion effects. The very nature of the cases considered by Holtec introduces eccentricities into the model that are far in excess of those required to model the effects of non-vertical waves.

2. Claims Raised in Section D.1.b of Unified Contention – Pad Rigidity

Q58. Please describe the claim raised by the State in Section D.1.b of the Unified Contention.

A58. (AIS) In Section D.1.b of the Unified Contention, the State claims that the Applicant's calculations incorrectly assume that the pads will behave rigidly during the design basis earthquake and that this assumption of rigidity leads to "[s]ignificant underestimation of the dynamic loading atop the pads, especially in the vertical direction," and to "[o]verestimation of foundation damping."

Q59. Is it appropriate to model the concrete cask storage pad as a rigid body for purposes of Holtec's cask stability calculations?

A59. (AIS) Yes. We believe that the three-foot thick reinforced concrete cask storage pad can be modeled as a rigid body for purposes of Holtec's analysis of cask stability. No body is perfectly rigid. Therefore, whether the inherent flexibility of a body needs to be accounted for in analytical evaluations depends on the nature of the evaluation being performed. To take a simple example, consider a table with three legs, with a load placed somewhere on the table top. To predict what the load in each leg is, and whether the table will fall over, the table may be considered as a rigid body. On the other hand, if we wished to know how much the table top bends when the load is applied (assuming we show that it doesn't overturn), we must now consider the table top as a flexible body supported by the three legs.

The purpose of Holtec's cask stability calculation is to analyze the cask/pad interface in order to establish the interface forces and displacements between the cask and the pad. With respect to the characterization of these forces and displacements, a minor flexibility of the pad would produce only second-order effects that would not affect the validity of the results of Holtec's calculation. In reality, the large rigid casks, even though free standing, effectively confine the pad to a rigid motion under the casks' 11 ft diameter. In the 4 ft free space between casks (comparable to the thickness of the pad), there should be minimal flexible movements ascribed to the pad, since the free section of the plate has a thickness comparable to its free span between casks.

Q60. Has Holtec ever analyzed the potential effect of pad flexibility in its calculations of free standing casks on top of a concrete storage pad?

A60. (AIS) Yes. Holtec has included pad flexibility in its analysis of a pad proposed for the Tennessee Valley Authority's Sequoyah Nuclear Power plant. At the request of the client, Holtec performed analyses assuming that the pad was flexible. The pad was modeled with 16 casks in a square array, with the pad being approximately 64 ft. on each side and only 24 inches thick (compared to 36 inches for PFSF). The model was run for a fully populated pad with 16 casks and for the extreme case of a single cask located in one corner. Subsequently, the analysis was redone removing the flexible pad contributions from the model.

Comparison of the results from both analyses showed that the inclusion of pad flexibility produced only insignificant changes in the pad and cask movements and in the character of the interface force time histories used as input for the structural design and qualification of the pad.

Q61. What conclusions can be drawn from your analyses for the Sequoyah Nuclear Power Plant of the difference between modeling the pad as a flexible body and modeling it as a rigid body?

A61. (AIS) The results of our comparison for Sequoyah confirm that it is appropriate to treat the pad as a rigid body for characterizing the forces and displacements between the cask and the pad in evaluating the stability of the casks. We note that the same approach that was employed at PFSF (i.e., the use of a global dynamic analysis in which the pad is considered to determine the nature of the cask to pad interface forces and to prove cask stability, followed by a finite element analysis of the pad for pad design purposes that assumes the pad to be flexible) has been followed at all sites where Holtec has participated in the seismic/structural analysis of the cask storage pads.

Q62. The State claims that the results of Calculation No. 05996.02 G(P017)-2, "Storage Pad Analysis and Design" by International Civil Engineering Consultants ("ICEC") shows that the storage pads are not rigid and contradicts the assumption of pad rigidity in Holtec's analyses. Do you agree?

A62. (AIS) No. The ICEC calculation is directed toward calculating the detailed stress distribution within the pad subject to the interface force time history results determined from the global dynamic analysis. To determine pad stresses, one must assume that the pad is flexible since there are no stresses developed unless one includes elasticity. However, what is a necessary assumption for a stress analysis is unnecessary for a global dynamic analysis. As long as the elastic deformations arising from the loads are small, the flexibility effect on the global dynamic solution can be ignored.

Realizing that every man-made structure has some flexibility, it is instructive to consider the following simple analogy: A grandfather clock has, as its basis for keeping time, the oscillation of a simple pendulum. Rigid-body dynamics establishes the relationship between the pendulum length and the time to complete one oscillation. Adjustment of this length allows one to ensure that the time is correct. However, to ensure that the pendulum is not overstressed during operation, the pendulum must also be treated as a flexible body subject to the applied loads from gravity, and the pendulum arm sized accordingly. The same situation applies with respect to the PFSF cask storage pads.

Q63. Please describe the computation of the foundation damping used in Holtec's cask stability analysis as it relates to the issue of pad rigidity.

A63. (AIS) The Holtec dynamic model incorporates the effect of the foundation by using a set of six springs and associated dampers in series with the springs. These springs and dampers were defined, based on the material properties provided by Geomatrix (lower range, best estimate, and upper range properties, based on a weighted average over a 30 ft depth below the pad, including the effect of soil cement). The soil springs and dampers were defined by Holtec using the applicable formulas in ASCE 4-86, which assume that the pad acts like a rigid body.

Q64. Does the assumption of pad rigidity lead to overestimation of foundation damping as claimed in Section D.1.b(ii) of the Unified Contention?

A64. (AIS) No. Based on our evaluation of the effect of pad flexibility for Sequoyah, any effect of pad flexibility on foundation damping would be minimal. This is confirmed by the testimony by Dr. Wen Tseng being filed simultaneously with this testimony. Dr. Tseng testifies that the pad behaves as a rigid body insofar as it affects foundation damping in the frequency range of interest here. Therefore, treatment of the pad as rigid does not lead to an overestimation of foundation damping as claimed by the State in Section D.1.b(ii).

Q65. The State claims in its Response to Applicant's Eighth Set of Discovery Requests relating to its claim under Section D.1.b(ii) of the Unified Contention that Holtec's use of a 5% Beta damping coefficient is too high. Does Holtec's use of a 5% Beta damping coefficient in any way relate to the State's claim of overestimation of foundation damping based on asserted flexibility of the pad?

A65. (AIS) No. The "Beta damping" factor accounts for the energy loss during a vertical impact between cask and pad. It relates to the damping that Holtec used in modeling the compression-only springs at the interface of the cask and the pad. A damping element in parallel with the compression spring (between the pad's upper surface and the base of the cask) is incorporated to account for this energy dissipation mechanism. Such damping has no relationship to the damping values for the soil underlying the pad.

Q66. The State also claims in its Response to Applicant's Eighth Set of Discovery Requests that the asserted flexibility of the storage pad violates Holtec's assumption "that a uniform coefficient of friction exists between the bottom of the casks and the top of the pad." Do you agree?

A66. (AIS) No. Our assumption as to the coefficient of friction between the casks and the pads does not depend on whether the pads are flexible or rigid. Nor did we assume that the coefficient of friction at the cask-pad interface would be uniform (a single value) as claimed by the State. Rather, the coefficient of friction will vary between two moving objects regardless of whether the bodies are rigid or flexible. To account for the effect of expected variations due to surface effects, we performed our cask stability analyses at both an upper and a lower bound coefficient of friction to envelop the effects of this potential variation. We discuss the State's claims concerning the proper coefficient of friction further in the context of Section D.2.c(iii) of the Unified Contention.

3. Claims Raised in Section D.1.c of the Unified Contention – Evaluation of Potential Storage Pad Motion in Relation to Sliding of the Casks on the Pads

Q67. Please describe the claims raised by the State in Section D.1.c of the Unified Contention.

A67. (AIS) The State claims in Section D.1.c of the Unified Contention that the Applicant has failed to provide a realistic evaluation of the foundation pad motion with cement-treated soil under and around the pads in relation to the motion of the casks sliding on the pads in that Applicant's evaluation ignores (i) the effect of soil-cement around the pads and the unsymmetrical loading that the soil-cement would impart on the pads once the pads undergo sliding motion, (ii) the flexibility of the pads under DBE loading, and (iii) the variation of the coefficient of sliding friction between the bottom of the casks and the top of the pads due to local deformation of the pad at the contact points with the cask.

Q68. Did Holtec perform an analysis to show the relationship between the potential sliding of the foundation storage pads and the sliding and tipping of casks on the storage pads?

A68. (AIS) Yes. Holtec performed an analysis for PFS of the relationship between the potential sliding of the pads and the sliding and tipping of the casks on the pads. Our analysis is summarized in a August 6, 2001 letter from Holtec to PFS, which PFS forwarded to the NRC Staff by letter of August 7, 2001. The two letters are collectively identified as PFS Exhibit NN.

Q69. Please describe the analysis performed by Holtec.

A69. (AIS) As discussed in the testimony of Mr. Paul Trudeau being filed simultaneously with this testimony, the storage pad will not undergo sliding under the 2,000-year design-basis earthquake. Therefore, sliding of the pads is a beyond design basis event and Holtec's analyses of the effect of sliding of the pads were performed only to demonstrate the conservatisms in the PFS design basis.

Nonetheless, to simulate the potential effect of a postulated sliding of the pad relative to the foundation, the design basis simulation model was altered to replace the three translation soil springs beneath the storage pad (one vertical spring to simulate tension-compression resistance and two orthogonal lateral springs to simulate the shear resistance from the underlying soil/soil-cement) with a vertical compression-only spring and two orthogonal horizontal friction springs. The vertical compression-only spring represents the resistance to movement due to the normal downward force of the loaded storage pad and the orthogonal horizontal friction springs represent the resistance to movement due to friction between the pad and the soil (for which a coefficient of friction of 0.306 was used). Holtec analyzed three cases, each having eight casks on the pad and assuming a coefficient of 0.80 between the cask and the pad. The only difference between the three cases was the damping associated with the vertical compression only spring and the two orthogonal horizontal frictions springs. Case 1 assumed the damping values used in the original simulation, Case 2 assumed damping values reduced to 10% of the values used in Case 1, and Case 3 assumed damping values reduced to 1% of the values used in Case 1.

Q70. What were the results of your analysis?

A70. (AIS) The results of calculation showed that sliding of the pad dramatically reduces the movement of the cask. For example, whereas the maximum cask lateral excursion, relative to the pad, in the original model simulation was on the order of 3 to 4 inches, for Case 2 of the simulation -- where sliding of the pad of was less than four inches -- the maximum excursion for the casks, relative to the pad, did not exceed 0.02 inches. Thus, sliding of the pad even a few inches reduces the maximum excursion of the cask relative to the pad by more than two orders of magnitude.

Q71. Is this result consistent with what one would expect based on general physics considerations?

A71. (AIS) Yes. As discussed in PFS Exhibit NN one would expect as a general matter that sliding of the pad would reduce the seismic energy transferred to the casks, and therefore decrease the motion of the casks relative to the pad. Indeed, this is the theory behind base isolation design of structures or buildings to protect them from earthquake damage. The base on which the building or structures rests is designed to freely move with the earthquake such that the forces of the earthquake are not transferred to the building or structure. Therefore, insofar as cask stability is concerned, pad sliding is a favorable occurrence.

Q72. Did you take into consideration the behavior and effect of the soil cement in your pad sliding analyses?

A72. (AIS) No. Since our analysis was a simplified analysis intended only to demonstrate the general effect of sliding of the storage pads on cask motion, Holtec did not take into consideration the effect of soil cement or any other material (e.g., soil) around the pad. Such effects would have not altered significantly the results of the analysis.

Q73. Would the presence of soil cement around the pads result in unbalanced (unsymmetrical) loadings on the pads once the pads undergo sliding movement?

A73. (AIS) There could be some minute effects due to thin cracks in the soil cement, which I understand from the testimony of Mr. Paul Trudeau could occur. However, even assuming (unrealistically) that all these cracks between pads were aggregated into a single gap between the soil cement and one of the pads, the maximum size of the gap, according to Mr. Trudeau, would be on the order of ½ inch. Assuming such a gap, oscillations of the pad under earthquake motions could then involve some mild impacts if the pad were to bump against the soil cement. But, any such impact would be small because earthquake motions rapidly change direction, so the pad and the soil cement often would be moving in the same direction and would not collide. In the analysis Holtec performed, it was considered appropriate to neglect the effect of the soil cement adjacent to each pad as it would likely be negligible.

Q74. To what extent would such unsymmetrical loadings as you just described affect the stability of the pads and casks?

A74. (AIS) If one postulated that gaps of the size I just described were present, and further postulated that the pads did slide under the design basis seismic event, there would be additional lateral restraint forces coming into play to resist further movement of the pad on each cycle. On the one hand, this postulated closure of the soil cement pad gap would lead to horizontal impacts not included in the current analysis; however, on the other hand, the same non-linear effect would be accompanied by an additional energy absorption not currently included in the analysis. On balance, it is our opinion, based on engineering judgment and experience with a large number of similar simulations involving horizontal rack-to-rack impacts, that the sum total of the effects would result in minimal changes to the results of the existing analyses.

Q75. In his deposition, State witness Dr. Ostadan claimed that Holtec improperly failed to take into account the soil cement in its analysis under design basis conditions, in which Holtec assumes that the pad does not slide. According to Dr. Ostadan, the oscillations of the pad, even though not sliding would be out of phase with the oscillations of the soil cement resulting in the soil cement and the pads bumping against each other as they oscillate.[1] Is this aspect of the State's claim, as articulated by Dr. Ostadan, realistic?

A75. (AIS) No. The potential impacts referred to by Dr. Ostadan would be even less than those discussed above because the movement of the pads under purely oscillatory motion with no sliding would be even less than those occurring if the pad were to slide. Therefore, any loads resulting from the abutment of the pads and the soil cement would continue to be negligible and would not affect the conclusions from the analysis. Indeed, Dr. Ostadan acknowledges that the effect of any pad to soil cement interaction would be small and that he raises the issue because of the allegedly "slim margins" against sliding present in the design.

Q76. In Section D.1.c(ii), the State again takes issue with your treating the pad as rigid, claiming your analysis does not take into account "the flexibility of the pads under SSE loading." Do you understand the State to raise any issues different here than those you already responded to with respect to the State's claims in D.1.b. of the Unified Contention?

A76. (AIS) No.

Q77. In section D.1.c(iii), the State claims that, in evaluating the motion of the casks sliding on the pad, Holtec failed to take into account the variation of the coefficient of sliding friction between the bottom of the casks and the top of the pads due to local deformation of the pad at the contact points with the cask. What is your response to this claim?

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[1] Deposition of Farhang Ostadan ("Ostadan Dep.") (March 8, 2002) at 143.

A77. (AIS) The interface between the cask and the pad consists of the steel surface of the bottoms of the HI-STORM System casks and the concrete surface of the storage pads. In our cask stability analysis for the PFSF, Holtec evaluated the potential for casks to tip over and for casks to impact each other by sliding. We analyzed the stability of the casks at two bounding coefficients of friction, a lower bound coefficient of 0.2 and an upper bound coefficient of 0.8. The analysis at the lower coefficient of friction of 0.2 emphasizes the potential for the casks to slide and impact each other on the concrete pad. The analysis at the higher coefficient of friction of 0.8 emphasizes the possibility for cask tip-over.

The chosen values of 0.2 and 0.8 effectively bracket the expected range of the coefficient of friction for the interaction of a steel-bottomed cask with a concrete pad. Typical upper and lower bounds for the coefficient of friction given by various handbooks for metal on concrete/stone surfaces range between 0.3 to 0.7. See, e.g., Mark's Standard Handbook for Mechanical Engineers 3-22 (Eugene A. Avallone & Theodore Baumeister, III, eds., 10th ed. 1997) (coefficient of friction for iron on stone – 0.3 to 0.7); Harry Parker and James Ambrose, Simplified Mechanics and Strength of Materials 34 (5th ed. 1992) (coefficient of friction for metal on stone, masonry, or concrete – 0.3 to 0.7). The value of the lower coefficient of friction analyzed by Holtec of 0.2 is less than the lower bounds cited by these handbooks, and the value of the higher coefficient of friction analyzed by Holtec of 0.8 is greater than the upper bounds from these handbooks.

Thus, Holtec did not assume that the coefficient of friction would be a single value. Rather, it assumed a lower bound coefficient of friction and an upper bound coefficient of friction such that its analyses would bracket the range of coefficients of friction that one would expect for a free-standing steel surface on a concrete pad. This approach is consistent with the analyses performed by Holtec for spent fuel storage racks in spent fuel pools.

Q78. The State also contends in its Response to Applicant's Eighth Set of Discovery Requests that because of the asserted flexibility of the storage pad that the "sliding resistance will not be constant due to local deformations of the surface of the pads resulting from inertial loadings imposed by the casks." What is your response to this claim raised by the State?

A78. (AIS) As stated above, Holtec did not assume that the sliding resistance would be a single, constant parameter but chose an upper and lower bound for the coefficient of friction in its analyses to emphasize the potential for sliding or tipping. Use of this procedure has been accepted by the regulating body as appropriate in the many license submittals for Holtec's spent wet storage fuel racks, where we used an upper bound coefficient of friction of 0.80 and a lower bound of 0.20.

Nor will small pad deformations adversely affect the sliding of the casks as asserted by Dr. Ostadan in his deposition. As set forth in the testimony of Dr. Wen Tseng, ICEC has calculated that the maximum local deformations sustained by the pad under the design basis earthquake due to the dynamic forces of the casks are on the order of 1/8 of an inch. Such small deformations would not occur as sharp ridges, but would develop gradually over many feet. Such negligible deformations create neither a depression nor a ridge in the pad that would have any perceptible effect on the sliding of a 19 ft high, 360,000 lb cylindrical cask, with a diameter of 11 ft and bottom surface area of 95 square feet.

4. Claims Raised in Section D.1.d of the Unified Contention – Lateral Variations in the Phase of the Ground Motions

Q79. Please describe the claim raised by the State in Section D.1.d of the Unified Contention.

A79. (AIS) In Section D.1.d of the Unified Contention, the State claims that the "Applicant has failed to consider lateral variations in the phase of ground motions and their effect on the stability of the pads and casks."

Q80. What is your understanding of this claim?

A80. I understand from Dr. Ostadan's deposition and the testimony of Dr. Youngs and Dr. Tseng that this claim is essentially the same claim as raised in Section D.1.a of the Unified Contention, which, as discussed above, is addressed in the testimony of Drs. Young and Tseng.

5. Claims Raised in Section D.1.e of the Unified Contention – Frequency Dependency of Soil Spring and Damping Values

Q81. Please describe the claims raised by the State in Section D.1.e of the Unified Contention.

A81. (AIS) In Section D.1.e of the Unified Contention, the State claims that "Applicant's calculation for cask sliding do not address the frequency dependency of the spring and damping values used to model the foundation soils."

Q82. What is your response to this claim?

A82. (AIS) The terminology associated with "frequency dependency" arises from the formulation and solution of a linear problem in the frequency domain (as opposed to a solution in the time domain). The problem of free-standing casks on a pad is a non-linear problem; as such, the only correct methodology to use is a time domain solution. The design basis methodology employed by Holtec for the PFSF cask seismic stability simulations is, (correctly) time-domain based.

The soil spring, masses, and dampers derived by Geomatrix from its analyses incorporate the fundamental frequency of the soil foundation (predominantly 1 to 5 Hz). While there may well be some higher order frequency contributions, their effects on the cask responses will be secondary since the cask response to the earthquake (i.e., amplitude of excursion vs. time) is primarily at or below 5 Hz. Thus, if the soil's spring-mass-damper model used as the design basis input was replaced by a model involving multiple masses, springs, and dampers to incorporate effects of higher order frequency "bumps" in the spectra (if indeed, any such bumps were identified), the response of the casks would not be significantly altered and, certainly, the conclusions concerning overall stability of the casks would remain unchanged.

Q83. In the statements supporting this claim, the State witnesses assert that, "[b]ecause the cask-pad-soil-cement is a non-linear analysis, it is very important to consider all potential variation in the motion of the casks and the pads. If the casks and the pads move out-of-phase significant instability conditions may arise." To what extent does Holtec's casks stability analysis assume that the casks and pads will move in phase?

A83. (AIS) Holtec's cask stability analysis makes no *a priori* assumption concerning how the casks will move in relation to one another or in relation to the pad. The dynamic simulations performed by Holtec assume only that the casks and the pad are initially at rest at their respective locations, under a 1g gravitational loading, that the cask-to-pad interface has a dynamic coefficient of friction equal to either the upper or lower bound value, and that the coefficient of friction value remains constant through the seismic event's duration. There is no assumption of phasing imposed at the start of the time history simulation and there are <u>no</u> constraints imposed on the cask behavior at any point in the simulation.

Q84. Would out of phase motion between the casks and pads result in underestimating the potential instability of the casks, as claimed by the State?

A84. (AIS) The cask responses in each of the dynamic scenarios exhibit various degrees of phasing between the dynamic responses of each cask; however, this phasing is the solution from the dynamic analysis, not an imposed condition. We note that, even if the responses of adjacent casks were to be constrained to be completely out of phase in the analytical simulation, the magnitudes of the displacements at the top of the cask, resulting from the design basis 2,000-year return period, are such as to ensure large margins of safety against cask overturning and cask-to-cask impact. As discussed above, the maximum displacements are less than 3.25 inches, which is much less than 50% of the approximate 4 to 5 foot spacing between the casks on the pad.

Q85. What do you therefore conclude with respect to the State's claim in Section D.1.e. of the Unified Contention?

A85. In Holtec's opinion, the State's claim has no merit. Even assuming potential underestimation of the effect of out-of-phase motion of the casks, given the large cask-to-cask spacing at the PFSF and the large margins provided by the design against overturning and cask-to-cask impact, any such underestimation could not affect the results of the final analyses.

6. Claims Raised in Section D.1.f of the Unified Contention – Cold Bonding

Q86. Please describe the claims raised by the State in Section D.1.f of the Unified Contention.

A86. (AIS) In Section D.1.f of the Unified Contention, the State claims that the "Applicant has failed to consider the potential for cold bonding between the cask and the pad and its effects on sliding in its calculations."

Q87. What do you understand cold bonding to be?

A87. (AIS) We understand cold bonding to be a mechanical process wherein two bodies in contact, under a large pressure at their interface, develop a certain capacity to resist relative sliding. For example, titanium plates are often cold bonded to carbon steel plates by detonating an explosive charge which exerts a large interfacial pressure resulting in a bonding between the two plates. An essential precondition for cold bonding is the existence or application of a large interface pressure.

Q88. Will cold bonding develop over time between the casks and the pad as alleged by Dr. Ostadan?

A88. (AIS) No. The upper bound weight of a cask is 360,000 lb. The average pressure developed at the interface to support this weight is equal to the 360,000 lb of the cask divided by the area of the interface between the cask and the pad – i.e., the area of the bottom of the cask. Based on a 132.5 inch diameter cask, the average pressure at the interface is approximately 26 psi. We recognize the pressure distribution is not uniformly distributed and that higher pressures will exist around the periphery than at the center. But, even if we were to consider the entire load to be supported only over a 12" wide annulus around the periphery, the static contact pressure would rise only to 40 psi. This level of pressure is comparable to a 200 lb man standing on the ball of one foot. It is fair to assume that in such a situation the man would not become bonded to the concrete. In short, the large weight of the cask has no significance here, given the absence of a large interfacial pressure. There will be no bonding between the steel bottom of the cask and the concrete surface of the pad.

Q89. In responding to PFS's request to identify and fully describe each respect in which the PFS has failed to consider the potential for cold bonding between the casks and the pads, the State responded in part as follows (State's Response to Interrogatory No. 11 in Applicant's Eighth Set of Interrogatories):

> Holtec's design of the casks assumes that the casks will slide on the pad in a controlled in-phase manner during a large earthquake without excessive sliding, pounding or tipping . . . . However, such a bold design concept could be negated by the potential for cold bonding between the casks and the pad that may develop over time.

Does Holtec in any respect assume, as claimed by the State, that the casks will slide on the pad "in a controlled in-phase manner during a large earthquake without excessive sliding, pounding or tipping?"

A89. (AIS) No. We have previously described how Holtec modeled and performed the cask stability simulations. The Holtec analyses make no assumptions concerning cask phasing. The response of the casks, relative to one another, is an output from the simulations, not an input constraint. Sliding is not controlled in any manner by the solution methodology.

Q90. The State goes on to assert in the same answer to Interrogatory No. 11 answer that "[w]hen two bodies (cask and pad) with such a large load (the cask) are in contact, some local deformations and redistribution of stresses may occur at the points of contact which would create a bond, and thus would not allow the cask to slide on the pad or move smoothly during an earthquake and thus negate the design concept." What is your response to these assertions of the State?

A90. (AIS) The coefficient of friction between two bodies may vary over time due to the direction of relative motion at the interface and other factors. However, the average coefficient of friction obtained from a statistically significant set of measurements will yield a generally acceptable result for engineering analyses of performance and response over time. It is precisely because of the uncertainties involved with coefficients of friction that the PSFS analyses evaluated scenarios using acceptable upper and lower bound values for the coefficient of friction. While using an intermediate value or even some randomly varying value (over time) will lead to different results, using as we did upper and lower bound coefficients of friction for the design basis solutions does provide appropriate bounding results.

Q91. If the casks do not slide smoothly, will there be greater loadings on the casks than assumed by Holtec?

A91. (AIS) As noted in the previous response, any small perturbations in the cask response due to irregular sliding would be within the range of results encompassed by the design basis simulations.

Q92. In his deposition, Dr. Ostadan claimed that a practical consequence of cold bonding was that the coefficient of friction between the cask-pad interface would be 1.0. Would using a coefficient of friction of 1.0 change the results of your analysis?

A92. (AIS) If we hypothesized as a bounding scenario a coefficient of friction of 1.0 (rather than 0.8), our results could be somewhat altered, but the overall conclusions would not be altered. The reason is that, as a practical matter, the upper bound coefficient of friction that we used of 0.8 is already set high enough to favor tipping of the cask. Potential cask tip-over would be essentially the same at a coefficient of friction of 0.8 as it would at a coefficient of friction of 1.0.

7. Claims Raised in Section D.1.g of the Unified Contention – Failure to Analyze for Pad-to-Pad Interaction in PFS's Sliding Analysis of the Storage Pads

Q93. Please describe the claims raised by the State in Section D.1.g of the Unified Contention.

A93. (AIS) In Section D.1.g of the Unified Contention, the State claims that the "Applicant has failed to analyze for the potential of pad-to-pad interaction in its sliding analyses for pads spaced approximately five feet apart in the longitudinal direction."

Q94. Do your cask stability analyses incorporate the effects of potential pad-to-pad interactions?

A94. (AIS) No. Holtec evaluated the possibility of pad-to-pad interactions and concluded that any such interaction would have only second-order effects that would not affect the validity of the calculations. Accordingly, Holtec did not incorporate pad-to-pad interaction effects into its analysis.

Q95. How did you evaluate the effect of pad-to-pad interactions, and on what basis did you conclude that they would be second order effects?

A95. (AIS) Based on the calculated pad movements for both the 2,000-year and 10,000-year return period earthquakes, it was our engineering judgment that any resistance from the soil cement between pads would not affect the system response in any material manner.

Q96. What effects may the nearest of the pads to one another (five feet apart) have on Holtec's cask stability analysis?

A96. (AIS) The potential effects for pad-to-pad interaction are essentially discussed in our responses to Section D.1.c. where we discussed the effects of potential loads caused by the pad collisions with the adjoining soil cement.

Q97. Does Holtec treat the soil cement as a reinforced concrete mat in its cask stability analysis?

A97. (AIS) No. The soil cement and the soil layers underlying the soil cement are modeled by six linear springs (three translation and three rotation springs); the magnitudes of these six springs are a function of a soil foundation modulus (averaged over a thirty foot depth) and the geometry of the pad. Formulas to derive the spring constants are obtained from industry standards (e.g., ASCE-4-86) and include the contribution of the soil cement layer under the pad.

Q98. If the cement-treated soil, soil-cement and storage pads for ten rows of pads did not behave as an "integrated unit," would that affect Holtec's cask stability calculations?

A98. (AIS) The cask stability analyses performed by Holtec do not rely on the cement treated soil, or soil cement for 10 rows of pads behaving as an "integrated unit". Therefore, such behavior, or lack of same, would not alter our results.

8. Claims Raised in Section D.1.h of the Unified Contention – Use of One Set of Time Histories

Q99. Please describe the claims raised by the State in D.1.h of the Unified Contention.

A99. (AIS) In Section D.1.h of the Unified Contention, the State claims that the use of one set of time histories in Holtec's cask stability analysis is inadequate because (i) nonlinear analyses such as Holtec's are sensitive to the phasing of input motion and more than one set of time histories should be used, and (ii) fault fling (i.e., large velocity pulses in the time history) and its variation and effects are not adequately bounded by one set of time histories.

Q100. What has been Holtec's experience with the number of sets of time histories used in the non-linear analyses for free-standing nuclear spent fuel components?

A100. (KPS, AIS) As discussed previously, in addition to Holtec's work in the area of dry cask storage, Holtec has also been a major supplier of wet storage (spent fuel racks) technology to the nuclear power industry. Since 1986, Holtec has made a large number of licensing submittals to the NRC and other agencies and had also prepared such documents for utilities evaluating the potential for increasing their wet storage capacity. Holtec's practice has been to follow NRC guidance on the number of sets of time histories that should be used in dynamic analyses of SSCs important to safety.

Q101. What has been the NRC guidance on the number of sets of time histories that should be used in dynamic seismic analyses?

A101. (AIS) The generation of time histories for use in dynamic simulations is discussed in NUREG-0800, Standard Review Plan ("SRP") 3.7.1. Revision 1 of this document, issued in July 1981, simply stated that the response spectra re-generated from the artificial time histories should envelop the design response spectra (with limited exceptions) at the same location for all damping values actually used in the analysis. The practical effect of requiring the design response spectra generated from the time histories to envelope the original earthquake response spectra is that the design response spectra will on average be larger than the earthquake response spectrum. Therefore, this process generally results in amplitudes of the generated design response spectra that are conservative compared to the original earthquake response spectra.

Revision 2 to the SRP was issued in August 1989. This Revision introduced two options for the use of artificial time histories in analysis: Option 1 allowed the use of a single time history (the same as Revision 1), except that in addition to enveloping the original response spectra, a regenerated Power Spectral Density ("PSD") distribution also had to be shown to adequately match a target PSD compatible with the original response spectra. A PSD is a measure of the energy contained in the earthquake as a function of the frequency range, and the requirement to adequately match a target PSD compatible with the original response spectra was intended to insure that all significant energy was captured by the derived artificial time histories and that no important frequency ranges containing peaks in the PSD function were missed.

Option 2 allowed the use of multiple time histories. The SRP recommended a minimum of four time history sets, but specifically provided that each individual set did not have to envelop the target response spectra. Also, Option 2 did not impose any requirement to match a target PSD compatible with the earthquake response spectra.

Although the SRP guidance provided two options, it provided no guidance on when these differing options should be implemented. Neither Option 1 nor Option 2 is restricted to linear or non-linear problems when artificial time histories are considered.

Q102. How did Holtec's practice of generating and using one or more sets of time histories for its non-linear analyses evolve in relation to the change in guidance in the NRC SRP?

A102. (AIS) A partial list of Holtec's licensing submittals and/or plant requested analyses appears below. The list contains, in the final column, whether the seismic inputs involved: a single time history or multiple time histories. As can be seen by examination of this table, Holtec generally followed Revision 1 of the SRP, and then Option 1 of Revision 2 through 1992. However, in the 1993-1994 time period, as a general matter, Holtec followed Option 2 of Revision 2 of the SRP and utilized multiple sets of time histories for its non-linear analyses of spent fuel storage systems. After 1994, Holtec generally returned to using single sets of time histories.

Plant Name	Date	NRC Docket #	# of Time Histories
Diablo Canyon Unit I & II	1986	50-275 50-323	Single (3 Different Spectra)
St. Lucie Unit No. I	1987	50-335	Single
Byron Units I & II	1987	50-454 50-455	Single
Chin Shan	1988	-	Single
Vogtle	1989	50-425	Single
Millstone Unit I	1989	50-245	Single
Ulchin Unit II	1989	-	Single
Kuosheng	1989	-	Single
Indian Point Unit II	1990	50-247	Single
Laguna Verde	1990	-	Single
J.A. FitzPatrick	1990	50-333	Single
Three Mile Island Unit I	1990	50-289	Single
D.C. Cook	1992	50-315 50-316	Single
Fort Calhoun Station	1992	50-285	Single
Hope Creek	1992	50-354	Single
Zion Station	1993	50-295 50-304	Single
Salem Generating Station	1993	50-272 50-311	Multiple
Sequoyah Unit I	1993	50-327	Multiple

and Unit II		50-328	
Beaver Valley Power Station Unit I	1993	50-334	Multiple
Fort Calhoun Station	1993	50-285	Multiple
Duane Arnold Energy Center	1994	50-331	Single
Duane Arnold Energy Center	1994	50-293	Multiple
Limerick	1994	50-352 50-353	Multiple
Ulchin Unit I Spent Fuel Pool Capacity Expansion	1994	-	Single
Kori-4 & Yonggwang Units I & II	1995	-	Single
Comanche Peak	1995	50-445 50-446	Single
Connecticut Yankee Spent Fuel Pool	1996	50-213	Single
Ulchin Unit 2 Spent Fuel Pool	1996	-	Single
Watts Bar – TVA	1996	50-390	Single
Vogtle	1997	50-424	Single
Diablo Canyon Power Plant	1997	50-275 50-323	Single
Callaway and Wolf Creek	1998	50-483 50-482	Single
Chinshan Unit I & II	1998	-	Single
Waterford 3	1998	50-382	Single
Vermont Yankee	1998	50-271	Single
J.A. FitzPatrick	1998	50-333	Single

Kuosheng Unit I & II	1999	-	Single
Oyster Creek	1999	50-219	Single
Byron/Braidwood	1999	50-456/457 50-454/455	Single
Harris	1999	50-400	Single
Yonggwang	1999	-	Multiple
Millstone Unit 3	2000	50-423	Single
Fermi Unit II	2000	50-341	Single
Edwin I. Hatch Nuclear Plant Unit I & II	2000	50-321/366	Single
Davis Besse Unit I	2001	50-346	Single
Kewaunee	2001	50-305	Single
Nine Mile Point Unit II	2001	50-410	Single
Virgil C Summer	2002	50-395	Multiple

Q103. Was Holtec's change to multiple sets of time histories in the 1993-94 time frame or its return to a single set of time histories in the 1995 timeframe mandated in any respect by the NRC?

A103. (AIS) The changes were not mandated by the NRC in any formal written document. It is our collective recollection that the original change from a single to multiple time histories was motivated both by our client's wishes and the NRC staff suggestions to conform to the latest revision of the applicable SRP. However, in the 1995 timeframe, the NRC staff reviewers dealing with wet storage suggested that we return to the use of a single time history with the added requirements of adequately matching the PSD.

Q104. What are the advantages and disadvantages of the two methodologies as applied to the free-standing spent fuel storage casks modeled by Holtec?

A104. (AIS) The use of a single time history set constructed according to the SRP 3.7.1 guidelines ensures that the time history will generate a set of enveloping response spectra. The requirements of SRP 3.7.1 for use of a single set of time histories would lead to an "average" re-generated spectra set. On the other hand, the use of multiple histories may capture additional phasing effects. Based on the geometry and size of the pads and the testimony of Dr. Youngs, we do not believe that the phasing issue is of importance at the PSFS site. Our analysis of cask stability is most affected by the input seismic amplitudes. The single time history procedure is more likely to ensure that maximum amplitudes and proper frequency content are captured and utilized in the seismic design of the PFSF.

Q105. What has been Holtec's practice with respect to the number of sets of time histories it used since the NRC provided the option of using single or multiple sets of time histories?

A105. (AIS) Since that time, Holtec has used a single set of spectrum-compatible time histories for its analysis of free standing spent fuel racks and dry cask storage systems, unless directed otherwise by the client.

Q106. Based on the results of your dynamic analyses for the PFSF and your previous experience, can you draw any conclusion concerning the sensitivity of your non-linear cask stability analysis for the PFSF 2,000-year design basis earthquake to the phasing of input ground motions and whether considering additional sets of time histories with different phasing might affect the results of your analysis?

A106. (AIS) On the basis of the above-discussed results of our analyses, one would expect that use of different sets of time history inputs might alter individual results, but not the final conclusions.

Q107. Do you know whether the set of time histories for the current 2,000-year design basis earthquake that you used in your cask stability analyses incorporated what is known or referred to as fault fling?

A107. (AIS) Based on the testimony of Dr. Robert Youngs, we understand that the set of time histories for the 2,000-year design basis earthquake that we used in our cask stability analysis incorporated fault fling.

Q108. Do you have an opinion of whether a different set of time histories incorporating fault fling would affect the results of your cask stability analysis for the PFSF 2,000-year design basis earthquake?

A108. (AIS) Based on the testimony by Dr. Youngs, we would expect different results from different time history sets, independently of the inclusion of fault fling.

However, our opinion is that for the same seismic input strengths, use of one or more sets of time histories, with or without incorporating fault fling, would not alter the basic result. The casks would remain upright and would not impact each other.

Q109. What conclusion do you draw on about the State's claimed need for additional sets of time histories?

A109. (AIS) Holtec's cask stability analyses are based on the use of a time history set that ensures bounding of the design basis response spectra and the power spectral density functions in accordance with SRP 3.7.1, Option 1. The design basis time histories do include fault fling. The level of cask response from the current 2,000-year return period design-basis seismic input ensures that there is a large margin of safety against cask tip-over and/or cask-to-cask impact. While use of different time histories will give different response levels, the margins of safety that exist based on the current design basis results lead us to conclude that there is no merit to the State's claimed need for additional time histories. In Holtec's opinion, any such temporal differences in the cask excursions would be small and would not compromise the conclusion that the casks would remain stable.

Q110. Do you know what process other vendors used for their wet storage submittals?

A110. (AIS) Our knowledge of other cask vendors submittals is limited. However, we have some information on Westinghouse spent fuel rack analyses for San Onofre Units 2 and 3 (circa 1990) and Westinghouse spent fuel rack analyses for Comanche Peak (circa 1994). Both of these analyses used a single set of time histories. For San Onofre, time histories bounding the response spectra were developed without a corresponding comparison of the PSD function. The later submittal, for Comanche Peak, developed time histories that bounded the response spectra and produced re-generated PSD functions in accord with the latest version of SRP 3.7.1.

9. Claims Raised in Section D.1.i of the Unified Contention

Q111. In Section D.1.i of the Unified Contention, the State claims that the because of the alleged errors and omissions and unsupported assumptions asserted in Sections D.1.a through D.1.h of the Unified Contention, "the Applicant has failed to demonstrate the stability of the free standing casks under design basis ground motions" and thus has failed to show that "excessive sliding and collision will not occur or that the casks will not tip over" as required by 10 C.F.R. § 72.122(b)(2). What is your response to the State's claim?

A111. Holtec has examined the cask response at PFSF for different magnitude design basis seismic events and accompanying input soil properties. A multitude of cask arrays on the pad have been considered, which provided both symmetrical and asymmetrical loads on the pad. Under all conditions, including an evaluation of pad sliding on the foundation, the results from the analyses have demonstrated that casks will not overturn nor will adjacent casks impact one another. The methodology employed to obtain the results is based on a time-domain solution of the governing equations of motion and considers each cask on the pad as a free standing body. There are no constraints imposed on the behavior of casks during the seismic event. No assumptions on in-phase or out-of-phase motion are required, and both upper and lower bounds on friction coefficients between casks and pad are employed to ensure that uncertainties in the instantaneous contact behavior at the cask/pad interface would be encompassed by the totality of simulations. Based on the totality of results and on the large margins of safety against tip-over and impact, we conclude that the requirements of 10 C.F.R. § 72.122(b)(2) and NUREG-1536 at 3-6 have been achieved by the analyses performed. We also note that confirmatory independent calculations have been performed by Sandia Laboratories for the NRC. These confirmatory calculations, performed using a finite element code and including pad flexibility and explicit representation of the soil layers, confirmed that for the parameters considered, the levels of cask response from the Sandia analyses and from the Holtec analyses were in good agreement, and that no adverse effects on the stability of the casks would be experienced under design basis earthquake loadings.

Q112. Have you performed any additional analysis to evaluate the various claims raised by the State in Section D.1?

A112. (KPS, AIS) Yes. Holtec performed additional computer simulations to evaluate certain other issues raised by the State. The State's witnesses have challenged the modeling of the soil/soil cement foundation under the pad and the level of damping that can be ascribed to the soil. Our simulation have confirmed that these concerns are unfounded.

Q113. What computer code did you use for these additional analyses?

A113. (KPS AIS) Holtec used the VisualNastran ("VN") code that it had previously used for evaluating the beyond-design basis 10,000-year earthquake. Holtec used the VN code because it conducted most of the additional analyses at the 10,000-year earthquake level. VN is better able to model large rotations of the cask that would be expected to occur under the 10,000-year earthquake event.

Q114. Please describe the issues raised by State that were addressed in the additional analyses.

A114. (KPS, AIS) The State has raised three general issues regarding the previous cask stability analyses that Holtec performed for the PFSF. These are as follows:

1. The State asserts that the 2,000-year design basis earthquake is inadequate in some respects, such as non-vertically propagating waves or lack of sufficient time histories that would increase the strength of that earthquake and adverse affect cask stability.

2. The State argues that pad flexibility significantly affects the level of damping provided by the soil foundation during a seismic event, and that PFS has overestimated the amount of soil damping available to inhibit seismic response of the casks; and

3. The State hypothesizes that the soil frequency response may actually be "in-tune" or, "in resonance" with the major energy producing frequency of the input seismic event and alleges that PFSF has not included this "resonance" potential in its model, leading to an underestimate of the amplification that may be imposed on the pad.

Q115. How do the additional analyses address the State's concerns regarding the adequacy the seismic input for the 2,000-year design basis earthquake?

A115. (KPS, AIS) Our analyses generally used a 10,000-year return period earthquake as the ground motion input so that there are no issues on whether our analyses use a bounding input. We do, however, include some analyses using the 2,000, year return period seismic event in order to demonstrate the dramatic difference in the results when the only change is the input driving function; and, to provide an independent check, using an entirely different computer code, that the level of response predicted from DYNAMO is in fact correct. The new analyses use a bounding seismic event whose strength, as measured by the peak ground acceleration, is far in excess of the 2,000-year return period design basis seismic event and would bound, by virtue of the increased strength, any issues raised by the State concerning the appropriateness of PFS's evaluation of the response to the 2,000-year design basis earthquake.

Q116. How do the additional analyses address the State's claim that Holtec's assumption of pad rigidity results in overestimation of soil damping?

A116. (KPS, AIS) The State's concern is addressed by arbitrarily imposing a low level of soil damping that provides a conservative lower bound on the level of damping actually expected in the soil. For a conservative simulation that minimizes the effect of soil damping, we conservatively choose the soil damping to be a low value of 1% of critical damping (as defined for a 1-degree of freedom mass-spring-damper system); for example, commensurate with an appropriate choice of the spring constant, the soil damper, C, in parallel with that spring is computed from the formula:

$$C = 2 \text{ x } (0.01) \text{ x } (k_0 \text{ x } (W/g))^{1/2}$$

Q117. How do the additional analyses address the State's concerns regarding "potential resonance effects"?

A117. (KPS, AIS) To determine the effects of "in-tune" or "resonance" increases in pad motion, we extended the simulation model used in the previous 10,000 year return period analysis to include the entire 30' x 67' pad, a simulation of soil springs displacement, and the rotation resistance provided by the foundation between the input motion and the pad. The simulation also included multiple casks on the pad. In this analysis, each cask is modeled as a rigid cylinder weighing 360,000 lb. The pad is modeled as a rectangular solid having a total weight consistent with that of a 3' thick concrete pad, and the effect to the soil substrate is modeled by three linear springs and three rotational springs and associated dampers in parallel with the springs.

A major source of input energy from the seismic event occurs in the vicinity of 5 Hz. Therefore, in many of the beyond-design bases bounding analyses performed in these new simulations, we have used the total vibrating mass (pad plus one or eight casks), and defined linear springs so that the mass-spring system has a resonant frequency of 5 Hz in order to show maximum "in-tune" or "resonance" effects.

The resonant soil properties are defined as follows:

For a given total problem mass (i.e. 30'x67'x3' slab + 8 casks), determine the vertical and horizontal linear soil spring constants to have a resonance at 5 Hz.

$k_0 = (W/g) \times (2\pi f)^2$

f=5, W= weight of entire slab + weight of total number of casks on pad.

With the total stiffnesses proportional to slab displacement chosen, these springs can be distributed over the pad interface area, and then the net rotational resistance about the three centroidal axes of the slab can be defined, providing the definition of the three rotational stiffness values. These stiffnesses are assumed to be positioned at the slab/soil interface.

We are thus able to choose two sets of stiffnesses that ensure a resonance effect for the case of one cask or eight casks on the pad. As noted, damping is chosen at 1% of critical based on the spring constant determined and the vibrating weight.

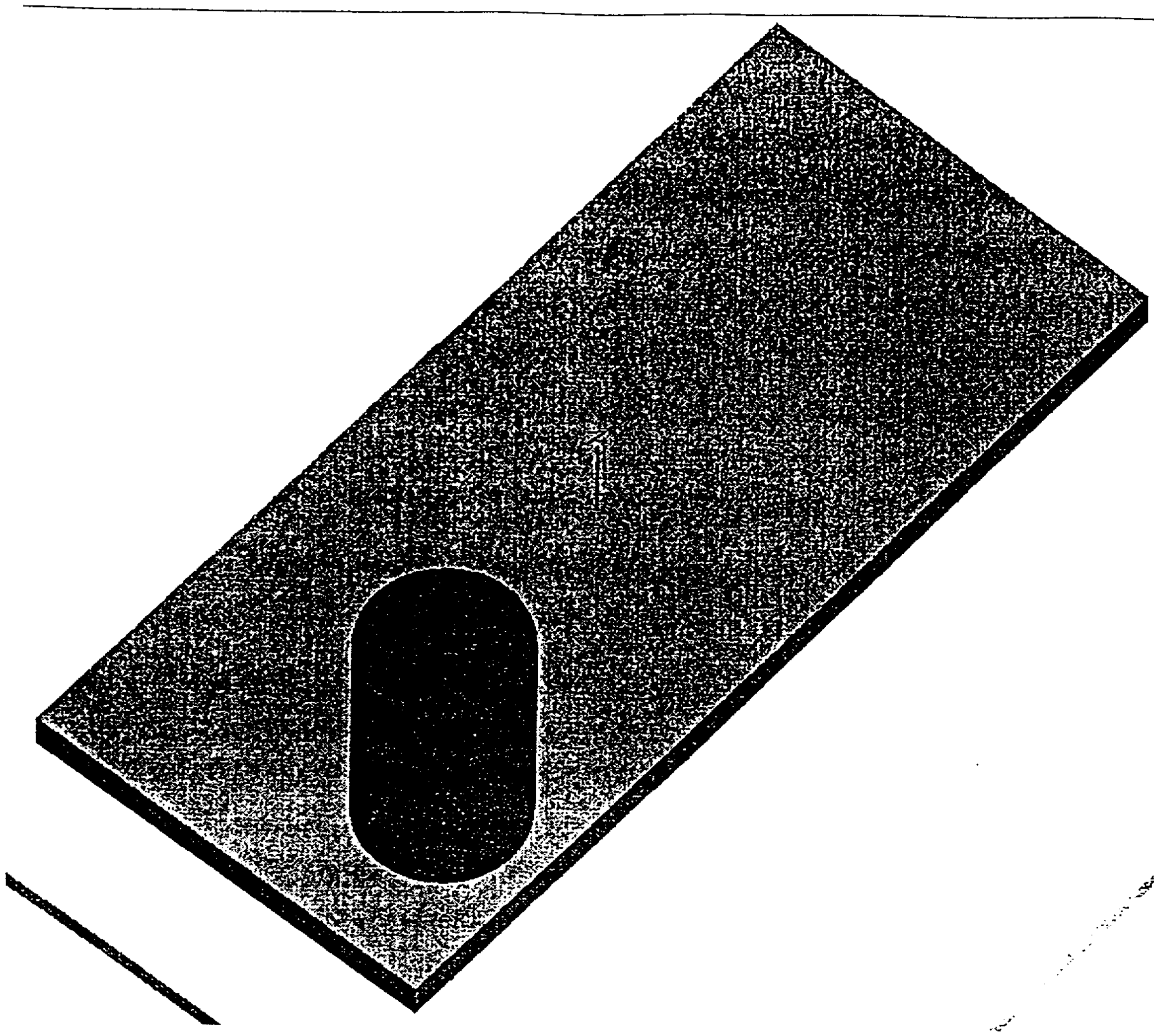
Q118. Please describe each of the analysis performed to address the State's concerns.

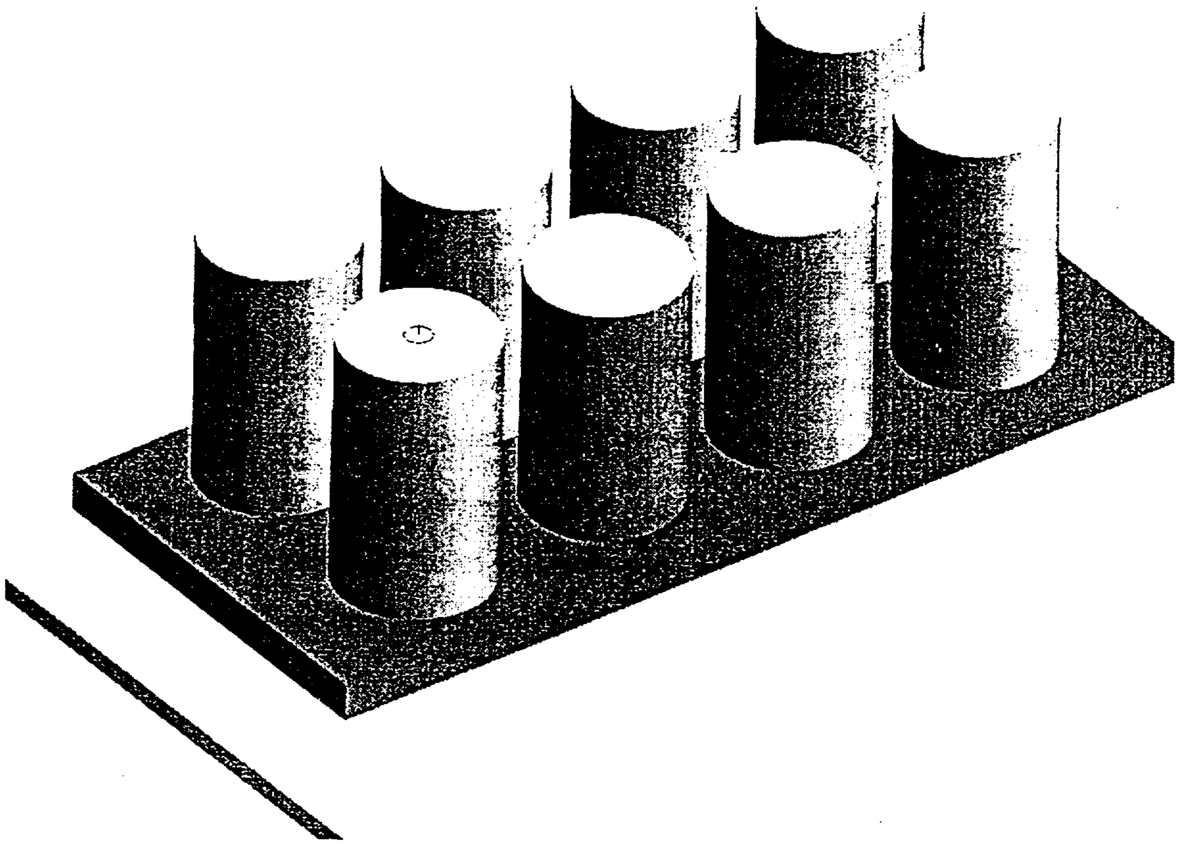
A118. (KPS, AIS) The table below describes the complete set of additional cask stability analyses performed in support of this testimony. For clarity, two 3-D graphics are included from the VN simulation. The graphics show the extreme cases modeled – one and eight casks on the pad. The soil springs between the pad and the reference plane are not depicted in either graphic.

SUMMARY OF VISUALNASTRAN ANALYSES

Case # - Description	Event	Stiffness	Damping	COF	Remarks
1. – 8 casks	2k	Lower Bound design basis	Lower bound design basis	.8	~~J,lkjlkj;lkjl~~ Demonstrate agreement with DYNAMO results
2. – 8 casks	2k	Resonance @ 5 Hz	1%	.8	Evaluate effect of "tuning" soil springs and low damping
3.-1 cask on pad	10k	Based on mass of 1 cask + entire pad oscillating at 5Hz	1%	.8	Lowest stiffness that gives 5 Hz tuning
4. – 1 cask on pad	10k	Based on mass of 1 casks + entire pad oscillating at 5Hz	5%	.8	Check damping effect
5.-3 casks on pad	10k	Based on mass of 1 casks + pad @ 5 Hz	1%	Random between 0.2 and 1.0	Check ~~sliding~~ real configuration
6.-3 casks on pad	10k	Based on mass of 1 cask + entire pad oscillating at 5Hz	1%	.8	Intermediate loading with low stiffness
7.- 4 casks on pad	10k	Based on mass of 8 casks + entire pad oscillating at 5Hz	1%	.8	Intermediate loading with ~~low~~ high stiffness
8.- 8 casks on pad	10k	Based on mass of 8 casks + entire pad oscillating at 5Hz	1%	.8	Fully populated with tuned stiffness and damping
9.- 8 casks on pad	10k	Based on mass of 8 casks + entire pad oscillating at 5Hz	1%	0.2	Fully populated with tuned stiffness and damping
10. – 8 casks on pad	10k	Based on mass of 8 casks + entire pad oscillating at 5Hz	1%	Random between 0.2 and 1.0	Fully populated with tuned stiffness and damping – evaluation of the effect of real behavior of friction between casks and pads
11. – 8 casks on pad	10k	Geomatrix Lower Bound Values consistent with 10k	Geomatrix Lower Bound Values consistent with 10k	.8	Design basis equivalent of 2k event

Notes: Horizontal shear springs chosen = to vertical spring. Then values are divided by 8 and an individual vertical and two horizontal springs located under each cask so as to define the applicable rotational resistance.





Q119. Please describe the results of your analyses.

A119. (KPS, AIS) The results from each simulation are summarized as a computer animated video, viewable with Windows Media Player or real player. These animated simulated effects form an integral part of the report summarizing each of the models and the resultant effects. These video files are on a single CD-ROM identified as PFS Exhibit ~~MM~~ OO.

Q120. Please summarize verbally, what these computer modeling simulations demonstrate.

A120. (KPS, AIS) The animation illustrates the following conclusions of the analysis:

(1) The results of the VN simulation using a 2,000-year return period event and the lower bound set of soil stiffness and damping elements, agree with the results predicted by DYNAMO. To the extent that there may be differences, these are due to the fact that

VN recomputes the equilibrium equations at each instant in time and accounts for the changes in orientation (even though they are small) throughout the entire run duration. DYNAMO, by contrast, uses the original equilibrium equations and does not update them continuously. Thus, the results from VN more accurately display slightly larger rotations than those predicted from DYNAMO if the rotations reach the upper end of "small rotations".

(2) The VN simulations using the 10,000 year return period event experience significant rocking behavior and out of phase motion of the casks when the coefficient of friction is 0.8. At certain instants, some casks impact each other with the net result that one of the two casks involved in the impact, slows down almost completely for a period of time following the contact.

(3) For coefficients of friction of 0.2, the casks move in phase and there are no contacts between casks.

(4) No overturning of any cask was experienced in any of the analyses.

(5) Random coefficients of friction reduced the rocking behavior of the casks.

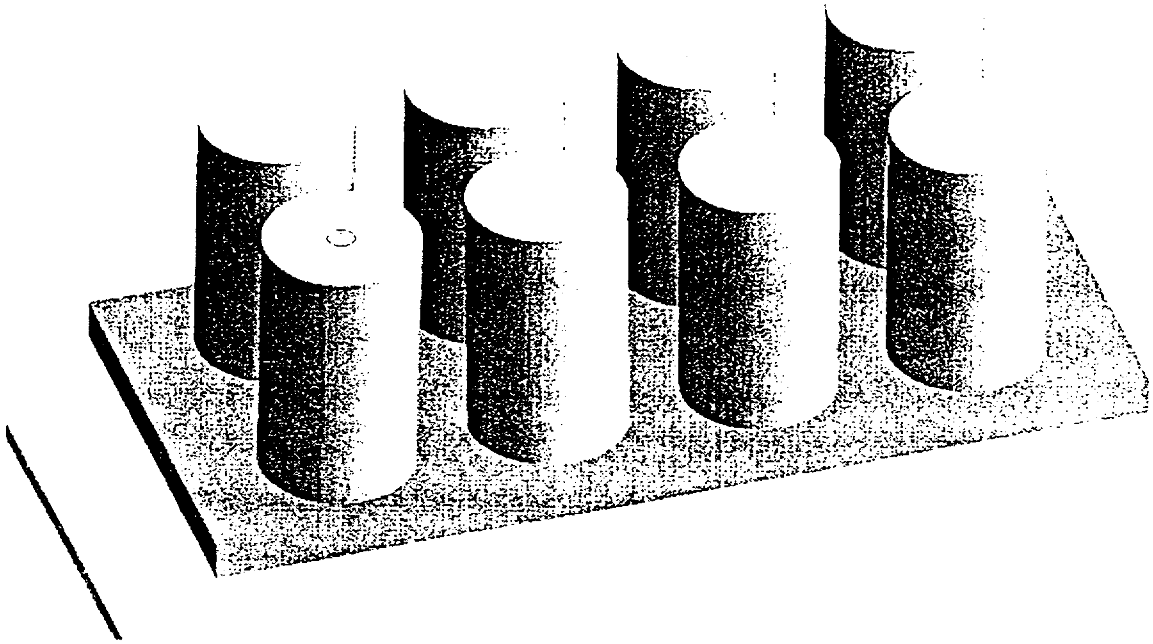
(6) While there was some effect on the system behavior due to "tuning" the stiffness values to match a input seismic frequency, the major contribution to the large motions was the earthquake strength.

Soil spring

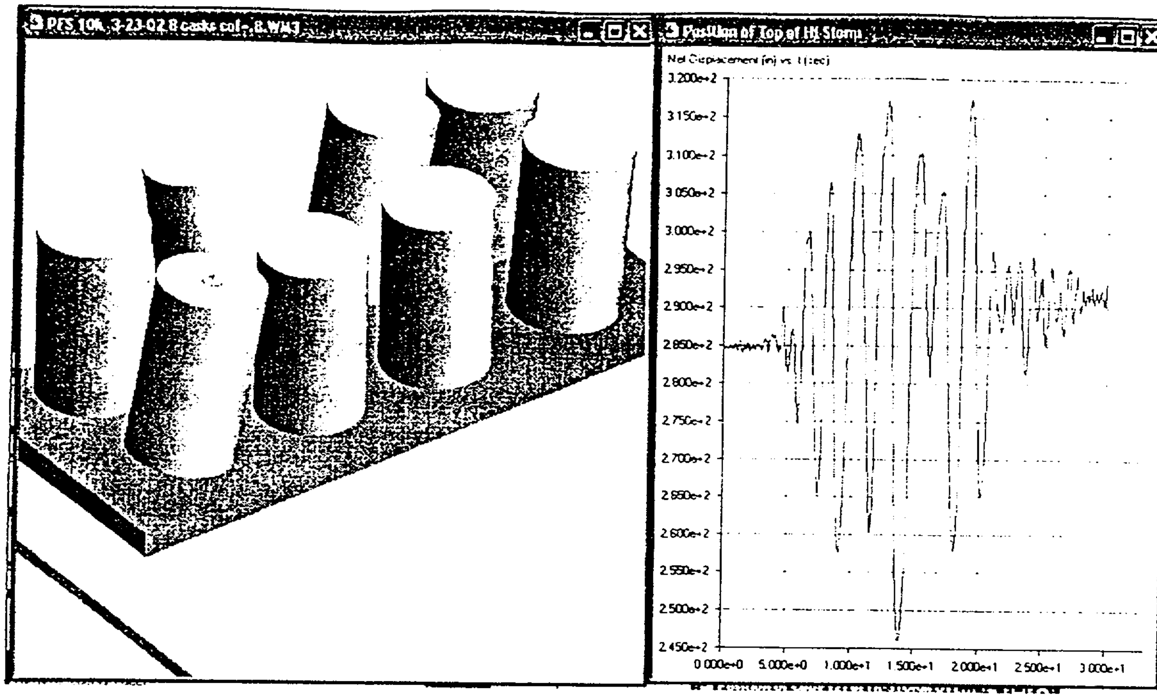
(7) The use of conservatively low soil damping values, while increasing the cask response, does not lead to a condition where severe pad oscillations occur.

(8) Maximum excursions of the pad horizontally are generally below 0.5".

The following figure shows the configuration of the Case 1 (current design basis) at an instant when maximum movement of any cask on the pad is observed. Because the movement is relatively small, only close observation of cask #3 reveals that it has the most deviation from vertical. There is no significant out-of-phase motion apparent throughout the entire duration of the design basis event.



In contrast to the above figure, the following figure shows the nature of the results from Case 8 where the 10,000-year return period seismic event is driving the system and conservatively "tuned" soil stiffness and 1% soil damping is assumed. It is very clear in this figure that the casks are experiencing large motions, with a significant contribution from out-of-phase effects. A plot of the net displacement of Cask #1 (the closest corner cask to the reader) shows the extreme position of this location as a function of time. Despite the orientations observed, at the end of the simulation, all casks are in their original vertical orientation, although perhaps, as can be seen in the graph, in a new location (the final rest position of this cask is approximately 8" from where it started).



Q121. What do you conclude from this additional study?

A121. (KPS, AIS) The additional analyses were performed using input values for earthquake, soil stiffness, and soil damping that was chosen to maximize any deleterious effects (as opposed to using expected real-world values). The results of these analyses shows that none of the State's claims have any merit. It is our opinion that the bounding simulations performed here demonstrate that the casks and the storage pad, under worst-case scenarios, show no significant detrimental effects that would lead to cask tipover. Accordingly, these recent analyses reconfirm our conclusion that the HI-STORM System will exhibit satisfactory performance at the design basis earthquake, and demonstrate capability of the HI-STORM System to withstand much larger earthquake events, up to and beyond the 10,000-year return period earthquake.

V. OTHER EVALUATIONS OF CASK STABILITY AT THE PFSF

A. Overview and Summary

Q122. Please identify what other analyses you have reviewed concerning the stability of the HI-STORM 100 casks at the PFSF.

A122. (KPS, AIS) We have reviewed and evaluated a cask stability analysis performed on behalf of the State of Utah by Dr. Moshin Khan of Altran Corporation, entitled "Analytical Study of HI-STORM 100 Cask System for Sliding and Tip-Over Potential During High-Level Seismic Event." The report is identified as Altran Technical Report No. 01141-TR-001, Revision 0, prepared for the Office of the Attorney General, State of Utah, dated December 11, 2001 ("Altran Report"). We also reviewed an earlier version of this Report dated November 30, 2001 filed by the State of Utah as part of its December 7, 2001 Opposition to PFS's Motion for Summary Disposition of Utah L, Part B (now Section E of the Unified Contention). We have also reviewed a report prepared on behalf of the NRC Staff by Sandia Laboratories, and other technical consultants, entitled, "Seismic Analysis Report on HI-STORM 100 Casks at Private Fuel Storage Facility" ("Sandia Report"), dated March 8, 2002.

Q123. Have you performed other activities in connection with your evaluation of the Altran Report?

A123. (KPS, AIS) In addition to reviewing the Altran Report, we also attended the March 5, 2002 deposition of Dr. Khan at which he explained various aspects of his analysis. We also performed various calculations to test what results his model would provide in standard problems whose solution is well known, to test the validity of the model used by Dr. Khan in the analysis described in the Altran Report. We have also reviewed pertinent information in the Finite Element Analysis (FEA) literature concerning the modeling of contact problems. Finite Element Analysis is a numerical approach to the solution of complex problems in structural analysis (and other fields). It required the development of computers to make the technique viable. Essentially, the continuum is broken into a large number of manageable elements where the displacement shape may be assumed. Continuity equations ensure that the elements are tied together properly, and the computer solves the large number of equations that ensue.

Q124. What are your conclusions from your evaluation of Dr. Khan's methodology and the results set forth in his report, as further elaborated on at his deposition?

A124. (KPS, AIS) Based on our review of Dr. Khan's work and the additional items performed as noted above, we conclude 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. Because his input values are unrealistic, they lead to non-converging solutions from which he draws improper conclusions on the behavior of the HI-STORM System casks.

Q125. What were the results of your review of the Sandia Report?

A125. (KPS, AIS) We concurred with the reasonableness of the model described in the March 8, 2002 report submitted to the NRC by Sandia Laboratories. We reviewed the results obtained by Sandia Laboratories for the cases and seismic events considered; on the basis of our review, we concluded that, although there are differences in the models used in the Sandia and Holtec analyses, the conclusions were in agreement. In fact, we view the Sandia results as confirmation that Holtec's assertions on the absence (or lack of effect) of pad flexibility and the applicability of soil springs in the dynamic analyses are reasonable and proper.

B. REVIEW AND EVALUATION OF ALTRAN REPORT ON CASK STABILITY AT THE PFSF

Q126. Please describe your major areas of disagreement with the Altran Report, as elaborated on by Dr. Khan at his deposition.

A126. (KPS, AIS) The major areas of our disagreement are: (1) Dr. Khan uses a model for his analysis that – unlike Holtec's model – has not been validated to show that it correctly models, and provides good solutions to, standard problems for which the correct solutions are known; (2) Dr. Khan fails to follow established guidance for developing inputs for key parameters used in his model and instead assumes values for key input parameters that provide unrealistic and physically impossible answers to real life situations; (3) Dr. Khan misinterprets results from his analyses for which his model has clearly failed to produce a correct solution (i.e., very large horizontal movements, way out of proportion to the strength of the input) and claims his results to represent accurate solutions. Because of these errors in Dr. Khan's analysis, his results are meaningless and therefore, the conclusions he draws from them are faulty; and (4) Dr. Khan's criticisms of Holtec's model are invalid and based on a misunderstanding of the inputs used in the Holtec model.

1. Lack of a Validated Model

Q127. Please describe the models that Dr. Khan used to evaluate HI-STORM System cask stability at the PFSF.

A127. Dr. Khan uses three models. His initial model is a simple mass weighing 360,000 lb that can slide and uplift. Dr. Khan used this simple mass model in an attempt to benchmark his analysis code, SAP2000, by running the model on both ANSYS (another general purpose industry computer code) and SAP2000. The second model simulates a HI-STORM System cask by a small, single, rigid beam element that can slide and uplift. The third model stimulates a HI-STORM System cask using 72 beam elements. The Altran Report claims that under this third model the "cask can slide, lift and rock, or tip-over under the specified seismic impact motions." [Altran Report at 12]. The last two models were run on SAP2000, which is a general purpose structural program that can be adapted to stimulate a wide range of problems. For these last two models, Dr. Khan performed several analyses in which he attempted to show the effect of changing various parameters (contact stiffness, coefficient of friction, and damping) that may bear upon the movement of a HI-STORM System cask on a concrete storage pad during a seismic event.

Q128. Had Dr. Khan ever constructed such a model before?

A128. No. Dr. Khan acknowledged that this was the first time that he had ever attempted to model the movement of a large free standing object, such as the HI-STORM System. <u>See</u> Deposition of Dr. Moshin Khan, March 5, 2002 (Khan Dep.") at 143 (identified as PFS Exhibit PP.) In addition, instead of using a specialized computer code that was tailored for the features of the PFSF cask/pad/soil configuration, Dr. Khan attempted to adapt a general purpose structural program, SAP2000, to model the free-standing HI-STORM System cask on a storage pad, something he also had never done before.

Q129. What steps did Dr. Khan take to attempt to validate his model?

A129. (KPS, AIS) The only step Dr. Khan took to attempt to validate his model was to compare the solution of his initial simple mass model using SAP2000 with runs using the program ANSYS. He did not attempt to validate any of his three models in any other manner. In particular, he did not attempt to compare the solutions derived from simulations using his models with known classical solutions, as required by the NRC. (As noted earlier, Holtec has performed thorough, successful validations of its DYNAMO code and has had the code and its results approved by the NRC in numerous dockets).

Q130. Did Dr. Khan's running his simple mass model on two different general purpose computer codes prove the validity of simple mass model, or that of the other two models that he used?

A130. No. It only demonstrated that the model algorithm had been properly programmed using both computer codes, such that when both programs were given the same model input they provided the same model output. As Dr. Khan readily acknowledged at his deposition, the same wrong input parameters to both would lead to equally erroneous result for both. Khan Dep. at 77. While his two solutions show good agreement with each other, the modeling itself is clearly erroneous, and leads to results that defy physical reality. Using his model with some of the key parameters applicable to the PFSF cask stability analysis -- coefficient of friction of 0.2 and a mass of 360,000 lb -- the mass should begin to slide at a horizontal load equal to F=0.2 x 360,000 lb. = 72,000 lb. However, his simple model predicts that if we apply a force of 71,000 lb., just below that force required to initiate sliding of the block, this 360,000 lb. mass (equal to the mass of a fully-loaded HI-STORM System cask) would move - without sliding -- more than 2/3 of an inch. There is no physical mechanism for this phenomenon to occur in the real world. Because his model is the same for both computer codes, his validation succeeds only in showing that both computer codes give the same spurious answer. In short, the "validation" Dr. Khan claims to have accomplish fails to validate the adequacy of his model or demonstrate the suitability of his analysis of the stability of the Holtec HI-STORM System cask.

Q131. In the joint declaration describing his model and criticisms of the Holtec model filed by the State in Opposition to PFS's Motion for Summary Disposition on Part B of Utah L (now Section E of the Unified Contention), ("Utah Joint Declaration") Dr. Khan states that both "SAP2000 and ANSYS have been benchmarked with known analytical solutions to provide adequate results for dynamic analyses." Is the comparison between SAP2000 and ANSYS that you just described sufficient to validate or benchmark Dr. Khan's model for analyzing the dynamic motion of a free-standing spent fuel storage cask on a storage pad?

A131. (KPS, AIS) No.

Q132. Why not?

A132. (KPS, AIS) For the same reason as we stated above, comparing results from two computer codes simply proves that the code algorithms produce similar results to similar inputs. In the final analyses, even if the code's algorithims are appropriate, the codes will only give an answer that is as good as the input provided. To 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. The ANSYS FEA Code, for example, provides a suite of verification problems to demonstrate that the ANSYS Code can reproduce the solutions to well-known problems. Indeed, ANSYS provides verification for modeling contact stiffness that shows how to correctly solve such a problem. Dr. Khan did not follow this ANSYS guidance; instead, the simple mass model he used was not verified and predicts an incorrect and non-sensical solution for a simple problem. Had Dr. Khan studied the simple problem considered in the ANSYS verification manual, he most likely would have realized his error in utilizing unreasonably "soft" stiffness values.

Q133. Unlike Dr. Khan's model, has Holtec's model been validated and benchmarked for analyzing nonlinear dynamic solutions?

A133. (KPS, AIS) Yes, as stated above, the Holtec program was validated, using various benchmarking problems, in a manner consistent with ASME NQA-2a-1990, Part 2.7, "Quality Assurance Requirements of Computer Software for Nuclear Facility Applications." The Validation Manual for the Holtec Code DYNAMO (also referred to as "DYNARACK") was prepared many years ago and has been continuously updated, most recently in 1998. The validation is equally applicable to both wet and dry storage applications.

Q134. What computer code validation requirements does ASME NQA-2a-1990 impose?

A134. (KPS, AIS) ASME NQA-2a-1990 mandates that a computer code be benchmarked against classical solutions and peer computer codes to the extent possible using appropriately selected test problems so as to establish the suitability and stability of the code for the genre of problem being analyzed. In accordance with the ASME requirements in this respect, DYNAMO has been specifically validated using problems that test its ability to predict the dynamic behavior of free-standing bodies in the presence of friction. Of pertinent interest here is one of the test problems used to benchmark DYNAMO, which deals with static and sliding friction and is a published paper in the Journal of Applied Physics, Volume 21, Number 9, September, 1953 (Static and Sliding Friction in Feedback Systems, by J. Tou and P.M. Schultheiss) (which is identified as PFS Exhibit QQ). As shown from the portion of the Validation Manual for DYNAMO identified as PFS Exhibit RR , DYNAMO correctly predicts the solution for this classical test problem. Dr. Khan's model does not.

2. Failure to Follow Authoritative Guidance in Developing Contact Stiffness Input Parameters and Choosing Contact Stiffness Input Parameters, Resulting in Unrealistic And Physically Impossible Solutions to Real Life Situations

Q135. You stated earlier that Dr. Khan failed to follow authoritative guidance with respect to key input parameters and chose key input parameters that provide unrealistic and physically impossible solutions to real life situations. What key input parameters were you referring to?

A135. (KPS, AIS) The key parameters that we were referring to were the values for choice of contact stiffnesses between the HI-STORM System storage casks and the concrete storage pads on which they rest. There are two such stiffness parameters, a vertical contact stiffness parameter and a horizontal contact stiffness parameter. Dr. Khan's major criticism of Holtec's cask stability analysis is Holtec's choice of these contact stiffness parameters. However, the values that Dr. Khan recommends for these parameters are both contrary to authoritative guidance and produce results that are contrary to the laws of physics.

Q136. Would you please explain what is meant by contact stiffness?

A136. (KPS, AIS) Vertical contact stiffness represents the amount of force, applied at the interface points of contact between two bodies, that would be required to have one of the bodies to approach the other a unit distance. The parameter is measured in the pounds of force required to cause one body to approachthe second body by one inch. For example, assume that you have two pads made of undefined materials and you place on each pad a loaded HI-STORM System cask weighing 360,000 lbs. Assume for Pad Material 1 that the HI-STORM System cask would move towards the pad by 1.0 inches, at and that for Pad Material 2, the HI-STORM System cask would move toward the pad by only 0.01 inches. With respect to Pad Material 1 you would say that the vertical contact stiffness of the material would be 360,000 lbs. per 1 inch, or 0.36 x 10^6 lbs. per inch. For Pad Material 2, the vertical contact stiffness would be 36 x 10^6 lbs. per inch, since placement of the cask on the pad caused a movement of only .01 inch. The numbers for both of these examples can be derived from this simple formula:

$K = W/d$ where W is the vertical load applied (in this example, the weight of the cask), d is the average deformation under the cask (assumed rigid for the purpose of this discussion), and K is the contact stiffness (in this case, based on known weight and measured information on the deformation of the cask "into" the pad.

Q137. How is the vertical contact stiffness used in modeling the motion of a large free standing object, such as the HI-STORM System cask?

A137. (KPS, AIS) It is used to define the stiffness of the vertical-only "compression springs" at the interface of the cask and the pad that are used in the dynamic modeling of cask motion on the pad.

Q138. What vertical contact stiffness did Holtec use in its modeling of the HI-STORM casks for the PFSF and in what respect does Dr. Khan's differ?

A138. (KPS, AIS) In the design basis analysis for the 2,000 year return period earthquake using Holtec's computer code DYNAMO, Holtec used a vertical contact stiffness of 454,000,000 lbs per inch or 454×10^6 lbs/in. Dr. Khan, however, claimed to be doing a parametric study on the effect of choice of contact stiffness on the solution, and ran his models using a range of contact stiffnesses. According to Dr. Khan, Holtec's choice of a vertical contact stiffness of 454×10^6 lbs/inch is too high. He claimed instead that, "[b]ased on [his] experience, it is [his] opinion that a more appropriate contact stiffness value for unanchored casks is 1×10^6 lbs/inch." Utah Joint Declaration ¶ 67. However, as already noted, Dr. Khan acknowledged that he did not have any experience in modeling the motion of large free standing bodies, and his choice of contact stiffness is contrary to ANSYS guidance on choosing an appropriate contact stiffness.

Q139. Where does one find the authoritative guidance that you claim that Dr. Khan failed to follow in developing contact stiffnesses for modeling purposes?

A139. (KPS, AIS) Such authoritative guidance is typically found in user manuals for the various computer codes that can be used for modeling. In fact, one of the computer codes used by Dr. Khan, ANSYS, has extensive guidance on how to develop contact stiffness for modeling purposes.

Q140. What about Dr. Khan's claim in his deposition that ANSYS doesn't provide detailed guidance on choosing of contact stiffness?

A140. (KPS, AIS) Dr. Khan is wrong. The Verification Manual provided by ANSYS contains a number of sample problems covering friction and contact issues. Additionally, the ANSYS Advanced Contact and Bolt Pretension, Training Manual and Workshop Supplement (Version 5.6) contains more than 100 pages devoted almost entirely to friction and contact problems, several of which are reproduced and identified as PFS Exhibit SS. It is made eminently clear there that in order to achieve realistic modeling, the choice of contact and friction springs should not imply a "measurable" penetration or elastic movement prior to sliding. If this occurs, then the stiffness should be increased.

Q141. Please elaborate on this guidance provided by ANSYS.

A141. (KPS, AIS) ANSYS in essence says that "although physical contradicting bodies do not interpenetrate" some "finite amount of penetration" is required to mathematically model the contact between bodies. It therefore states that "[m]inimum penetration gives best accuracy" and that, "[t]herefor, the contact stiffness should be very great." However, it notes that too stiff a value may cause difficulty in having model converge to a solution and determining the stiffness value "usually requires some experimentation." It clearly states, however, that "if you can visually detect penetration . . . the penetration is probably excessive" and one should "[i]ncrease the stiffness and restart." Thus, the general guidance provided by ANSYS is that minimum penetrations, denoting large contact stiffnesses, give the best accuracy.

Q142. Given that Dr. Khan used ANSYS to run his models, did he follow this guidance from ANSYS on how to develop an appropriate contact stiffness?

A142. (KPS, AIS) No. He was apparently unaware of, or disregarded, the guidance provided by ANSYS. When questioned at this deposition, Dr. Khan testified that "ANSYS never provided any guidance on sliding, how to calculate the stiffness for a sliding problem," and that "there is no guidance from ANSYS how to solve a nonlinear sliding problem with large horizontal motions." Khan Dep. at 168-69.

Q143. Is Dr. Khan's choice of 1 x 10^6 lbs/inch for modeling the seismic response of HI-STORM 100 at PFSF in accordance with the guidance from ANSYS?

A143. (KPS, AIS) No. Dr. Khan's choice violates the fundamental precept of the ANSYS guidance, i.e., that there should be no visible interpenetration of the two objects. Using the same formula that we set forth above, the penetration or deflection can be computed as follows:

$$D \text{ (deflection or penetration)} = \frac{\text{Weight in lbs. (W)}}{\text{Contact stiffness in lbs/inch (K)}}$$

Applying this formula to Dr. Khan's professed "appropriate choice" of contact stiffness leads to a contact interpenetration of approximately 3/8 of an inch, just due to placing the cask on the top surface of the pad. This is computed as follows:

D = (360,000 lb.) / (1,000,000 lb./inch) = 0.36 inch

We have previously calculated the pressure placed by a fully loaded HI-STORM cask on the pad to be 26 psi, which is less than a man standing on the ball of one of his feet. To say that the cask placing that little pressure on the concrete pad would interpenetrate the pad by 3/8 of an inch defies physical reality and common, everyday experience. Objects do not sink into concrete pads just by being placed on them. Dr. Khan's choice or contact stiffness is also directly contrary to the guidance provided by ANSYS that "if you can visually detect penetration . . . the penetration is probably excessive."

Q144. Did Holtec develop the contact stiffness that it used in its cask stability analysis in a manner consistent with the guidance from ANSYS and other available authoritative sources?

A144. (KPS, AIS) Yes. Holtec seeks to use contact stiffness values that produce very small interpenetrations, but yet permit the code to achieve a converging solution. While we may draw upon known physical solutions to obtain a specific value of contact stiffness (i.e., examine some relevant classical solutions), any choice of stiffness we make in real cases must give meaningful results. For example, the Holtec choice of stiffness of 454,000,000 lb./inch used in the DYNAMO model was based on a result from a classical solution of a rigid body on a half space. However, the real reason we used that value is not that it comes from a classical solution, but that the static penetration of a HI-STORM System cask into the concrete predicted using that value for stiffness is d=360,000 lb/454,000,000 lb./inch = 0.00008," an acceptable, realistic prediction. In our latest analyses for the beyond-design basis 10,000-year return period earthquake, we used an equally valid rationale for the choice of contact stiffness; namely, for a simple vertical vibration of the cask, we set the stiffness so that it was consistent with the assumption that the lowest frequency of vibration was 33 Hz. This requirement yielded a vertical stiffness value of 40,130,000 lb/inch. This different value, however, also met the test of "no visible penetration" as formulated in the ANSYS guideline manual, for it yielded an interpenetration d=360000 lb/40,130,000 lb./inch = 0.009", a value sufficiently low to be deemed to be acceptable.

Q145. You appear to have made your choices of vertical contact stiffness values on the basis of some physical principle. Is there any guidance on the appropriateness of doing so?

A145. As stated earlier, the underlying rationale is one of providing no "visible" interpenetration when you place the bodies in contact; to the extent that the value can be chosen from the solution of a physically relevant problem that satisfies the primary test, that is a "plus".

Q146. You stated earlier that there was also a horizontal contact stiffness parameter. What does this parameter measure?

A146. (KPS, AIS) This parameter measures the force at the point of contact between two bodies in the horizontal direction that causes a relative deflection of 1 inch in the horizontal direction between two originally coincident points on the interface.

Q147. Does Dr. Khan's model use reasonable values of horizontal contact stiffness?

A147. (KPS, AIS) No. Dr. Khan assumes that the force in the horizontal direction required to cause a relative deflection of 1 inch in the horizontal direction is 100,000 lbs/in. and that the cask will slide at a coefficient of friction of 0.20. If you apply a force greater than the 20% of the weight of the cask, or 72,000 lb, the cask will slide; a force below 72,000 lb should impart no visible relative movement in the horizontal direction. But if we use Dr. Khan's horizontal stiffness value and apply just 71,000 pounds of force on the cask in the horizontal direction, the cask should not slide, yet Dr. Khan's model predicts a "visible" horizontal deflection of 0.71 inches, which again defies physical reality.

Q148. Have you done any other evaluations of the capability of Dr. Khan's model to correctly predict solutions to classical problems?

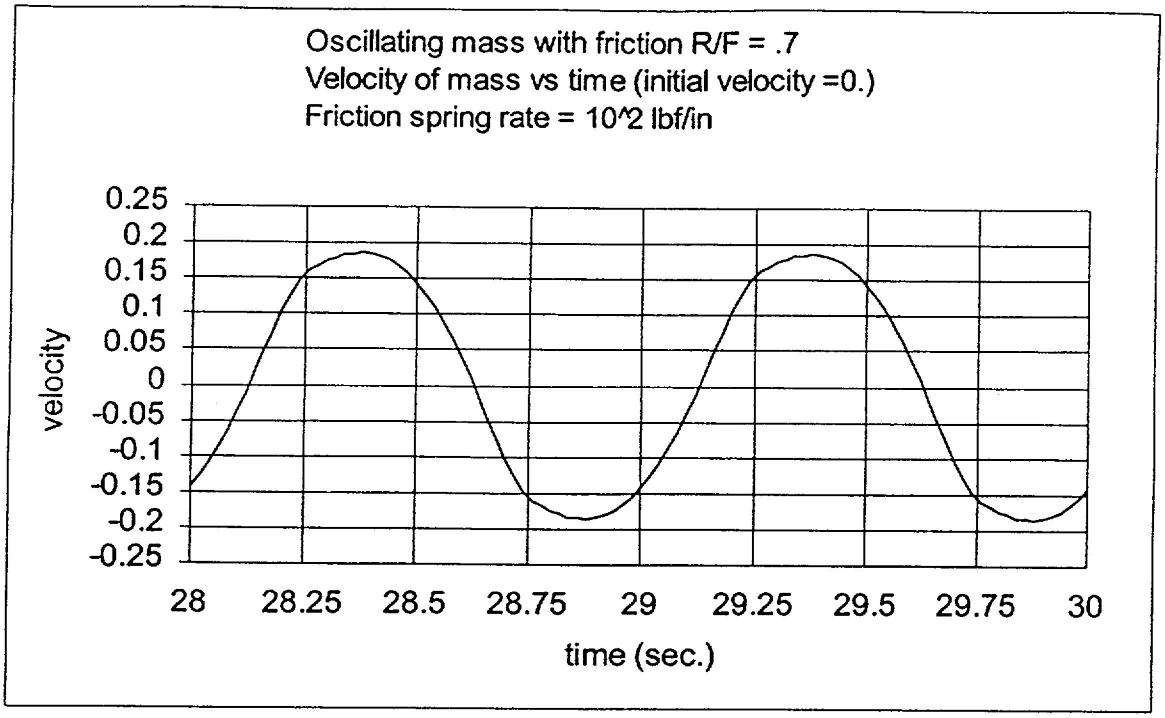
A148. (KPS, AIS) Yes. We have evaluated the capability of Dr. Khan's model to correctly predict the classical problem discussed by J. Tou and P.M. Schultheiss in the Journal of Applied Physics, Volume 21, Number 9, September, 1953 (Static and Sliding Friction in Feedback Systems). We had previously noted that in benchmarking DYNAMO that DYNAMO had correctly predicted the solution for this classical test problem. The classical solution and the Holtec simulation results are included in PFS Exhibits QQ andRR.

Q149. Please describe the classical problem which is discussed by Tou and Schultheiss.

A149. In this problem, a rectangular box is placed on a flat surface which permits a frictional resistance force to be developed as the mass oscillates on the flat surface. An external sinusoidal force is applied to the mass. Depending on the ratio of maximum frictional force that can be developed to the maximum amplitude of the applied sinusoidal force, different effects may be observed. For maximum friction force amplitude to applied force amplitude ratio less than 0.536, it is shown in the reference classical solution that the response of the mass is approximately sinusoidal with discontinuities in the acceleration. However, if the same ratio is greater than 0.536, then the motion is sporadic, with "dead bands" occurring in time, where the motion halts (and later resumes). Finally, when the ratio of friction resistance to applied force exceeds 1.0, then no motion, save an initial transient, occurs.

Q150. Please describe how you went about evaluating the capability of Dr. Khan's model to predict the solution of this problem.

A150. In the validation performed by Holtec, we modeled the mass, the frictional surface, and the applied sinusoidal force. To ensure that we correctly modeled the "stick-slip" nature of frictional resistance, we assumed a large value for the horizontal spring (10,000,000 lb./inch) that simulated the behavior prior to sliding (since, the problem was fairly simple, the use of this very large value to simulate an "infinite stiffness" gave us no convergence problems). Our results reproduced the phenomena predicted by the classical solution (see PFS Exhibit RR). To demonstrate the inappropriateness of the low value for horizontal spring rate suggested by Khan, we took the Holtec DYNAMO Code and modified the input so that Dr. Khan's choice of input data was used. Since he feels that a ratio of weight to friction spring rate of 360,000/100,000 = 3.6 is appropriate, we used the DYNAMO Code and used a friction spring rate of 107.33 lb/in (note that the benchmark application uses a mass of 1 lb-sec^2/inch, which is a weight of 386.4 lb; therefore, to get the same ratio that Dr. Khan suggests is appropriate for the friction spring, requires that k = 386.4/3.6). The remainder of the parameters were set so that the solution should produce "dead bands". The figure below represents what we call the "Khan Solution" and plots the velocity of the mass vs. time. Since no dead bands are evident, Dr. Khan's choice of parameters, applied to this problem, produces a solution that clearly does not agree with the theoretical results (PFS Exhibits QQ andRR).



Q151. What is your conclusion therefore with respect to Dr. Khan's choice of contact stiffness values?

A151. Dr. Khan violated the first and foremost principle in simulating contact friction: namely, choose stiffness values that are high enough so that no visible penetration or elastic movement, prior to sliding, is predicted. Dr. Khan's vertical stiffness value of 1 x 10^6 lbs/inch and his horizontal stiffness value of 1 x 10^5 lbs/inch produce nonsensical results for simple, easily understood physical problems. Dr. Khan's proposed input parameters also predict a static vertical interpenetration of 0.36" and a movement of 0.71" prior to sliding, again unreasonable and at odds with reality. A computer code whose application in test cases gives unreasonable results is likely to run into convergence problems when applied to real life situations.

Q152. Do you see any convergence problems manifesting themselves for the contact stiffnesses that Dr. Khan professes to be "appropriate?"

A152. (KPS, AIS) Yes. Clear evidence that Dr. Khan's model, at his proposed contact stiffness values, runs into convergence problems can be seen by close

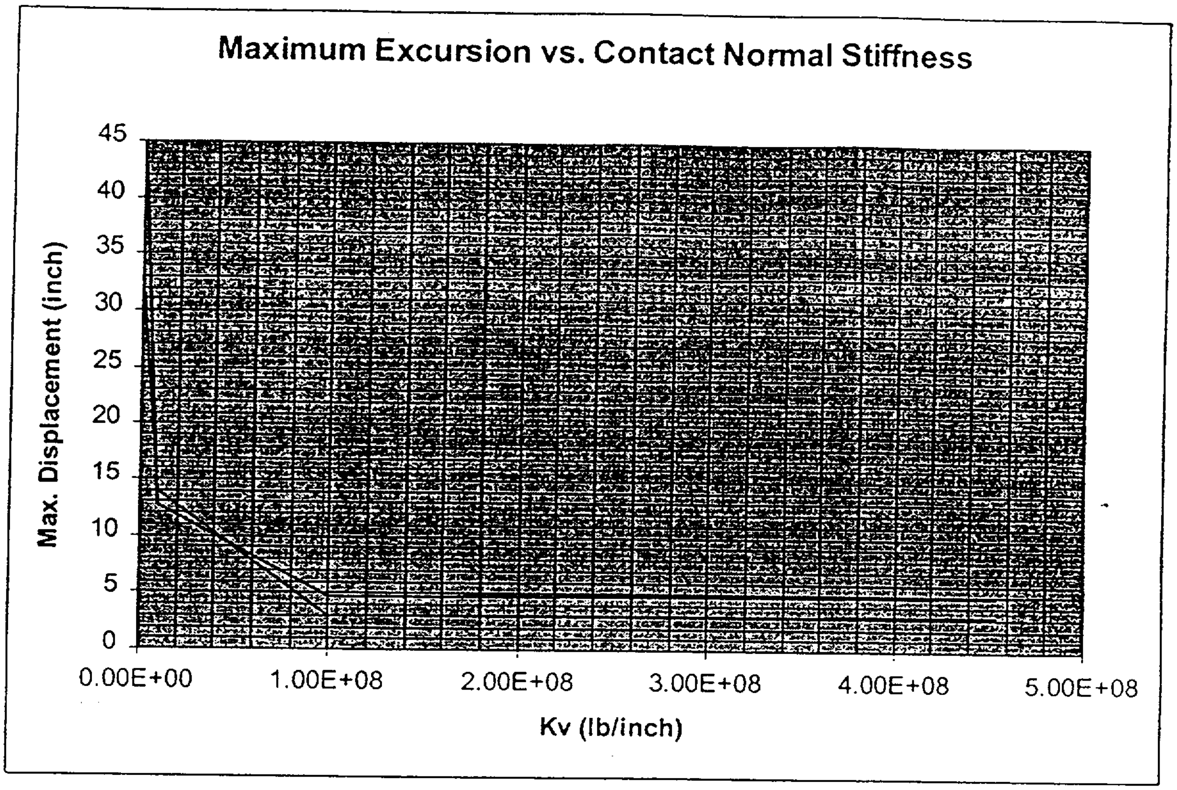
- examination of some results in Table 2 of the Altran report, in particular cases 2, 4, 6 and 10. These cases are set forth in the Table below, which extract the relevant data from the Altran Report.

Information Excerpted from Table 2 of Altran Report					
		Stiffness for Non-Linear Elements		Relative Cask Displacements	
Study Run #	Coefficient of Friction	Vertical Stiffness (lb/inch)	Horizontal Stiffness (lb/inch)	Horizontal Displacement (inch)	Vertical Displacement (inch)
2	.8	1,000,000	100,000	42.74	31.35
4	.8	10,000,000	100,000	12.70	14.03
6	.8	100,000,000	100,000	4.74	3.05
10	.8	454,000,000	100,000	4.83	3.06

These cases are of interest since the only difference between them is the value for the vertical stiffness. Thus, the Khan solution of these cases is supposed to show the effect of changing only the vertical stiffness.

Q153. Please describe what this Table shows?

A153. (KPS, AIS) We focus on these cases because the assumptions for them differ only in the choice of vertical stiffness at the contact interface (although they all use the horizontal friction stiffness having an unrealistically invalid low value of 100,000 lb./inch, as previously discussed above). A plot of the results from Dr. Khan's analysis is given below (the two lateral excursions (the last two columns of the Khan excerpted data) are plotted against vertical stiffness value (the third column of the extracted data)) . The key point is not that the displacement results are different, but rather, that they "settle down" (converge) to a value that is independent of the exact stiffness chosen.



Q154. What do you conclude from this graphic display of the results of the table?

A154. (KPS, AIS) This table and the graph show that Dr. Khan's results are insensitive to changes in contact stiffness values after some plateau is reached, which would generally correspond to the lack of visual penetration of the two objects. In reality, this aspect of Dr. Khan's results serve as a validation of the correctness of Holtec's stiffness value at 100,000,000 lb/inch, and show that the results are insensitive to the choice of stiffness after a certain plateau is reached, as they should be. As noted earlier, the results with lower stiffness values also fail the "visible" interpenetration test (these initial values are not reported in the Khan analysis) and thus, do not conform to the guidance provided by ANSYS; therefore, it would be obvious to a practitioner more familiar with this kind of problem that the assumptions should be suspect.

Q155. In his deposition, Dr. Khan argued that the examples involving static conditions, such as those you have discussed above, were irrelevant to modeling dynamic motion where the contact stiffness between the casks and the pads would be constantly changing. What is your response to Dr. Khan's argument?

A155. (KPS, AIS) As previously discussed, the model should be able to provide realistic answers to all such situations, as does Holtec's.

Q156. How does Holtec's computer code model dynamic motion situations?

A156. (KPS, AIS) The dynamic change of contact stiffnesses between the pad and the cask, due to changing contact area, is modeled by having a series of springs between the pad and the cask over which the contact stiffness is divided. For example, Holtec's DYNAMO model employs 36 springs between the cask and the pad around the circumference of the cask, which means that each spring represents a contact stiffness of 454 x 10^6 lbs/inch divided by 36, or 12.6 x 10^6 lbs/inch. Thus, if part of the cask lifts off during an earthquake, the instantaneous contact stiffness between the cask and the pad will change and will only include those points actually in contact at that instant.

Q157. Dr. Khan also suggests that use of a high contact stiffness, such as that used by Holtec, is inappropriate because "high stiffnesses absorb significant amount of energy" before either sliding or tipping occurs. What is your response to this assertion by Dr. Khan?

A157. (KPS, AIS) Dr. Khan is simply wrong, and misconstrues the laws of physics governing linear springs. The energy absorbed by a linear spring is given by a simple relation $E = 0.5 \times K \times d^2$ where "K" is the stiffness of the spring and "d" the compression of the spring, which in the model here, where the springs represent local contact stiffness at an interface, is also the deflection or interpenetration at the cask-pad interface. For a given value of compression force W, since $W = K \times d$, the energy absorbed by the spring can be expressed as: $E=0.5 \times W^2/K$. This is recoverable energy (since we deal only with linearly elastic springs) which means that the spring will "give back" the energy that it absorbed during the compression cycle when it decompresses (prior to separation) Therefore, as K gets larger for a given W, the energy absorbed by the spring is less, rather than more (since K appears in the denominator of the energy relation, a larger K means less energy for the same value of W), directly contrary to Dr. Khan's assertion.

Q158. Dr. Khan also claims that although high contact stiffness values are generally used in mathematical simulations, the high stiffness values artificially treat the solution as linear without amplifying it in the upward direction and give non-unique or invalid results. Do you agree with Dr. Khan's assertions?

A158. (KPS, AIS) We agree with Dr. Khan's first assertion that "high contact stiffnesses are generally used." Indeed, that is precisely the guidance provided by ANSYS that "contact stiffness should be very great" because "[m]inimum penetration gives best accuracy." ANYSY recommends lower values only if "too stiff of a value causes convergence difficulties, but the lower values should still pass the test of "no visible penetration". His second assertion that the use of high contact stiffness values "gives non-unique or invalid results" is flatly wrong and contrary to accepted modeling practice, as demonstrated by the ANSYS provisions just quoted. As stated, the objective in choosing an appropriate contact stiffness value is to pick one in the range where your results are not sensitive to the precise choice of the contact stiffness value chosen. In the range of contact stiffness values proposed by Dr. Khan, his own results shows that this fundamental precept is violated.

Q159. What is your conclusion regarding Dr Khan's claims concerning an appropriate contact stiffnesses to use in modeling cask stability?

A159. (KPS, AIS) In our opinion, Dr. Khan's report does not support any of the claims made by the State. Dr. Khan's choice of model parameters for a number of his simulations do not satisfy the basic test required of all contact and friction analyses; namely, that they do not predict excessive penetration nor excessive movement prior to sliding. Dr. Khan has failed to validate his model; indeed, we have shown in our responses that Dr. Khan's choices do not give agreement with simple exact solutions.

3. Dr. Khan's Misinterpretation of other Key Holtec Input Parameters

Q160. In what other respects does Dr. Khan misinterpret the input parameters used by Holtec in its cask stability analysis?

A160. (KPS, AIS) Dr. Khan misinterprets and misapplies the 5% beta damping value that Holtec used in cask stability analysis. According to Dr. Khan, the 5% beta damping is a structural damping, and Dr. Khan further argues that 5% structural damping is much too high for two bodies assumed to be rigid in the Holtec analysis -- the cask and the pad -- and argues that the beta damping value should be on the order of 1%. Dr. Khan fails to understand that the damping used in Holtec's model does not represent structural damping (since rigid bodies have no structural damping); rather, the damping included in the cask-to-pad contact elements represents impact damping, and reflects the physical fact that there is energy lost when the cask impacts the target concrete and then rebounds. The simple discussion and problem, excerpted from a Holtec report on another project and identified as PFS Exhibit TT, illustrates this point. In the simple example, when a known mass is dropped from a fixed height, it is physically observable that it does not return to its initial height. It can be shown that the difference in height is related to a quantity defined as the "coefficient of restitution". In simple terms , if H0 is an initial drop height for the mass, and H1 is the measured height to which the mass returns, after impact, then the coefficient of restitution, "e", is defined by the equation

$$e^2 = H1/H0$$

Alternatively, the coefficient of restitution is equally definable in terms of the relative velocity of approach, "Va", and the relative velocity of separation, "Vs". Recognizing that for the case of a vertical drop of the mass, the approach velocity is "down", and the separation velocity is "up," the coefficient of restitution is also defined as:

$$Vs/Va = e$$

These two definitions are interchangeable. We can simulate the physical phenomena by defining a mass-spring-damper system and studying its behavior during the time period when impact begins, and when impact ends. The solution of this simple problem can be done analytically and provides a solution for the velocity ratio solely in terms of the critical damping constant. Thus, a unique relation between critical damping value and coefficient of restitution can be defined. PFS Exhibit TT. contains details of the development.

Thus, contrary to Dr. Khan, the 5% damping used by Holtec is not structural damping of the cask (even though there would be considerable structural damping of the canister and canister internals which Holtec conservatively ignores in its model). Rather, it is the damping or dissipation of energy resulting at the contact points between the cask and the pad. The use of 5% damping for dampers at the contact interface implies a coefficient of restitution, "e" approximately 0.85. In physical terms, if we drop the cask from a height of 12", then classical impulse-momentum considerations predict that it would rebound to a height of H = (.85)(.85)(12") = 8.67" The use of dampers, with an appropriate percentage of critical damping, in parallel with the contact stiffness, is the appropriate way to model this phenomena.

Q161. In his deposition, Dr. Khan claimed that it was inappropriate to assume impact damping at the cask-pad interface. Khan Dep. at 124-134. What is your response to Dr. Khan's claims on this point?

A161. (KPS, AIS) Dr. Khan, in his deposition, refused to consider the possibility of a cask moving up and down and dissipating energy by impact damping during the period when it contacts and then rebounds from the target. As we have just shown, the loss of energy in a vertical impact problem can only be simulated in a numerical analysis by including a damper in the model. Dr. Khan's impression would be that the spring absorbs the energy (p.126, line 17) but fails to mention that it gives it all back when it expands. Dr. Khan does not consider an automotive shock absorber as a damper but implies that a car's vibration is slowed and ended because it being stopped by a rigid surface. He continues by claiming, erroneously in our opinion, that the spring is "dissipating the energy through stiffness".

Q162. In a similar vein, in the Utah Joint Declaration, Dr. Khan claims that friction should be the primary energy dissipation mechanism, not damping or any other form of dissipation of energy associated with the spring at the cask-pad interface. What is your response to this claim by Dr. Khan?

A162. (KPS, AIS) At the interface, the friction effect predominates when horizontal sliding predominates, and the damper in parallel with the normal contact spring will be the only energy dissipator when there is no sliding. Under no circumstances, will linear springs permanently remove energy from the problem.

Q163. Dr. Ostadan has also claimed that the 5% damping used by Holtec is too great and has suggested that the damping that you have illustrated by your example of a bouncing ball is resistance damping attributable to the damping effect of the soils and foundations. What is your response to this claim raised by Dr. Ostadan?

A163. (KPS, AIS) Dr. Ostadan has misinterpreted the modeling in the Holtec simulation. There is damping to account for the effect of the cask impacting a target, and there is also damping associated with the soil response. If the cask was fixed to the pad to the pad, you would have only soil damping; on the other hand, if the soil were perfectly rigid, you would still have to model the observable fact that when an object is dropped, it does not rebound to its same height. As noted in our previous response, a damper in parallel with a contact spring is necessary to characterize this behavior. The damping referred to by Dr. Ostadan is the damping associated with the soil spring under the pad whereas the damping that we are discussing here is associated with the spring between the cask and the pad. Thus, we have two different stiffnesses and specific damping associated with each stiffness.

Q164. What is your conclusion regarding the State's claims that use of 5% damping by Holtec in its modeling of cask stability is inappropriate?

A164. (KPS, AIS) The use of 5% damping for energy dissipating dampers in parallel with contact stiffness elements leads to a reasonable and conservative estimate of the rebound if we imagine dropping the cask from a fixed height and calculating the rebound. The same methodology has been reviewed and accepted by the NRC in the wet storage licensing submittals. Its application to the cask analyses is reasonable and appropriate.

4. Dr. Khan and the State's Other Witnesses Inappropriately Rely upon the Results of Dr. Khan's Model From Inadequate Model and Erroneous Input Parameter as Realistic Solutions

Q165. What are your conclusions regarding the information provided in the Altran Report in Table 3.

A165. The results in the cited table, in our opinion, are completely erroneous. The reason for this is primarily that they all use a low value of horizontal stiffness which cannot be expected to give agreement with any known exact solutions. In addition, some of the simulation results compound the error by also assuming improper vertical stiffness. We note that all of the results, quoted by Khan and used by the other State experts, that lead to approximately 30 ft. lateral movements, and the casks "jumping" into the air, have as their inputs, the discredited low values for vertical and horizontal stiffness. Therefore, the results, besides being physically unbelievable, suffer from bad input data. There is no evidence of any trend in the tabular results. Therefore, we cannot even begin a rational dissection of the results in Table 3 as we did with Table 2 of the report as there is no two sets of results that can be "trusted" as being based on good input data.

Q166. Please explain why the examples of large objects tipped over or otherwise disturbed by large earthquakes referred to by the State's experts do not support the results of Dr. Khan's model or otherwise show that excessive sliding or tipping of the Holtec casks during a large earthquake event is likely.

A166. The examples cited by the State's witnesses of large objects turning over do not support any conclusions reached by Dr. Khan or by Dr. Ostadan concerning the response of HI-STORM casks. Simply stated, the ratio of object height to object supported width in the State's examples is much larger than the same ratio applied to the HI-STORM cask. Given the same earthquake strength, objects with a larger height/width ratio are more prone to overturning. For HI-STORM, the ratio is approximately 1.8. For the State' examples, the corresponding ratios would appear to be much higher (based on estimates from the photographs).

VI. TESTIMONY CONCERNING SECTION E OF THE UNIFIED CONTENTION

VII.

Q167. What is your understanding of the State's claims in Section E of the Unified Contention?

A167. (KPS, AIS) Section E challenges the granting of the exemption from the requirements of 10 CFR § 72.102(f) to allow PFS to employ a probabilistic seismic hazard analysis using a 2,000-year return period earthquake as the design basis for the PFSF. The State asserts that PFS should be required to either use a probabilistic methodology with a 10,000-year return period or comply with the existing deterministic analysis requirements of section 72.102(f), or, alternately, using a return period significantly greater than 2,000 years.

Q168. Is the HI-STORM System able to withstand earthquakes greater than the 2,000-year return period design basis earthquake used for the PFSF?

A168. (KPS, AIS) Yes. As discussed earlier, the design of the HI-STORM System has many conservatisms that would allow it to survive and continue to fulfill its safety function under far greater ground motions than those produced by the 2,000-year design-basis earthquake. First, the cask stability analysis performed by Holtec demonstrates that a HI-STORM System storage cask can withstand much larger seismic events than the 2,000 year design basis earthquake without significant pure sliding motion or tipping over. Second, even if a cask were to sustain an impact due to sliding, or a cask were otherwise to impact another without tipping over, that impact would be significantly less severe than the impacts posited in the hypothetical cask tip-over analysis. Third, assuming that a cask were to tip over, the velocity of the impact due to the tipover would be in the same range as that in the hypothetical cask tip-over analysis that we performed, which shows that canister's confinement integrity would not be threatened. Fourth, even if one were to assume that a tip-over would have a larger velocity than that postulated in the hypothetical cask tip-over analysis, the huge margins in the design of the cask and canister system would prevent the release of radioactive material.

Q169. Please summarize the results of the various cask stability analyses that Holtec has performed for the PFSF.

A169. (KPS, AIS) Under design basis earthquake loadings, the maximum calculated cask displacement is less than 3.25 inches, which leaves large margins (at least over three feet of clearance) before the casks were to impact each other, and a large margin exists against cask tip-over. In a 10,000-year return period earthquake, large margins still exist against cask tip-over, the factor of safety against tip-over at the 10,000 year earthquake is still on the order of 2 to 3 as measured against the center-of-gravity over corner location. Further, even under unrealistic, "worst-case" assumptions as to damping and other factors, the casks do not tip-over in a 10,000-year earthquake. Under some of the scenarios that we studied, some of the casks may impact each other, but the impacts occur at relatively low speeds with no damage to the casks or loss of stability; the net effect of the collision is that one of the cask loses most of its energy and its motion and shortly comes to a halt. No impacts due to sliding were observed under any of the scenarios that were run using the 10,000-year earthquake, even those based on "worst case" assumptions. Even if sliding impacts were to occur, the velocities of the impacts would be much lower than the velocity of impact determined in the hypothetical cask tip-over event. The conclusion, therefore, is that even at the 10,000-year earthquake ground motions, large margins exist against cask tip-over or any cask-to-cask impacts that might threaten the confinement integrity of the MPC canister.

Q170. Assuming hypothetically that a cask were to tip over in a beyond-design basis earthquake, would the confinement capability of the MPC canister be threatened?

A170. (KPS, AIS) No. In reviewing the computer-generated movie files showing the behavior of the casks in an earthquake, we observed that casks tend to tilt from the vertical, resulting in a plane of precession for certain durations in the course of the earthquake event. The cask experiences an oscillatory rocking motion, while precessing, with periodic returns to the vertical position, until the rocking finally ends when the earthquake subsides. This behavior supports the assumption of a zero initial angular velocity if the cask ever begins to tip over. Observation of the simulated motion experienced by the PFSF casks during the 10,000-year event and other non-PFSF simulations of cask tipover leads us to conclude that, if the strength of the seismic event were increased to the point where the cask did tip over, the initiating angular velocity propelling the cask towards the ground is quite small. Furthermore, the precession characteristics of the motion of the cask enables it to remain stable even while the center of gravity of the cask is well past the corner. As a result of the precession motion, with superimposed rocking, the initial height of the cask center of gravity is apt to be much lower than the statically computed tipover scenario (where tipover begins as soon as the center of gravity crosses the vertical plane containing the axis of overturning rotation). With less distance to fall, and a negligible initial angular velocity propelling the tip-over, a cask tipping away from the precession motion is expected to have substantially less kinetic energy of collision than one tipping from zero velocity with center of gravity of over corner. Moreover, even if one were to assume that a tip-over would have a larger velocity than that posited in Holtec's hypothetical cask tipover analysis, the huge margins in the design of the MPC canister system would prevent the release of radioactive material. This has been demonstrated by the canister's capability to withstand a 25 ft. straight drop, unprotected by a cask onto a hard concrete surface, with a still significant margin, after impact, before reaching the failure strain limit of the material.

Q171. Based on the conservatisms you have described, do you have an opinion regarding the magnitude of a beyond design basis earthquake that the HI STORM 100 storage cask system could withstand?

A171. (KPS, AIS) Yes. As discussed above, the cask storage system can experience a 10,000-year return period earthquake without cask tip-over or significant sliding. Moreover, there are significant additional margins of safety within the storage cask system in the unlikely event of an actual cask tipover event. Thus, it is clear that the HI-STORM System can experience and withstand, without the release of radioactive material, not only a 10,000-year return period earthquake, but also earthquakes of substantially larger magnitude.

Q172. Does that conclude your testimony?

A172. Yes it does.

KRISHNA P. SINGH, Ph.D., PE

EXECUTIVE ENGINEER
HOLTEC INTERNATIONAL

EDUCATION

University of Pennsylvania
Ph.D. in Mechanical Engineering (1972)
GPA: 4.0 Out of 4.0

University of Pennsylvania
M.S. in Mechanical Engineering (1969)
GPA: 4.0 out of 4.0

B.I.T. Sindri, Ranchi University
B.S. In Mechanical Engineering (1967)
(Ranked in the top 1% of Engineering Graduates)

AREAS OF PROFESSIONAL CONCENTRATION

Application of ASME, ACI, and NUREG-0612 Codes. Mechanical and civil/structural design of weldments and reinforced concrete systems. Applied heat transfer and fracture assessment of dry storage systems.

PROFESSIONAL EXPERIENCE

HOLTEC INTERNATIONAL
Marlton, New Jersey

1986-Present	President and CEO

JOSEPH OAT CORPORATION
Camden, New Jersey

1979 - 1986	Vice President of Engineering
1974 - 1979	Chief Engineer
1971 - 1974	Principal Engineer

R.I.T. ALLAHABAD
India

1967 – 1968	Assistant Professor of Applied Mechanics

PROFESSIONAL CERTIFICATIONS

Registered Professional Engineer - Pennsylvania (1974-present)
Registered Professional Engineer - Michigan (1980-present)

PROFESSIONAL SOCIETY MEMBERSHIPS/ACTIVITIES

Elected Fellow of the ASME (1987); Member ANS (1979-Present); Member, ASME (1973-Present); Chairman, TEMA Vibration Committee (1979 - 1986); Chairman, PVP Committee Of the ASME, Nuclear Engineering Division (1988-92); Member, ASME O&M Committee (1991 to present); Member ASCE (1977-83), Member, Heat Exchange Institute (1976-86).

PATENTS

"Heat Exchanger for Withstanding Cycle Changes in Temperature" (with M. Holtz and A. Soler), U.S. Patent No. 4,207,944 (1980).

"Radioactive Fuel Cell Storage Rack" (with M. Holtz), U.S. Patent No. 4,382,060 (May, 1983).

"Apparatus Suitable for Transporting and Storing Nuclear Fuel Rods and Methods for Using the Apparatus", U.S. Patent No. 5,898,747 (April, 1999)

"Apparatus Suitable for Transporting and Storing Nuclear Fuel Rods and Methods for Using the Apparatus", U.S. Patent No. 6,064,710 (May 16, 2000)

"Duct Photon Attenuator for Installation in a Ventilated Overpack Used to Store Spent Nuclear Fuel" (with Everett L. Redmond, John C. Wagner, and Stephen Agace) (Patent Pending)

"Below Grade Cask Transfer Facility" (with Stephen Agace) (Patent Applied For)

"Seismic Cask Stabilization Device" (with A.I. Soler) (Patent Applied For)

"Ventilated Overpack for Storing Spent Nuclear Fuel" (with Stephen Agace) (Patent Applied For)

BOOKS AND ARCHIVAL VOLUMES (authored or edited):

1. "Mechanical Design of Heat Exchangers and Pressure Vessel Components", (authored with A. I. Soler), Arcturus Publishers, Cherry Hill, New Jersey, 1100 pages, hardbound (1984).

2. "Theory and Practice of Heat Exchanger Design" (sole author), Arcturus Publishers (ca. 2000).

3. "Feedwater Heater Workshop Proceedings", edited with Tom Libs, EPRI 78-123 (1979).

4. "Feedwater Heater Technology: State-of-the-Art", sole author, EPRI - cs - 4155 (1985).

5. "Analytical Correlations of Fluid Drag of Fuel Drag of Fuel Assemblies in Fuel Rack Storage Locations", sole author, EPRI Project RP-2124.

6. "Thermal/Mechanical Heat Exchanger Design", (edited) ASME, PVP - Vol. 118 (1986).

7. "Time Dependent and Steady State Characterization of the CAES Recuperator", (principal author) EPRI TR-104224 (July 1994).

8. "Pressure Vessels, Heat Exchangers and Piping", Proc. ASME, IEEE Joint Power Generation Conference, (editor) NE-14 (1994).

EXPERT WITNESS AND TECHNOLOGY APPRAISAL SERVICES FOR NUCLEAR PLANTS AND NATIONAL LABORATORIES

Most of the expert witness activities pertain to spent fuel storage technology and PWR steam generator design.

1. Pacific Gas & Electric Company vs. National Sierra Club (1986-87).

2. Florida Power & Light Company vs. Stuart Intervenor Group (1990).

3. Duquesne Light Company vs. Westinghouse (1993-1994).

4. Portland General Electric vs. Westinghouse (1993-1994).

5. Houston Light and Power vs. Westinghouse (1994-1995).

6. Pacific Northwest Laboratories, Rockwell International, and U.S. DOE vs. RSI (1994).

7. Northern States Power vs. Westinghouse (1996)

8. Commonwealth Edison Company vs. Westinghouse (1997)

ACADEMIC ACTIVITIES

Chair, Advisory Committee On Mechanical Engineering and Mechanics, University of Pennsylvania (1993-1999)

Professor (Adjunct) in Mechanical Engineering and Mechanics, University of Pennsylvania (1986-92), Offered Graduate and Undergraduate Courses in Heat Transfer Equipment and Pressure Vessel Technology.

CONTINUING EDUCATION COURSES OFFERED TO PRACTICING GRADUATE ENGINEERS

1. I.I.T. Bombay, One Week Course on Heat Exchanger Design (1979).

2. Duke Power Company, Charlotte, NC (1982, 1983, 1986, 1990) - In-house Training Course on Heat Exchanger Design and Testing.

3. National Italian Reactor Authority, Genoa, Italy - On Condensers, Steam Generators, and Moisture Separator Reheaters (1985).

4. Mississippi Power & Light Company, In-House Course on Moisture Separator Reheaters and Surface Condensers (1987).

5. Center for Professional Advancement (1988, New Brunswick, NJ; 1990, Caracas, Venezuela; 1991, Houston, Texas; 1992, Amsterdam, Holland).

SPENT FUEL STORAGE TECHNOLOGY

- Developer of the industry's first multi-purpose canister design (ca. 1993), later licensed by the USNRC under Docket 71-9261 for transport and Docket 72-1008 for storage. Patent for a unique spent fuel basket design granted by the U.S. Patent Office in April, 1999 (U.S. Patent No. 5,898,747).

- Co-developer of Cask Transfer Facility Specification and Design.

- Developed the nonlinear methodology for cask drop analysis within §50 jurisdiction in support of Shorehams defueling project (ca. 1994). Participated in dynamic (drop) analysis of TN-12 and IF-300 casks.

- Developer of the multi-layer transport overpack design in 1993, subsequently licensed as the HI-STAR 100 dual-purpose overpack.
- Performed brittle fracture analysis of MPC lid welds in Holtec MPC systems.

- Participated in the development of Holtec's thermal evaluation methodologies for dry storage systems.

- Developer of the thermosiphon action MPC design.

- Developed dozens of company position papers and generic reports for Holtec International for cask system design and analysis.

- Author of over 200 industry reports on dry and wet storage technologies.

- Developer of detuned honeycomb rack design used by Holtec International in over sixty rerack projects.

- Led licensing of over fifty O.L. amendment requests for reracking spent fuel pools.

- Over a dozen technical papers in dry and wet storage of spent nuclear fuel.

TECHNICAL CONSULTING

Technical consulting services to over fifty national and international organizations, including: Electric Power Research Institute (EPRI); Pressure Vessel Research Council (PVRC); Tubular Exchanger Manufacturers Association (TEMA); Department of Energy (DOE) (Idaho Operations); Department of Energy (DOE) (Chicago Operations); American Electric Power Corporation; Baltimore Gas and Electric; Carolina Power & Light; Commonwealth Edison Company; Detroit Edison Company; Duke Power Company; Entergy Operations; GPU Nuclear; Iowa Electric Light and Power; New York Power Authority; Niagara Mohawk Power Corporation; North Atlantic Energy Services; Northeast Utilities; Northeast Nuclear Energy; Pacific Gas and Electric Company; PECO Energy; Southern Nuclear Operating Company; and Tennessee Valley Authority.

PUBLICATIONS

1. "A Method for Solving Ill-Posed Integral Equations of the First Kind", (with B. Paul), Computer Methods in Applied Mechanics and Engineering 2 (1973) 339-348.

2. "Numerical Solutions of Non-Hertzian Elastic Contact Problems", (with B. Paul), Journal of Applied Mechanics, Vol. 41, No. 2, 484-490, June, 1974.

3. "On the Inadequacy of Hertzian Solution of Two Dimensional Line Contact Problems", Journal of the Franklin Institute, Vol, 298, No. 2, 139-141 (1974).

4. "How to Locate Impingement Plates in Tubular Heat Exchangers", Hydrocarbon Processing, Vol. 10, 147-149 (1974).

5. "Stress Concentration in Crowned Rollers", (with B. Paul), Journal of Engineering for Industry, Trans. ASME, Vol. 97, Series B, No. 3, 990-994 (1975).

6. "Application of Spiral Wound Gaskets for Leak Tight Joints", Journal of Pressure Vessel Technology, Trans. ASME, Vol. 97, Series J, No. 1, 91-93 (1975).

7. "Contact Stresses for Multiply-Connected Regions - The Case of Pitted Spheres:, with B. Paul and W. S. Woodward, Proceedings of the IUTAM Symposium on Contact Stresses, August 1974, Holland, Delft University Press, 264-281, (1976).

8. "Design of Skirt-Mounted Supports:, Hydrocarbon Processing, Vol. 4, 199-203, April 1976.

9. "Predicting Flow Induced Vibration in U-Bend Regions of Heat Exchangers - An Engineering Solution". Journal of the Franklin Institute, Vol. 302, No. 2, 195-205, August 1976.

10. "A Method to Design Shell-side Pressure Drop Constrained Tubular Heat Exchangers", with Mr. Holtz, Journal of Engineering for Power, Trans. of the ASME, Vol. 99, No. 3 July 1977, pp 441-448.

11. "An Efficient Design Method for Obround Pressure Vessels and Their End Closures", International Journal of Pressure Vessel and Piping, Vol. 5, 1977, pp 309-320.

12. "Analysis of Vertically mounted Through-Tube Heat Exchangers", Journal of Engineering for Power, Trans. ASME, Vol. 100, No. 2, April, 1978, pp 380-390.

13. "Study of Bolted Joint Integrity and Inter-Tube-Pass Leakage in U-Tube Heat Exchangers: Part I - Analysis", Journal of Engineering for Power, Trans. ASME, Vol. 101, No. 1, pp 9-15 (1979).

14. "Study of bolted Joint Integrity and Inter-Tube-Pass Leakage in U-Tube Heat Exchangers, Part II - Applications", Journal of Engineering for Power, Trans. ASME, Vol. 101, No. 1, pp 16-22 (1979).

15. "On Thermal Expansion Induced Stresses in U-Bends of Shell-and-Tube Heat Exchangers", (with Maurice Holtz); Trans. ASME, Journal of Engineering for Power, Vol. 101, No. 4, October, 1979, pp. 634-639.

16. "Heat Transfer Characteristics of a Generalized Divided Flow Heat Exchanger", Proceedings of the Conference on Industrial Energy Conservation Technology, Houston, Texas, pp 88-97 (1979).

17. "An Approximate Analysis of Foundation Stresses in Horizontal Pressure Vessels", (with Vincent Luk), Paper No. 79-NE-1, Trans. ASME, Journal of Engineering for Power, Vol. 102, No. 3, pp 555-557, July, 1980.

18. "Generalization of the Split Flow Heat Exchanger Geometry for Enhanced Heat Transfer", (with Michael Holtz), AIChe. Symposium Series 189, Vol. 75, pp 219-226 (1979).

19. "Analysis of Temperature Induced Stresses in the Body Bolts of Single Pass Heat Exchangers", ASME Winter Annual Meeting, Paper No. 79 QA/NE-7, New York, NY, 1979.

20. "Optimization of Two-Stage Evaporators for Minimizing Rad-Waste Entrainment", (with Maurice Holtz), Journal of Mechanical Design, Trans. of the ASME, Vol. 102, No. 4, pp 804-806 (1980).

21. "A Comparison of Thermal Performance of Two and Four Tube Pass Designs for Split Flow Shells", (with M. J. Holtz), Journal of Heat Transfer, Trans. of the ASME, Vol. 103, No. 1, pp 169-172, February, 1981.

22. "A Method for Maximizing Support Leg Stress in a Pressure Vessel Mounted on Four Legs Subject to Moment and Lateral Loadings". International Journal of Pressure Vessels and Piping, Vol. 9, No. 1, pp 11-25 (1981).

23. "Design, Stress Analysis and Operating Experience in Feedwater Heaters",, (with Tom Libs), Proceedings of the Conference on Industrial Energy Conservation Technology, Houston, pp 113-118 (1980).

24. "On the Necessary Criteria for Stream Symmetric Tubular Heat Exchanger Geometries", Heat Transfer Engineering, Vol. 3, No. 1 (1981).

25. "Some Fundamental Relationships for Tubular Heat Exchanger Thermal Performance", Trans. ASME, Journal of Heat Transfer, Vol. 103, pp 573-578 (1981).

26. "Transient Swelling of Liquid Level During Pool Boiling in an Emergency Condenser", (with J. P. Gupta). Letters in Heat and Mass Transfer, Vol. 8, No. 1, pp 25-33, Jan/Feb., 1981.

27. "An Approximate Method for Evaluating the Temperature Field in Tubesheet Ligaments Under Steady State Conditions", (with M. Holtz), Journal of Engineering for Power, Trans. ASME, Vol. 104, pp 895-900 (1982).

28. "Feasibility Study of A Multi-Purpose Computer Program to Optimize Power Cycles for Operative Plants", (with Y. Menuchin and N. Hirota), Proceedings of the Conference on Industrial Energy Conservation Technology, Houston, (1981).

29. "Design Parameters Affecting Bolt Load in Ring Type Gasketed Joints", (with A. I. Soler), Trans. ASME, Journal of Pressure Vessel Technology, Vol 105, pp 11-13 (1983).

30. "A Design Concept for Minimizing Tubesheet Stress and Tubejoint Load in Fixed Tubesheet Heat Exchangers", (with A. I. Soler), Trans. ASME (C. 1982).

31. "Dynamic Coupling in a Closely Spaced Two-Body System Vibrating in Liquid Medium: The Case of Fuel Racks", (with A. I. Soler), Proceedings of the Third International Conference on "Vibration in Nuclear Plant", Keswick, England, May, 1982, pp. 815-834.

32. "Effect of Nonuniform Inlet Air Flow on Air Cooled Heat Exchanger Performance", (with A. I. Soler and Lee Ng), Proceedings of the Joint ASME-JSME Heat Transfer Conference, 1983, pp. 537-542.

33. "Seismic Response of Free Standing Fuel Rack Constructions to 3-D Motions", (with A. I. Soler), Nuclear Engineering and Design, Vol. 80, (1984), pp. 315-329.

34. "A Method for Computing Maximum Water Temperature in a Fuel Pool Containing Spent Nuclear Fuel", Heat Transfer Engineering, Hemisphere, Dec. (1986).

35. "On Minimization of Radwaste Carry-Over in a N-stage Evaporator", (with Maurice Holtz and Vincent Luk), Heat Transfer Engineering, pp. 68-73, Vol. 5, No. 1-1 (1984).

36. "Feedwater Heater Procurement Guidelines - Some New Performance Criteria", Symposium on State-of-the-art Feedwater Heater Technology, EPRI (c. 1984).

37. "Method for Quantifying Heat Duty Derating due to Inter-Pass Leakage in Bolted Flat Cover Heat Exchangers", Heat Transfer Engineering, pp. 19-23, Vol. 4, No. 3-4 (1983).

38. "Foundation Stresses under Support of Freestanding Equipment Subjected to External Loads", (with K. P. Singh and I. Gottesman), International Journal of Pressure Vessels and Piping, Vol. 20, No. 2 (1985) pp. 127-138.

39. "On Some Performance Parameters for Closed Feedwater Heaters, Journal of Pressure Vessel Technology, Trans. ASME (1987).

40. "A Design Procedure for Evaluating the Tube Axial Load Due to Thermal Effects in Multi-Pass Fixed Tubesheet Heat Exchangers", (with A. I. Soler), Journal of Pressure Vessel Technology, Trans. ASME (1987).

41. "An Elastic-Plastic Analysis of the Integral Tubesheet in U-Tube Heat Exchangers - Towards an ASME Code Oriented Approach", Int. Journal of Vessel and Piping (c. 1987).

42. "Feedwater Heaters", Heat Transfer Equipment Design, R. Shal et. al (editor), Hemisphere (c. 1988).

43. "Surface Condensers", Heat Transfer Equipment Design, R. Shal et. al (editor), Hemisphere (c. 1988).

44. "FLow Induced Vibration", Heat Transfer Equipment Design, R. Shal et. al (editor), Hemisphere (c. 1988).

45. "Mechanical Design of Heat Exchangers", Heat Transfer Equipment Design, R. Shal et. al (editor), Hemisphere (c. 1988).

46. "A Rational Method for Analyzing Expansion Joints":, (with A. Soler), ASME, Journal of Pressure Vessel Technology (c. 1988).

47. "An Analysis of the Improvement in the Thermal Performance of Surface Condenser Equipped with Tweener Supports", ASME Joint Power Generation Conference, Miami (Oct. 1987).

48. "Pressure Vessels - Design & Operation", Chemical Engineering, pp 62-70, Chemical Engineering, July 1990, McGraw Hill, N.Y.

49. "Spent Fuel Storage Options: A Critical Appraisal", Power Generation Technology, pp 137-140, Sterling Publications, U.K. (1990-91).

50. "Design Strength of Primary Structural Welds in Free-Standing Structures", with A.I. Soler and S. Bhattacharya, Journal of Pressure Vessel Technology, Trans. ASME (c' 1991).

51. "Seismic Qualification of Free-Standing Nuclear Fuel Storage Modules - The Chin Shan Experience", Nuclear Engineering International, U.K. (March, 1991).

52. "Transient Response of Large Inertia Cross Flow Heat Exchangers", with Y. Wang, A.I. Soler and K. Iulianetti, ASME 91-JPGC-NE-27 (1991).

53. "Some Results from Simultaneous Seismic Simulations of All Racks in a Fuel Pool", with A.I. I. Soler, INMM Spent Fuel Management Seminar X, Washington, D.C., January, 1993.

54. "A Case for Wet Storage", INMM Spent Fuel Management Seminar X, Washington, D.C., January, 1993.

55. "Application of Transient Analysis Methodology to Heat Exchanger Performance Testing" with I. Rampall and Benjamin H. Scott, ASME Joint Power Generation Conference, October, 1994.

56. "Predicting Thermal Performance of Heat Exchangers Using In-Situ Testing and Statistical Correlation", with K. Iulianetti and Benjamin H. Scott, ASME Joint Power Generation Conference (1994).

57. "An Overview of the HI-STAR Technology", INMM Conference, Washington, DC, January, 1997.

58. "A Structural Assessment of Candidate Fuel Basket Designs for Storage and Transport of Spent Nuclear Fuel", with Max Delong, INMM Conference, Washington, DC, January, 1998.

59. "Seismic Response Characteristics of HI-STAR 100 Cask System on Storage Pads", with Mark G. Smith and A.I. Soler, INMM Conference, Washington, DC, January, 1998.

60. "Analysis of Mechanical Impact Events in Spent Fuel Storage Equipment", with Charles Bullard and Jin Yop Chung (1997).

61. "Predicting the Structural Response of Free-Standing Spent Fuel Storage Casks Under Seismic Events", with Alan I. Soler and Mark G. Smith, 16th Conference on Structural Mechanics in Reactor Technology (SmiRT 16), Washington, DC August 12-17, 2001.

ALAN I. SOLER, Ph.D.

EXECUTIVE ENGINEER
HOLTEC INTERNATIONAL

EDUCATION

University of Pennsylvania
Ph.D. in Mechanical Engineering (1962)

California Institute of Technology
M.S. in Mechanical Engineering (1959)

University of Pennsylvania
B.S. in Mechanical Engineering (1958)

AREAS OF PROFESSIONAL CONCENTRATION

Dynamics of casks and fuel racks, impact, mechanical design of cask and MPCs, failure analysis of reinforced concrete structures, cask transporter design, NUREG-0612 compliance, crane design and stress analysis.

PROFESSIONAL EXPERIENCE

HOLTEC INTERNATIONAL
Marlton, New Jersey
1986 – Present — Executive Engineer

UNIVERSITY OF PENNSYLVANIA
Philadelphia, Pennsylvania
1966 - 1991 — Professor of Mechanical Engineering and Applied Mechanics

INGERSOLL-RAND RESEARCH CENTER
Princeton, New Jersey
May 1964–Sept. 1965 — Member of Technical Staff

DYNASTRUCTURES, INC., CONSULTANTS IN APPLIED MECHANICS
Philadelphia, Pennsylvania
May 1962–May 1964 — Research Specialist

ACADEMIC HONORS

Tau Beta Pi
Sigma Tau
Society of Sigma Xi

PROFESSIONAL SOCIETY MEMBERSHIPS/ACTIVITIES

Member, ASME, Fellow ASME, 1986
Treasurer, University of Pennsylvania Chapter, Sigma Xi, 1968-70.
General Arrangements Committee Member, 1969, ASME Vibrations Conference.
ASEE Local Activity Coordinator, 1968-1974.

Member, Rotordynamics Subcommittee, ASME Design Division, 1973-1974.
Local Arrangements Committee, 1971 Summer ASME Applied Mechanics Meeting.
Recording Secretary, ASME Applied Mechanics Division, Publication Committee, 1971-1972.
-Applied Mechanics Representative to ASME Power Division Subcommittee on Environmental Policy, 1974-1976.
Member, Turbine and Auxiliaries Committee, ASME Power Division, 1974-76, Papers Review
Member, Task Group on Heat Transfer Equipment, ASME, working group #1 (tubesheets), 1975-1998.
Member - Subcommittee on Pressure Vessels and Piping, Nuclear Engineering Division, ASME, 1976-1987, Chairman, 1984-1987.

TECHNICAL CONSULTING

Consultant to Solid Mechanics Group, Ingersoll-Rand Research Center, Princeton, New Jersey, September 1965 - December 1966.
Consultant to Condenser Engineering Department, Ingersoll-Rand Corporation, Phillipsburg, New Jersey, September 1965 – 1982. Consultant to Structural Mechanics Associates, November 1958 - January 1969.
Visiting Scientist, Mechanical Engineering Research Division, Livermore Laboratories, Livermore, CA, Summer 1973, 1974 (AEC "Q" Clearance).
Member of Consulting Group, Thermac Associates, 1975 - 1986.
Consultant to Joseph Oat Corp. - Manufacturers of Nuclear Heat Exchangers. Camden, New Jersey, 1975 - 1986.
Consultant to Heat Exchange Institute - Nuclear HEX, 1978-1979.
Consultant, Inc., Wilson Div., Reading, PA, 1979-1980.
Consultant, NADC, Willow Grove, PA, 1984-1986.

PATENTS

Patent #3,382,918, May 1968, Reinforcing Structure for Direct Flow Steam Dome for Condensers (with Mr. R. J. Stoker and Dr. B. Paul of Ingersoll-Rand Corporation).

DRY SPENT FUEL STORAGE TECHNOLOGY

1992-Present: Lead Analyst in Mechanical/Seismic/Structural analysis in support of Holtec=s Dry Storage submittals for dual-purpose casks (HI-STAR 100 for Storage and Transport) and for METCON casks (HI-STORM 100 for Storage).

1994: Performed cask tip-over and drop analysis to support §50.59 effort for defueling Shoreham Station using IF-300 casks.

1995: Principal Analyst for evaluating cask drop events for Connecticut Yankee.

1997: Co-developer of the dynamic formalism to predict peak cask deceleration from cask tip-over and drop event on ISFSI pads.

1996: Principal designer of HI-STAR 100 Impact Limiter.

1998: Developer of the "penetration area principle" to predict impact limiter response under cask drop events; method was verified using quarter-scale tests.

1999: Designer and principal analyst for Holtec International's autonomous "Cask Transfer Facility" (CTF).

HIGH DENSITY FUEL RACK STRESS ANALYSIS

- Principal developer of Holtec's rack dynamic analysis code DYNARACK. This code is widely recognized as the most sophisticated program for high density rack seismic analysis.
- Performed seismic analysis of high density racks for 36 Nuclear Power Plants in the period 1980 to present.
- Pioneered dynamic analysis techniques of elevated pool slabs. Qualified the elevated pool slabs of Quad City Units 1 and 2, Grand Gulf and Oyster Creek using dynamic reinforced concrete analysis (all approved by the USNRC).

LICENSING SUPPORT

- Provided licensing support on over forty high-density rack applications to the USNRC (in the past twenty years).
- Appeared as expert witness (support) for Pacific Gas & Electric in Diablo Canyon reracking license review (1987).

PUBLICATIONS/PRESENTATIONS

1. "On the Lobar and Longitudinal Vibrations of Solid Propellant Rocket Motors", (with H. B. Kingsbury and J. R. Vinson) Proceedings of the 6th Solid Propellant Rocket Conference, AIAA, Washington, D.C. (February 1965).
2. "On the Solution to Transient Coupled Thermoelastic Problems by Perturbation Techniques", (with M. A. Brull) presented at the Summer Applied Mechanics Meeting of ASME (June 1965) and published in the Journal of Applied Mechanics (June 1965).
3. "A New Perturbation Technique for Differential Equations with Small Parameters", (with M. A. Brull), Quarterly of Applied Mathematics XXIV, No. 2 (July 1966) and presented at the 5th National Congress on Applied Mechanics, Minneapolis, Minnesota (June 1966).
4. "On Rolling Contact and the Theorem of Angular Momentum", (with S. C. Batterman), Journal of Engineering Education 67, 9 (May 1967).
5. "Higher Order Effects in Thick Rectangular Beams", International Journal of Solids and Structures 4, (July 1968) pp. 723-739.
6. "On the Vibrations and Stability of Moving Bands", Journal of the Franklin Institute (October 1968).
7. "Higher Order Theories for Structural Analysis Using Legendre Polynomial Expansions", presented at ASME Winter Annual Meeting, Los Angeles, CA (November 1969), and published in Journal of Applied Mechanics (December 1969).

8. "One Dimensional Viscous Magnetofluidynamic Flow in an Annulus", (with S. Schwietzer), presented at the AIAA Fluid and Plasma Dynamics Conference, San Francisco, California (June 1969), and published in Journal of the Franklin Institute 289, No. 6 (June 1970).

9. "On the Solution of Finite Deformation Problems of Beams Using Rate Equations", (with J. Lehner), Journal of Applied Mechanics, (March 1970) pp. 207-210.

10. "Approximate Theory for Locally Loaded Plant Orthotropic Beams", (with H. Tsai), International Journal of Solids and Structures 6, (1970) pp. 1055-1068.

11. "Approximate Solution of the Finite Cylinder Problem Using Legendre Polynomials'< (with J. Fellers), AIAA Journal 8, No. 11 (November 1970) and presented at the 6th U.S. Congress on Applied Mechanics (June 1970).

12. "On Analysis of Cable Network Systems Using Galerkin's Method", (with H. Afshari), Journal of Applied Mechanics, (September 1970) pp. 606-612.

13. "On the Buckling of Rings", (with S. C. Batterman), ASCE Engineering Mechanics Journal (December 1970).

14. "Dynamic Response of Sincle Cables with Initial Sag", Journal of the Franklin Institute (October 1970).

15. "Analysis of Cable Dynamics and Optimum Towing Strategies for Tethered Submersibles", (with B. Paul), presented at the Ocean Engineering Symposium, University of Pennsylvania (November 19-20, 1970), and published in Journal of Marine Technology 6, 2 (April 1972) pp. 34-41.

16. "Circumferential Forces and Moments in Edge Loaded Conical Shell Elements", Journal of Applied Mechanics (March 1972) pp. 290-291.

17. "Pre-twisted Curved Beams of Thin-Walled Open Section", Journal of Applied Mechanics (September 1972) pp. 779-786.

18. "Thermal Stresses and Initial Deformation of Heated Condenser Tubes", Journal of Engineering for Power (April 1973) pp. 84-91.

19. "New Results on Applications of Multi-Segment Stepwise Integration to First Order Equations", (with G. J. Hutchins), Journal of Computer Methods in Applied Mechanics and Engineering (1972) pp. 307-316.

20. "Dynamics of Cables and Cable Systems", Shock and Vibration Digest 5, 3 (March 1973) pp. 1-9.

21. "Cable Network Vibrations Using Galerkin's Method of Polynomial Approximating Functions", (with H. Afshari), Journal of Applied Mechanics (June 1973) pp. 622-624.

22. "Analysis of Moderately Thick Shells of Revolution", (with G. J. Hutchins), Journal of Applied Mechanics (December 1973) pp. 955-961.

23. "Project Cyclops - A Design Study of a System for Detecting Extraterrestrial Life", contributing author, NASA Report CR114445 (October 1972).

24. "Vibration of Cable Gridworks with Small Initial Deformation", (with H. Afshari), Journal of Applied Mechanics (December 1973), and presented at Winter ASME Meeting, Detroit, Michigan (November 1973).

25. "Transverse Elastic Buckling of Plane Pipe Gridworks", (with H. Afshari, Journal of Structures, ASCE (April 1974).

26. "On Seal Forces in Removable End Closure in Very High Pressure Test Chambers", ASME Journal of Pressure Vessel Technology (February 1975).

27. "Limit Design of Condenser Hotwell Floors", ASME Journal of Engineering for Power (October 1975) pp. 628-633.

28. "Stability of Rotor-Bearing Systems with Generalized Support Flexibility and Damping and Aerodynamic Cross-Coupling", (with R. E. Warner), presented at ASME Lubrication Conference, Toronto (October 1974), and published in the ASME Journal of Lubrication Technology (July 1975) pp. 461-472.

29. "Tubesheet Design in U-Tube Heat Exchangers Including the Effect of Tube Rotational Restraint", published in Journal of Engineering for Industry 98, 4 (November 1976) pp. 1157-1160 and presented at Design Engineering Conference, Chicago, IL (April 1976).

30. "Effective Bending Properties for Stress Analysis of Rectangular Tubesheets", (with W. Hill), published in ASME Journal for Power 99, 3 (July 1977) pp. 365-370, presented at 1976 ASME Annual Meeting.

31. "Stress Analysis of a U-Tube Heat Exchanger Tubesheet with an Integral Channel and an Unperforated Rim", presented by Pressure Vessel and Piping Division, ASME Mexico City Conference (September 1976) (76-PV-58).

32. "Analysis of Beam Columns on Elastic Plastic Foundations with Application to Power Plant Condenser Support Plate Design", (with C. Shahravan), published in ASME Journal of Engineering for Power, 100 (January 1978) pp. 182-188.

33. "Analysis of Closely Spaced Double Tubesheets under Mechanical and Thermal Loading", presented at 1977 Joint Power Generation Conference, ASME, Los Angles, California (77-JPGC-NE-21).

34. "The Tubesheet Analysis Method in the New HEI Condenser Standards", (with M.D. Bernstein), presented at the 1977 Joint Power Generation Conference, ASME, Los Angeles, California, published in ASME Journal for Power 100 (April 1978) pp. 363-368.

35. "Design Curves for Stress Analysis of U-Tube Heat Exchanger Tubesheet with Integral Channel and Head", (with J. E. Soehrens) Journal of Pressure Vessel Technology 100 (May 1978) pp. 221-233.

36. "Design of Condenser Hotwell Floor for Pressure Loading", presented at ASME 1978 Annual Meeting, ASME Advances in Reliability and Stress Analysis H00119 (1979) pp. 203-215.

37. "A Preliminary Assessment of the HEI Tubesheet Design Method - Comparison with a Finite Element Solution", presented at ASME 1978 Winter Annual Meeting, ASME Advances in Reliability and Stress Analysis H00119 (1979) pp. 127-146.

38. "Analysis of Bolted Joints with Nonlinear Gasket Behavior", ASME Journal of Pressure Vessels 102 (August 1980) pp. 249-256.

39. "Stress Analysis of Rectangular Tubesheets for Condensers", Paper 80-C2/NE-14 presented at ASME Nuclear Engineering Conference, San Francisco, California (August 1980).

40. "A Finite Element Model for Thick Beams", (with D. Barrett) Computer Methods in Applied Mechanics and Engineering 25 (1981) pp. 299-313.

41. "A Design Concept for Minimizing Tubesheet Stress and Tubejoint Load in Fixed Heat Exchangers", (with K. P. Singh) 1982 ASME Pressure Vessel and Piping Conference, Orlando, Florida; Int. Journal for Pressure Vessel Technology, Trans. ASME (c. 1982).

42. "Dynamic Coupling in a Closely Spaced Two Body System Vibrating in a Liquid Medium: The Case of Fuel Racks", (with K. P. Singh) 1982 SMIRT Conference, Keswick, England (May 1982).

43. "A Finite Element Model for Thickwalled Axisymmetric Shell", (with D. J. Barrett), ASME Journal of Pressure Vessel Technology 104, (August 1982) pp. 215-222.

44. "Design Parameters Affecting Bolt Load in Ring Type Gasketed Joints", (with K. P. Singh), Journal of Pressure Vessel Technology, Trans. ASME (1984).

45. "Effect of Non-Uniform Inlet Air Flow on Air-Cooled Heat Exchanger Performance", (with K. P. Singh and T. L. Ng) presented at Joint ASME-JSME Transfer Conference, Hawaii (March 1983) and published in Conference Proceedings.

46. "A Method for Computing Maximum Water Temperature in a Fuel Pool Containing Spent Nuclear Fuel", (with K. P. Singh) presented at Fourth International Conference on Pressure Vessels and Piping, Portland, Oregon (June 1983), Nuclear Technology, ANS (c. 1984).

47. "Seismic Response of Free Standing Fuel Rack Constructions to 3-D Floor Motions", (with K. P. Singh) presented at the Fourth International Conference on Pressure Vessels and Piping, Portland, Oregon (June 1983) and published in Nuclear Engineering and Design 80, (1984) pp. 315-329.

48. "Analysis of Tube-Tubesheet Joint loading Including Thermal Loading", (with Xu Hong) published in Journal of Applied Mechanics (June 1984), and presented at 1984 Pressure Vessels and Piping Conference.

49. "Analysis and Design of Pressure Vessel Bolted Flanges with Non Linear Gasket Materials", 11th Conference on Production Research and Technology - Computer Based Factory Automation, Conference Proceedings, Carnegie Mellon University, Pittsburgh, PA (May 1984).

50. "Foundation Stresses under Support of Freestanding Equipment Subjected to External Loads", (with K. P. Singh and I. Gottesman), International Journal of Pressure Vessels and Piping, Vol. 20, No. 2 (1985) pp. 127-138.

51. "Finite Elements for Thick 3-D Shells", (with A. Khaskia), International Journal of Pressure Vessel Technology, 1985.

52. "Tube-to-Tubesheet Rolled Joints: Part I - Analysis Including Strain Hardening and Temperature Dependent Properties", (with S. Weinstock), Proceedings of ASME 1985 Pressure Vessel and Piping Conference H00329, New Orleans, LA.

53. "Tube-to-Tubesheets Rolled Joints: Part II - Experimental Analysis", (with K. Reinis), Proceedings of ASME 1985 Pressure Vessel and Piping Conference H00329, New Orleans, LA.

54. "An Elastic Plastic Analysis of the Integral Tubesheet in U-Tube Heat Exchangers - Towards an ASME Code Oriented Approach", (with K. P. Singh), Proceedings of ASME 1985 Pressure Vessel and Piping Conference H00329, New Orleans, LA.

55. "A Design Procedure for Evaluating the Tube Axial Load due to Thermal Effects in Multi-Pass Fixed Tubesheet Exchangers", (with K. P. Singh), ASME Journal of Pressure Vessel Technology (c. 1986).

56. "Tubesheet Analysis - A Proposed ASME Design Procedure" (with S. Caldwell and K. P. Singh), ASME Karl Gardner Memorial Symposium Proceedings (c. 1986). Channel and an Unperforated Rim, presented by Pressure Vessel and Piping Division, ASME.

57. "Some Results From Simultaneous Seismic Simulations of all Racks in a Fuel Pool", with K.P. Singh, INMM Spent Fuel Management Seminar X, Washington, D.C., January, 1993.

58. Application of Transient Analysis Methodology to Quantify Thermal Performance of Heat Exchangers, I. Rampall, K.P. Singh, A. Soler, and B. Scott, Heat Transfer Engineering, 1997.

59. "Seismic Response Characteristics of HI-STAR 100 Cask System on Storage Pads", with K.P. Singh and Mark G. Smith, INMM Conference, Washington, DC, January, 1998.

MR. GAUKLER: We'd also like to introduce some exhibits, your Honor.

JUDGE FARRAR: Okay.

MR. GAUKLER: These are exhibits associated with Dr. Singh's and Dr. Soler's testimony. Exhibit NN is a letter from John Donnell to the NRC dated August 7, 2001, with an attached letter from Holtec International, Brian Guntherman to Max DeLong, dated August 6, 2001.

Exhibit OO is the CD. I'll come back to that in a second.

Exhibit PP are excerpts from the deposition of Dr. Mohsin Khan on March 5th, 2002.

Exhibit QQ is an article, "Static and Sliding Friction in Feedback Systems," J. Tou and P.M. Schultheiss. I believe it's excerpts from that article.

Exhibit RR are excerpts from the Holtec validation report with respect to validation of this computer program DYNAMO.

Exhibit SS are excerpts from the ANSYS manual for the ANSYS program. ANSYS is capital A-N-S-Y-S.

Exhibit TT is a calculation done by Dr. Alan Soler with respect to the coefficient of restitution and linear viscous damping.

I would move that the exhibits be admitted into the record.

JUDGE FARRAR: Let's go off the record on the handling of exhibits for a moment.

(Discussion off the record.)

(APPLICANT'S EXHIBITS NN, OO, PP, QQ, RR, SS, AND TT MARKED.)

JUDGE FARRAR: Back on the record. Those exhibits are considered marked for identification. Now do you want to move their --

MR. GAUKLER: Move for admission into the record.

JUDGE FARRAR: Any objection? And these are the exhibits that everyone was given some time ago.

MR. GAUKLER: These were exhibits that were served with testimony and included in the black book I handed out yesterday.

JUDGE FARRAR: Mr. Turk, any objection?

MR. TURK: No, your Honor.

JUDGE FARRAR: State?

MR. SOPER: No objection, your Honor.

JUDGE FARRAR: All right. Then the exhibits will be admitted.

(APPLICANT'S EXHIBITS NN, PP, QQ, RR, SS AND TT WERE ADMITTED.)

JUDGE FARRAR: Did you want to play the CD now?

MR. GAUKLER: Yes. What I thought we would do is just briefly have Dr. Soler describe what he has in his testimony so you know what you're watching. We have eleven runs on there. I'm sure we'll go to the first two and the last, and if you want to see the others, that's fine just as well.

JUDGE FARRAR: Do we want -- is there a narration in it?

MR. GAUKLER: No, there's not a narration.

JUDGE FARRAR: Okay. Then the court reporter won't have to be doing anything during the running of the CD?

MR. GAUKLER: Except there will be -- Dr. Soler will give a brief description beforehand, and then he'll give a brief description of what each run is, summarizing what's in his testimony.

JUDGE FARRAR: Okay. Then are you set up to do that?

MR. GAUKLER: I believe we are.

JUDGE FARRAR: Mr. Soper?

MR. SOPER: Your Honor, I'm not sure that the State agrees with the idea that we ought to see just selected parts of this when we see it. I think we ought to see it all. I don't know what the basis of showing us a few is. I could guess, but --

MR. GAUKLER: I have no problem showing it all. It was just a matter of interest in saving time.

JUDGE FARRAR: How long is the entire video?

MR. GAUKLER: Each video is about 30 seconds.

JUDGE FARRAR: So eleven of them would take six minutes.

MR. GAUKLER: Yeah.

JUDGE FARRAR: Oh, okay.

MR. GAUKLER: With a brief description of each one.

JUDGE FARRAR: Then if the State would like us to show all of them, we can do that.

MR. SOPER: I don't mean to delay, but just not knowing how they're selected, I don't know how I can agree to just a few.

JUDGE FARRAR: Just following yesterday's rules -- oh, you weren't here yesterday.

MR. SOPER: I heard through the grapevine, your Honor.

JUDGE FARRAR: Following yesterday's rules, it's easier to watch them than to argue about whether we should watch them. So let's go ahead and -- go ahead, Mr. Gaukler.

MR. GAUKLER: I'll have Mr. Soler briefly describe what you're going to see, and then he'll show the cases and he'll tell you what cases you're looking at. I've given the court reporter three copies of the compact disc player -- compact disc with the simulations for the record. I have extra copies here in case people don't have their copy that was sent around in conjunction with the filing of our testimony.

MR. TURK: Can we go off the record for one moment?

JUDGE FARRAR: Yes.

(Discussion off the record.)

JUDGE FARRAR: Back on the record.

DR. SOLER: I'll refer you to the table on page 66 that's part of question 118. And I will give, first of all, a brief description on all of the analyses, and then before I run each simulation I will describe that particular one and clarify whatever might be too brief in the table.

What we did in response to certain items that were brought up during various depositions was to do some confirmatory analyses using an entirely different program from DYNAMO, and that program goes by the name of Visual NASTRAN Desktop. That program is capable of handling arbitrary rigid bodies, connecting them by various linear and nonlinear elements like springs, dampers, friction elements, and is able to simulate any degree of rotation that the bodies might want to undergo.

So therefore, to free ourselves from the limits of a small deformation program, we used this program to perform not only a confirmatory analysis of the DYNAMO runs, of particular DYNAMO runs, but also to extend our knowledge to a postulated beyond design-basis earthquake and see what happens.

What I will show you is a number of simulations. These simulations are created directly by the program, which has the capability of storing the data and then creating a movie file on the basis of the data. So these videos were not created outside the program, they are part of the program, and they use the results as they are calculated.

Now, the assumptions are basically these. I'll give you the general ones first and then those that are specific to a particular video.

The pad is assumed to be rigid in all simulations. The soil for the most part is modeled by the set of six springs in accordance with the formulations in 486, ASCE 486. The various soil springs are changed in their values according to the runs that we're doing. The casks are all modeled by single homogeneous cylinders that have the mass and inertial properties appropriate to a 360,000-pound vessel that's 133 inches in diameter and roughly 231 inches high.

The contact algorithm that is built into the code permits us to choose the contact stiffness between the cask and the pad and also allows us, if desired, to simulate behavior between the pad and the soil.

Now, let me tell you the first run that you're going to see is, and I will go in the order in which they appear in the table. It consists of eight casks on the pad, the 2,000-year return period earthquake, the lower bound design basis on soil stiffness. The damping attributed to the soil is that consistent with the lower bound soil stiffness and uses -- the values are calculated from the formulas in ASCE 486. The coefficient of friction between all casks and the pad is taken with .8, and the purpose of this demonstration is to show that an independent solution gives results that are the same order of magnitude as the DYNAMO results for the same case.

The -- one other thing. The simulations, of course, are computed using a small time step, and therefore you get lots of frames. The movies have been processed to squeeze the entire simulation down into 30 seconds. So what you will see on the screen is approximately real time, and the motion would occur with the real speeds.

JUDGE FARRAR: What do I see on the screen right now?

DR. SOLER: What you see on the screen right now is my desktop which consists of seven casks at the Hatch Nuclear Plant ISFSI. The four gray ones are HI-STORMs which would be similar to what would be proposed for PFS. The three white ones are HI-STAR transport casks.

JUDGE FARRAR: And those are the same size as what we're dealing with here?

DR. SOLER: The gray ones are. The white ones are not quite as high and are not quite as wide at the base.

MR. GAUKLER: Do you want to turn the lights down so you have a better view?

JUDGE FARRAR: Yeah. We're got our gentleman who fixes the air conditioner and takes care of the lights among his other duties.

DR. SOLER: Okay.

JUDGE FARRAR: Hold on. Off the record.

(Discussion off the record.)

JUDGE FARRAR: Back on the record.

DR. SOLER: I'll now get the first case running. This is running. This is basically the confirmatory run of DYNAMO, and I believe that the written testimony, the report submitted with the written testimony has the comparison. And we're talking about maximum excursions at the top of the cask, and the one that we tracked was this one, which is cask No. 1 in our terminology and is consistent with the terminology in the numbering scheme used in all of the reports that have been submitted. And we have -- any numbers that I quote with respect to top of cask displacements represent the horizontal excursion at that point.

DR. SINGH: This is a 2,000 year.

DR. SOLER: It's a 2,000-year return earthquake, and this uses the lower bound soil stiffness values.

Now --

JUDGE FARRAR: Let me make a suggestion procedurally that if anyone, if one of the parties has a question about what that represents, now would be the time to ask it. If you want to challenge the model or however this is done, that would be something you would hold till later. So if anybody has just questions to clarify what we have seen, feel free to ask them as we go along, but hold your challenges till later.

MR. GAUKLER: I was just going to suggest two things. One, since Dr. Singh's head got in the way, you might want to re-run it again.

Second, if the parties don't mind, we'll have Dr. Alan Soler just mention the displacement since it wasn't in the testimony, but it was in the report we gave to the State. So you can get an idea of the displacement of cask 1.

Why don't you run it again.

DR. SOLER: That's about four seconds right there. And this is roughly about 12 seconds. And that's the end of that simulation.

The -- and I'm speaking from memory here a little bit because I don't have the report in front of me. But the value for the net horizontal displacement at the top of the cask was a little bit larger than that predicted from the DYNAMO results in the report entitled "2,000-year Return Earthquake, Rev. 2." The number is still in the order of three inches.

MR. SOPER: I just have one question, Doctor. It looked to me in watching this that the casks to the right of cask 1 and to the right of that cask again moved more than the cask you pointed out. Why did you select the cask that didn't move as much?

DR. SOLER: As it turns out, I made a selection of which -- let me back off.

As you will see in later runs, you will find that there is a case in which only cask 1 is on the pad. And that was the first case that I simulated, and that's the one that I set up all of the data. I believe that you are probably correct

that some of the displacements, and you will
certainly see that in other runs, the displacements
of other casks may be somewhat larger. But they
are all in the order of what I would consider
small, meaning, say, three to five inches compared
to what I might consider large, which may be in the
order of 40 to 50 inches.

MR. SOPER: And how many other runs do
you have of the 2,000-year period?

DR. SOLER: I have one more run with the
2,000 year, which will be the next case I'll run.

MR. SOPER: When you said some of the
other runs, you mean the other run?

DR. SOLER: Well, we're going to run all
11 here, and some of the other runs deal with the
10,000-year beyond design basis earthquake.

MR. SOPER: Don't they all deal with the
10,000 year except for the other one?

DR. SOLER: Yes, except for these first
two.

Now, the next simulation --

MR. TURK: Before going forward, your
Honor, may I ask a favor? If the Applicant has the
report handy, it might be useful to get the precise
numbers on the record as we're watching it so we

can properly understand what the picture shows.

JUDGE FARRAR: Yes.

MR. SOPER: I think the direct testimony is in evidence. I'm not sure what part of the proceeding we're at here.

JUDGE FARRAR: Is this report -- was it a premarked exhibit?

MR. GAUKLER: This is the report we provided to the State as part of the backup for Dr. Soler's testimony. We did not have it as an actual exhibit.

MR. SOPER: Well, I thought what we were doing is introducing an exhibit and we were demonstrating the exhibit, and if we had a question about it we'd ask it, and then he's going to put it into evidence and then we're going to have cross-examination.

MR. TURK: Your Honor, I'm not asking for the report to be put into evidence, I'm just asking for a little bit more informative narration as we watch the movie.

JUDGE FARRAR: Let's do that. With due regard to your objection, Mr. Soper, let's do that. I do recall the witness saying that he didn't recall the exact number. It's in the report so let's have him use that, and we'll have a better record and you'll still be able to cross-examine.

MR. SOPER: Could we have that whole report admitted into evidence if it's going to be used at all?

JUDGE FARRAR: That's a fair request. Mr. Gaukler, what do you think of that?

MR. GAUKLER: I wouldn't --

DR. SOLER: It's okay.

MR. GAUKLER: No objection.

DR. SOLER: No objection.

JUDGE FARRAR: Wait a minute. Trying to be kind to the witnesses, but don't go too far.

MR. GAUKLER: You can't play lawyer.

JUDGE FARRAR: Then let's -- for right now, let's just go ahead with the narration, have him rely on the report, and then we'll go through the procedure of having admitted it when we're finished here.

DR. SOLER: Would you still like that number quoted?

MR. SOPER: Yes.

DR. SOLER: Okay. This report is entitled "PFSF Beyond Design Basis Scoping Analysis," and it is report No. HI 2022854. And in the results section there is a table which deals with exactly this run. And the results for cask No. 1, the net, the maximum net horizontal displacement, which means the instantaneously calculated square root of the sum of the squares of the X and Y displacements, is 3.7 inches. That -- and there is a note attached to that table that says that the other displacements are similar in magnitude.

That table also includes the results from the DYNAMO run and takes some results from an earlier report and does a square root of the sum of the squares for the same casks for the same value and calculates the value 3.08 inches.

And the statement that we make is that these are essentially of the same order of magnitude, the results, and provide the confirmatory solution and that the difference in results is most likely due to the fact that this program includes finite rotations, albeit small.

JUDGE FARRAR: Let me make sure, Mr. Gaukler, that -- I think you said the parties have previously received this report.

MR. GAUKLER: Yes.

JUDGE FARRAR: Then let's go ahead with

the narration. Let me just ask Dr. Soler one question. If during the course of the proceeding one of the parties or the Board wanted to focus on a case other than the 11 you set out in the table here, how difficult would it be and how long would it take for you to run that case for us?

DR. SOLER: Depending on whether or not you were asking for major modifications which would require modeling, it would depend on the question asked. If the case desired is simply one of let's say changing a spring constant value at some point, generally speaking, I would be able to have a result overnight.

JUDGE FARRAR: What if we wanted to change to a 5,000-year return earthquake?

DR. SOLER: If the earthquake were generated and given to me in the form of time histories, it would then be overnight. But I suspect that it would be -- the time to get a 5,000-year earthquake might be the long lead.

JUDGE FARRAR: "Long" meaning?

DR. SOLER: I'd have to defer to someone else on that.

MR. GAUKLER: I don't know how long, but it would be I think a fairly significant time.

JUDGE FARRAR: Days?

MR. GAUKLER: Yes.

JUDGE FARRAR: Then go ahead with the second one.

MR. TURK: May I ask for a clarification? You mentioned a 3.7-inch maximum displacement?

DR. SOLER: Yes.

MR. TURK: Is that at the top of the cask or the bottom?

DR. SOLER: That is at the top of the cask.

DR. SINGH: All maximum displacements are at the top of the cask.

JUDGE FARRAR: Then at the bottom -- if that's a greater displacement than at the bottom, then we have a tilt, not sliding?

DR. SOLER: Correct. I mean, the -- the picture says it all.

Now, the second case again with the design-basis 2K earthquake attempts to address a concern of the State's, that -- a two-fold concern that somehow the soil properties may not be attuned to the earthquake energy input and that perhaps the damping is too high.

So what we did in the second case, and I will use the terminology "tuned soil," and what that means is instead of choosing the soil properties, the soil stiffness in the vertical direction and in the horizontal direction, in accordance with any formula, we simply took the total mass involved in the simulation, in this case the pad mass plus the mass of eight casks, and asked ourselves what spring stiffness, what soil stiffness would we need to apply so that we would have a resonance of the totality of mass and this soil stiffness at 5 Hz, which from some previous deposition testimony appeared to be a frequency at which there was significant energy input.

So when I talk about tuned soil, what I mean is that soil that bears no relation to the results from any computer program that tied soil properties to an earthquake, but rather an artificially chosen soil stiffness value which was chosen in a manner to aggravate, if you will, the motion, the effect of the soil.

In addition, without again regard for any formulas for the appropriate damping to assign to the soil springs, we arbitrarily chose and conservatively chose a very low value of 1 percent of damping to assign to act in parallel with each of the soil springs.

I will -- when I make reference in any of these cases to tuned soil, that is what I mean.

The next case is going to be exactly case 1 except the soil has changed, and you will see the effect of the soil, if you kind of recall this run.

MR. GAUKLER: The damping has been changed?

DR. SOLER: The damping has been changed, too.

DR. SOLER: Okay, let me get rid of this. This is case 2. I have sometimes called it soil resonance, tuned soil.

Now, for the most part, in the remainder of these results I'm just going to refer to pictures, and it was clear that the effect of tuning the soil did have an effect on the response. The remainder of the runs were what I truly call scoping analyses, an attempt to address a lot of concerns of the State by simply choosing a model which essentially aggravates everything.

Using tuned soil, using a 10-K earthquake, using various numbers of casks on the pads, and for the most part the coefficient of friction between the casks and the pad was kept at .8. Occasionally, and I will point that out when it occurs, we examined what I tend to call the realistic case where the coefficients of friction between cask and pad were chosen randomly and changed at each instant of time so that they were between the values of .2 and 1 in a random manner according to the random number generator that is built into this computer code.

The third case is actually the first case I modeled, which was one cask on the pad. I must point out, for all of the remaining runs that the earthquake that we're using is a postulated beyond design basis earthquake of 10,000 years. Therefore you will see deformation -- not deformation. We'll see motion of the casks and it will be clearly observable.

MR. TURK: Dr. Soler, did you get the displacement, the maximum displacement for case 2?

DR. SOLER: I can, but it would require me about five minutes to actually load the program, and I could come back to that and actually load the program, bring up that run and look at the displacement.

MR. TURK: Is it cited in your report?

DR. SOLER: Let's see. Let me see whether I've got the displacements plotted in the results.

Now, the report was written basically to say, look at the figures. We weren't so much interested in the numbers. What we were primarily interested in in the scoping analysis as it started off was, at the end of the earthquake do we have eight casks still standing. That was the criteria that we were looking at in this scoping analysis. Because we well recognized that we expected the casks to, I guess I'll use the terminology "rock and roll."

MR. TURK: So they rocked, but they didn't roll?

DR. SOLER: Well, they precessed. Yeah, they rocked but they didn't roll.

Case 3, which is the case I'm going to run now, is one cask, actually cask No. 1, which is in the corner of the pad, this one. The tuned soil -- now, for the case of one cask on the pad, obviously the total mass that I tuned against is a different value. One cask is 360,000 pounds. The total mass of the pad is just under a million pounds. So the mass that we were tuning the soil to to get a 5 Hz natural frequency was a different mass, and therefore we got a different set of stiffness values.

So when I talk about high stiffness, low stiffness in some of these runs, what I mean is the stiffness was chosen either to tune the soil to 8 casks plus the pad or one cask plus the pad. Either of those two limits. And I will hopefully try to be clear in each case which soil stiffness I'm using.

In this particular case 3, it is one mass on the pad and 1 percent soil damping.

Now, there's one additional thing I should mention, and that is, this pad, as you see in this model, does not have any soil cement surrounding it. This pad is free to move horizontally in which any way it cares to move. The motions of this pad horizontally, generally speaking for all of the simulations involving the 10-K earthquake, was on the order of half an inch. So you do not get much pad motion based on the soil spring assumptions that we had. Now, you will notice here that for this case of 1 percent damping and the tuned stiffness, the pad ends up slightly what I'll call off the pad -- the cask ends up slightly off the pad.

DR. SINGH: There's no ledge on the pad.

DR. SOLER: Yeah, there's no ledge. Since the soil cement was not modeled here, it's not included here. But there's this pad. Even though it appears to rise above ground, in reality does not. It's just there's no credit or detriment, if that's your opinion, as to the effect of the surrounding soil cement.

JUDGE LAM: The soil, is it true for all these cases, no soil cement?

DR. SOLER: That is correct.

MR. TURK: And again, this was a 10,000-year case?

DR. SOLER: This run onward is the 10,000-year postulated beyond design basis earthquake.

MR. TURK: And do you have the maximum displacement number handy?

DR. SOLER: No, but I would guess -- probably I would say the best thing over lunch is if I retire to a corner and maybe construct that kind of table for you.

JUDGE FARRAR: I was just going to ask

that question of all counsel. While the video is interesting, I'm thinking of how you preserve the record for someone down the road, some reviewing authority. And while they will have the CD available to them, it still I think would be useful to have what I understand is not in Dr. Soler's report, a table or report of the various motions so that some reviewing authority could look at case 2 or case 3 and without looking at the video know what happened.

So Mr. Gaukler, we'll leave that to you and Dr. Soler to put together a mini report that captures, if not all of the motions of all of the casks, the maximum relevant motions of the worst -- worst performing casks.

DR. SOLER: May I interject a little bit? That one would take -- in order for me to track at this date all of the casks, it would require me rerunning all the casks. So...

JUDGE FARRAR: Tell me what you can't -- tell me what you can do --

DR. SOLER: What I can do is very easily report cask No. 1. Within I would say an hour I can construct a table for all ten runs.

JUDGE FARRAR: Why don't you do this.

Do whatever table of that nature you can do quickly. We'll distribute that to counsel, and then if they think you need to do more, we will keep coming back at you with what more you can do in what reasonable time frame and arrive at a record that's useful for future reviewing authorities and also something that counsel can cross-examine on.

MR. SOPER: Would one of those numbers be the maximum angle of rotation as well as displacement?

DR. SOLER: I could calculate that from the displacement, but I did not track that angle. The tracking that I did of that angle occurs in a previous report which was submitted initially where the angle for some of the large rotations which you have not seen yet did not exceed 10 degrees. I would be willing to make the statement that the maximum angle of rotation of any of the casks was on the order of I would say 10 to 12 degrees.

But I could calculate -- some of the angles you would be able to calculate after you see the video without having to rerun it. But to get that kind of information would be a rerunning. I would be able to do specific, say a specific run in say 12, 12 hours or so. But you can just add up the time. So I would prefer, you know, I suggest that I construct that small table, which I can do quickly. I can certainly then do whatever it is that your Honors desire.

JUDGE FARRAR: Let's do this small table. Again, rather than argue about what more you can do, let's do the small table, take a look at that, and then we can argue about whether something more is needed.

MR. GAUKLER: One point of clarification, your Honor. One point.

Q. (By Mr. Gaukler) Does the model include the soil cement under the pad?

DR. SOLER: No. The -- as I said, for the majority of these cases the soil is chosen not on the basis of what actually is -- or the soil resistance is chosen not on the basis of what is actually present, but on the presumption that we are going to have an equivalent single degree of freedom model that oscillates at 5 Hz natural frequency. But the case, the case 1, which used the lower bound design basis soil, and case 11, which we will get to which uses the lower bound values consistent with the 10-K earthquake that were provided to us, they both include the effect of soil cement.

Now, the only difference between the next case and this case is, I examined the effect of changing the soil damping from the 1 percent very conservative value to a 5 percent value. But it is still the same one cask; it still has the same tuned soil. Now, that stays on the pad.

The next case, again with 10K earthquake, again with tuned soil, I will admit to a bit of laziness on my part in that I did not tune the soil for three casks plus a pad, but I kept it with the values that I had for one cask on the pad. So that's why I've taken to calling it the low stiffness values.

The 1 percent damping, again, the coefficient of friction here, this was an attempt to simulate three casks on the pad with the beyond design basis earthquake and checking a real configuration where you would expect the coefficient of friction not to remain constant for each cask over the entire duration of the event, but to change instantaneously with time. So what you're going to look at is casks in positions 1 -- I better bring up the picture before I make this statement -- 1, 2, and 3 random coefficients of friction for each cask at each instant of time.

Now, the next case is the same as this except I forced the coefficient of friction to be .8 for all casks for all time. So this, the comparison of these two cases simply examines the effect of a random coefficient of friction versus a constant coefficient of friction.

Different view.

Q. And this is case 6, then?

DR. SOLER: This is case 6.

Q. If you can just label the cases by the case number as we go through them.

DR. SOLER: Now, case 7, I'm going to put a fourth cask in there, and at this point I switched to the high stiffness, kept the 1 percent soil damping, 10K earthquake, .8 coefficient of friction. I'm gradually building up the number of casks on the pad. I tried to capture different views. If you look at cask 1 --

JUDGE FARRAR: That's the red one?

DR. SOLER: The red one. I believe that is the one that has the maximum excursion for this case, and therefore I would be able to add to the table a calculation of the rotation based on that maximum excursion.

Case 8, and the remaining cases, 8, 9, 10, and 11, will all have eight casks on the pad.

MR. TURK: May I ask a question about this last run you just showed?

DR. SOLER: Yes.

MR. TURK: Cask number 1 seemed to rotate.

DR. SOLER: To precess.

MR. TURK: To precess?

DR. SOLER: Yeah.

MR. TURK: Do you have the maximum excursion on that?

DR. SOLER: I could get it. I couldn't get it with the data available, and I will go into the program and tell you basically where the top of the cask is at the end in reference to where it was at the beginning.

MR. TURK: And also just for clarification, you used the .8 coefficient of friction between the cask and the pad?

DR. SOLER: Yes.

MR. TURK: And that's to maximize the tip-over effect?

DR. SOLER: That was to maximize the

tip-over.

DR. SOLER: Okay. I'm going to eight casks.

Q. (By Mr. Gaukler) Is this case No. 8?

DR. SOLER: Yes, this is case No. 8. Tuned stiffness at 5 Hz for eight casks. And I believe that you do get cask-to-cask impact in this case. And I can -- if it's so desired now or later, I can manipulate this movie to focus on a particular frame if you want to look more closely.

Q. And that was 1 percent damping?

DR. SOLER: This is 1 percent damping, completely tuned against this mass to have a natural frequency in the horizontal and both vertical directions of 5 Hz.

Q. And with the .8 coefficient?

DR. SOLER: .8 coefficient of friction.

Now, the case 9 is simply, I've changed the coefficient of friction to .2 just to examine sliding. It doesn't look as dramatic, but remember the scale you're looking at is a 67-foot-long object.

MR. TURK: So these again are 10,000-year earthquakes?

DR. SOLER: Everything except for the

first two cases is beyond the design basis earthquake.

Case 10, here is the same as case 7 except I'm using a random coefficient of friction that at every instant of time each cask gets a value somewhere between .2 and 1, and each cask does not get the same value. So it is completely random cask to cask.

JUDGE FARRAR: Dr. Soler, before you do No. 10, take me back to No. 9. You changed the coefficient of friction so you wouldn't get as much tipping?

DR. SOLER: Generally we expect at .2 not to get any tipping.

JUDGE FARRAR: So you should have gotten, in my simple language, a lot more sliding, but I thought I didn't see a lot of sliding.

DR. SOLER: You are correct. If you'll notice in some of the .8 runs, the top of the cask moves close to, if not equal to, 48 inches. The sliding is not of that magnitude that we predict.

DR. SINGH: And if you use a small coefficient of friction, sliding would always be less than what you will get if you were to attempt to fix the cask by using a high coefficient of friction. The sliding absorbs energy. The more the cask slides, the less the total aggregate response of the cask.

JUDGE FARRAR: I understand that, but I would have expected to see sliding, and I -- of some visible magnitude.

DR. SOLER: I will put this in the table, but as I recall, the number we get is about nine or ten inches. That's why I pointed out, we've got to bear in mind the scale of the problem and what you've seen in the case of tipping, and it doesn't look like much.

MR. TURK: For the record, from my vantage point I noticed some sliding off towards the right, towards the right end of the pad.

JUDGE FARRAR: Okay, I must have been looking at -- can you re-run that one?

DR. SOLER: Yeah, sure.

JUDGE FARRAR: You said, Mr. Turk, on the right end?

MR. TURK: I thought the casks were sliding towards the right.

MR. GAUKLER: Case 9?

DR. SOLER: That's case 9, yeah. There it goes.

JUDGE FARRAR: Which looked like some sliding at the beginning, and then a little sliding there.

DR. SOLER: It's about, usually it's only about 4 seconds and somewhere around 12 to 15 seconds.

JUDGE FARRAR: Thank you.

DR. SOLER: Now, case 10 is the same as case 8 except the coefficient of friction is random cask to cask.

Let me make one observation which I forgot to make at the beginning. Every time there is a change in a stiffness value, what we do is we first have to put the system in static equilibrium. So the earthquake is turned off, the simulation is allowed to proceed under gravity alone, and you wait long enough and it goes into a static equilibrium position so that for the case of 1, 3, or 4 casks, there was actually a slight initial tilt to the pad because the heaviest masses is over at one end.

Once the system is in static equilibrium we rezero time, zero out all the velocities, the small velocities that were picked up, turn on the earthquakes, and that is the run that you're seeing. So casks don't necessarily start in exactly the same place, because in satisfying the static equilibrium they may move .00 something inches one way or the other. So I just wanted to point that out for accuracy.

JUDGE LAM: Dr. Soler, in this particular case did the casks contact each other?

DR. SOLER: I -- let me go back and run it slowly, and I'll give you my opinion based on what I know about this. I know -- and what I'll do is I'll -- let me stop it and run it through -- let me run it and then try to freeze it. Let me back off a little. Difficult for me to hit the exact position.

I am not necessarily convinced that these casks hit, but I will say they come awfully close. And I certainly know in the earlier report which was using the 10,000-year beyond design basis earthquake, we predicted displacements that had we modeled other casks would have indicated that you would get contact.

I believe that the contacts when they occur, basically you can see it by one of the two casks that comes in contact, subsequent to contact almost comes to rest. All of its energy gets dumped. But the contacts that I see -- of course this is all rigid body dynamics -- are what I would term minuscule compared to the contact you get when you run through a cask tip-over analysis. So these contacts are I guess more or less one cask kissing the other one, to make it simple.

The final case is again the 10,000-year design basis. Instead of a tuned stiffness, we took the moduli values corresponding to the 10K beyond design basis earthquake and we calculated the springs and the damping in accordance with ASCE 486. And that I have labeled the Geomatrix lower bound values consistent with 10-K, and I would call it the beyond design basis equivalent of the 2K event.

Now, I will preface the running of this by saying that if you take some of the stiffness values that you get for the lower bound set of numbers, they're not too far away from the 5 Hz key frequency. They are certainly at a higher frequency, but as you will see in a second, motions of the cask don't just disappear. So I will run this final case, and that will -- case 11.

There's an impact, cask 6 and 8.

MR. TURK: Can I ask that you run that

again and also identify your numbering system? Which cask is -- if you could use your highlighter to show which one is 6 and 8.

DR. SOLER: Okay. One, two, three.

JUDGE FARRAR: Wait, wait, wait. We have to have a record here. You're going to start in the lowest corner nearest the viewer, and that's 1?

DR. SOLER: That's 1.

JUDGE FARRAR: Then you go to the other row or column. You go to the -- in the direction in which there are only two casks, and you go to 2. Then you come back next to No. 1 and go alternately back and forth in the direction in which there are two casks. Is that correct?

DR. SOLER: Yes. 3, then 4. There is a figure in I believe the report which is already on the record having to do with the design-basis earthquake which shows the figuring and the numbering.

MR. GAUKLER: The figure is actually in the testimony as well. Page 23 of the testimony has the numbering configuration of the casks.

MR. TURK: Just so it's clear on the record, at this point I would observe that the row of four casks closest to us is numbered 1, 3, 5, 7, and the row that's more distant to us is 2, 4, 6, 8.

DR. SOLER: That is correct. And you wanted it run again?

MR. TURK: I'd like to see that impact.

DR. SOLER: Okay. There. You'll notice how cask 6 kind of comes to rest and then begins to move again. That completes --

MR. GAUKLER: Just one thing for clarification. You mentioned that the angle of rotation was about 10, 12 degrees. How does that compare to the angle at which the cask would tip over on its own weight?

DR. SOLER: What is commonly known as CG over corner where you imagine that the cask is tilted up to a position where it's -- where a line drawn from its center of gravity down to the contact point on the edge is a vertical line, that angle is 29 degrees plus a little bit. So if you wanted to compute, if you will, margin against reaching CG over corner, we're talking about a margin, a ratio of three.

JUDGE FARRAR: "CG" meaning center of gravity?

DR. SOLER: Center of gravity.

DR. SINGH: Yes.

MR. GAUKLER: Your Honor, I move for the admission of Exhibit OO.

JUDGE FARRAR: Off the record. Have we not already admitted all the exhibits?

MR. GAUKLER: I did not include OO in what I went through because they were documents, and so I held that off till the end.

JUDGE FARRAR: Any objections?

MR. SOPER: OO is the visual simulation, is it not? I have a couple questions.

Dr. Soler, I notice in the table on page 66 that you've used to describe OO, case 11 when it gets down over to the column under damping, it says "the Geomatrix lower bound values." Do you see where I'm referring to, sir?

DR. SOLER: Yes.

MR. SOPER: Other cases above that have an actual number, 1 percent, 5 percent, so forth.

DR. SOLER: That is correct.

MR. SOPER: What would -- wouldn't there be a number associated with this rather than a description?

DR. SOLER: It's difficult to calculate

that number because critical damping is defined in terms of the mass, and the formulas in ASCE 486 simply give you a very complex formula for damping in terms of various moments of inertia of the pad, various parameters that you pick off a chart, and values of one or more stiffness values. So I did not attempt to correlate these damping values, since there are six of them, to any kind of a simple number. I simply state that whatever ASCE 486 would ask you to use for the soil properties given to us, that is what we used.

MR. SOPER: Let me ask you this. Is damping a value that's required as an input factor on VN to run this?

DR. SOLER: A value for the damper is, but not a percent damping.

MR. SOPER: I see. Well, you can't input words into this formula, can you?

DR. SOLER: No.

MR. SOPER: Well, what numbers did you put in, is my question.

DR. SOLER: I would have to get those -- I put in the -- I put in numbers which were calculated from, and I believe, I'd have to look, but I believe that those numbers are in the report that's going to be submitted. I think there's an appendix to that. Let me look.

MR. SOPER: Well, then at any rate, so you've put in numbers that are not disclosed on this table. Is that true?

DR. SOLER: That is correct. I did not give you the numbers or the percentage.

MR. SOPER: How many input factors are required for VN to run this simulation? Do you know?

DR. SOLER: For damping?

MR. SOPER: No, to run the whole simulation.

DR. SOLER: Values for six dampers, values for six stiffnesses having to do with the soil, values for a coefficient of friction between cask and pad, of course the appropriate masses and the locations of the pads, and the contact stiffness between the cask and the pad.

MR. SOPER: And what about --

DR. SOLER: And of course the earthquakes.

MR. SOPER: -- the excitation?

DR. SOLER: The excitation, yes.

MR. SOPER: And I see those numbers

don't appear on this table. Is there any document that shows us exactly what numbers you put into Visual NASTRAN to create this?

DR. SOLER: I -- well, no, you don't have -- I have -- what happened to that report? Oh, there it is. Let me tell you exactly what is in the report that goes along with these.

MR. SOPER: Well, I'm not sure that's my question.

DR. SOLER: There is no document which lists every one of these numbers, but it could be produced.

MR. SOPER: I see. And I also noticed that there is no column that says "results" or any kind of a numerical computation, but rather a column that says "remarks."

DR. SOLER: Yes.

MR. SOPER: And then there's some various comments on what was observed.

DR. SOLER: Uh-huh.

MR. SOPER: Is there any place where the actual numerical results are shown?

DR. SOLER: Well, there is a spreadsheet which is created in the course of running this program which would have whatever results that I had chosen to track during the simulation.

MR. SOPER: My objection, your Honor, to this exhibit is this. Unless it's accompanied by every numerical value that was plugged into it so it can be examined and shown what actually we're watching the result of -- I think Dr. Soler in his deposition used the phrase "garbage in, garbage out." To simply produce this, describe its input parameters with a few words and say "this is what the situation is" is not scientific in my mind. And I think that the exhibit, if admitted, ought to have all the variables and all the results.

MR. GAUKLER: Your Honor, first of all, Dr. Soler indicated that he used the same ground movements that were part of the normal development of this model with respect to the information he received from Geomatrix and used in the formula from ASCE-4-86. There is an appendix in I believe in the reports which kind of go through this process, if I'm correct, Dr. Soler?

DR. SOLER: Yes.

MR. GAUKLER: Also the State has had two depositions on these reports in terms of how these numbers are developed. They had a chance in November 2001 deposition to go through these reports and ask about the methodology. They again had a similar chance in the March 2002 deposition to go through these reports and ask questions. These are part of the technical reports that have been provided throughout this case by Holtec. We've had ample opportunity to know what questions they may have with respect to that, and this is the first time that we've heard this. This is the same methodology that is used with respect to the reports, same as we've seen throughout this case.

JUDGE FARRAR: I'm not sure the objection was so much to surprise as to it deals with a concern the Board has that we have in front of us a vivid illustration of something, but we -- anyone reviewing the record later won't know what that something is if they don't have all the assumptions that went into creating the video.

Did I understand that correctly, Mr. Soper, or do you have a different --

MR. SOPER: You captured it just right. Thank you, your Honor.

JUDGE FARRAR: Mr. Turk, does Staff have anything on this?

MR. TURK: No, your Honor.

DR. SOLER: May I add something?

MR. TURK: I am willing to offer an opinion, however.

MR. GAUKLER: There is an opinion.

JUDGE FARRAR: No, let's keep these two people arguing.

MR. GAUKLER: There are appendices to the report that we are introducing into evidence that I believe will describe their methodology. These are very similar to the appendices that have been provided to the State before, but they describe the basic calculation of the damper.

Dr. Soler, would you please correct me if I'm --

JUDGE FARRAR: Yeah, let's ask the witness. You heard the State's objection. What is in the documents that have been admitted or are expected to be admitted, or what's in other documents that would satisfy the State's and the Board's concern that we need to know more about how you created these illustrations or simulations than we know now in order to know what they represent?

DR. SOLER: All right. This particular report which goes with these simulations contains five appendices, two of which are simply listings of the computer programs and listings of the simulations. But the three appendices that deal with calculations, there is an appendix which describes and goes through the calculation of the parameters for the contact interface between cask and ground and the calculation of tuned soil, springs and dampers. There is an appendix which has the calculations in accordance with ASCE 486 for the lower bound design-basis 10K seismic event, which was run number 11. And there is also an appendix for -- a similar appendix for the springs and dampers associated with the 2-K seismic event. So the column which lists damping which is described in words, the formulas and the numbers are provided in the appendix, appendices.

JUDGE FARRAR: And that's the report that has not been offered but which we talked about earlier and perhaps may be?

MR. GAUKLER: That's the one that we would be willing to produce as an exhibit.

JUDGE FARRAR: And Mr. Soper, your people have seen that document in the past?

MR. SOPER: Oh, yes, we've seen it, but I don't think it answers my question, for each scenario which values were used as input.

JUDGE FARRAR: Wait. Let me -- does it

answer that?

DR. SINGH: Can I comment on this?

JUDGE FARRAR: Certainly.

DR. SINGH: In any solution, any report that we provide, we provide the methodology, we provide the authority to reference that are used to calculate the individual numbers, and then we use that in the program. All that is available in this report that Dr. Soler just described, this report HI 2022854. Any engineer conversant with using Visual NASTRAN and with this report and references that this report cites, for example, ASCE 4-86, one can reconstruct this problem. We have taken care to ensure that an individual skilled in the state of the art can reproduce the results. That information is available to the State in this report, the written documentation, and the video available to you.

MR. SOPER: If that's the case, then I would like to ask for one of these scenarios that Dr. Singh tell us each variable, looking at this report, that went into, for example, case No. 3. Can you do that, sir?

DR. SINGH: I didn't say that each numerical value.

MR. SOPER: Well, that's my problem.

DR. SINGH: I said the methodology, the procedure is available for one to come to those numbers and run the program, and that is the standard practice in engineering work today.

JUDGE FARRAR: The problem, though, is we're dealing -- we're beginning with standard practice in engineering, but we're ending with standard practice in the United States Court of Appeals, and somebody along the road has to be able to point to the assumptions or parameters, not recreate them themselves. And that's the point that I think Mr. Soler is getting at from his perspective, and it's also a point that concerns the Board from a different perspective.

MR. GAUKLER: But your Honor, the assumptions, etc., used in accordance with the established ASCE code. That's what he's talking about --

JUDGE FARRAR: Let me interrupt, Mr. Gaukler. No one to this point has challenged the engineering practice that went into this. That may happen down the road. What they're challenging is, answer this -- tell us the simple question -- tell us the answer to the simple question, what are the numbers that you used to create this. You know, maybe everybody in the room knows that, but if everybody in the room knows it, it ought to be something we can put on the record.

MR. GAUKLER: The numbers, how they're created, et cetera, are in the appendix.

JUDGE FARRAR: Well, if they were, Mr. Soper would have gotten a simple answer to a question he asked five minutes ago.

MR. GAUKLER: How they were created --

JUDGE FARRAR: No, not how they were created, what are they.

DR. SOLER: If I may, I'll read specifically from the various appendices, and if there's any data missing --

JUDGE FARRAR: No. Were you here yesterday?

DR. SOLER: Yes.

JUDGE FARRAR: Okay. We're not going to take all that time to do that. We may at some point take that time. What we're trying to focus on now is how do we get these, let me call them "missing numbers." How do we get them, put them on the record, and then Mr. Soper will be in a position to cross-examine.

DR. SINGH: We can take this as a task to take a case and provide the explicit numbers for them, that particular case --

JUDGE FARRAR: Why don't --

DR. SINGH: -- the documentation we have. We can take that as an undertaking and do it for the board.

JUDGE FARRAR: Why don't we do the one. Mr. Soper will not be happy with the one, he'll want all 11, but let's do the one to see if it in fact provides what he's asking for and what we're asking for, and then if that one is satisfactory, then I assume we will ask you to do the other ten.

MR. TURK: Your Honor, may I offer an observation? I know I ducked the question before that you asked me about. In fairness I should offer our views of this.

The information that Mr. Soper seeks I think seems very simple on its face, but if you note that one of the values or one of the inputs that he mentioned for the excitations for the earthquake, we have produced to the State Dr. Luk's report which also goes through an analysis of how the casks respond to seismic motions. We've also offered to the State three very large input files