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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

138TH MEETING

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TUESDAY,

NOVEMBER 19, 2002

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ROCKVILLE, MARYLAND

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The meeting convened in the Auditorium of the Nuclear Regulatory Commission, 2 White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., George M. Hornberger, Chairman, presiding.

MEMBERS PRESENT:

GEORGE M. HORNBERGER	Chairman, ACNW
RAYMOND G. WYMER	Vice Chairman, ACNW
B. JOHN GARRICK	ACNW
TIMOTHY KOBETZ	ACNW
MILTON LEVENSON	ACNW
MICHAEL RYAN	ACNW

ACNW STAFF PRESENT:

SHER BAHADUR	ACNW
HOWARD LARSON	Special Assistant, ACRS, ACNW
JOHN LARKINS	ACNW

GUESTS PRESENT:

DOUG AMMERMAN	Sandia National Laboratories
CHRIS BAJWA	Spent Fuel Project Office, NRC
E. WILLIAM BRACH	Spent Fuel Project Office, NRC
TOM DANNER	NAC International
LARRY FISCHER	Lawrence Livermore National Laboratories
ROBERT FRONCZAK	Association of American Railroads
BRIAN GUTHERMAN	Holtec International
ALAN HANSEN	Transnuclear
IAN HUNTER	Transnuclear/COGEMA
ROBERT LEWIS	Spent Fuel Project Office, NRC
PETER SHIH	Transnuclear
KRIS SINGH	Holtec International
ALAN SOLER	Holtec International
MICHAEL YAKSH	NAC International

I-N-D-E-X

P-R-O-C-E-E-D-I-N-G-S

8:30 a.m.

CHAIRMAN HORNBERGER: The meeting will come to order. This is the first day of the 138th meeting of the Advisory Committee on Nuclear Waste. My name is George Hornberger, Chairman of the ACNW. The other committee members present are George Wymer -- Raymond Wymer, Vice Chairman, John Garrick, Milt Levenson and Michael Ryan. During today's meeting the Committee will hold a workshop on the transportation of spent fuel and high level waste.

Tim Kobetz is the designated federal official for today's initial session. This meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act. We have received no requests for time to make oral statements from members of the public regarding today's sessions. Should anyone wish to address the Committee, please make your wishes known to one of the Committee staff. It is requested that speakers use one of the microphones, identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

I would like now to turn the meeting over to Milt Levenson who will Chair the Transportation

Working Group sessions. Milt?

MEMBER LEVENSON: Thank you, George. Good morning. This is a workshop for the Transportation Working Group. I'm Milt Levenson, Chairman of the Working Group. The Working Group is made up of all five ACNW Committee members. The objective of today's workshop is limited to examining the technical aspects of spent fuel transportation package design, analysis and testing methods to determine whether sufficient evidence exists or additional evidence needs to be obtained to substantiate that spent fuel can be transported safely. In addition, spent fuel and high-level waste transportation experience will be examined, that's tomorrow session, to determine whether the transportation packages have performed as designed.

The ACNW will use this information to make recommendations to the Commission as necessary on the technical aspects of transportation of spent fuel. In addition, it is our intent to publish the proceedings of this workshop in an NRC NUREG. On the first day, presentations will be made regarding research, development, analysis and testing of such packages. Presenters include various national labs, cask vendors, industry groups and NRC staff that have been directly involved in the evaluation of this type over the past 30 years. We focus on the package because if there is no significant package failure, there can be no significant radiation consequences.

On the second day, presentations will be made to the Working Group regarding spent fuel and high-level waste transportation safety experience in the U.S. and worldwide. For these discussions, the presenters include various federal regulatory agencies, industry representatives that have been directly involved in the regulation and shipment of spent fuel and high-level waste. Relevant experience, which is obviously omitted from the presentations, and for obvious reasons, is the experience of shipping tens of thousands of nuclear weapons multiple times around the country.

Presenters for today's workshop, because it is a workshop, are encouraged to participate in the discussions. If a presenter has a question or comment, please stand your nameplate on end, and that will notify me you have a comment to make. However, I want to caution all participants that I intend to stick strictly to the time schedule in order to not short circuit the later speakers. Members of the public will also have opportunity to make comments and ask questions. It is requested that when speaking, you first identify yourself, court reporter just doesn't know everyone, and use one of the microphones and speak with sufficient clarify and volume so you can be readily heard.

I would like to point out for those of you that hadn't already done so that there's a package of view graphs in the back of the room that's all inclusive for today's meeting. There will be a similar package for tomorrow's meeting. We have received no requests for time to make oral statements, and one written comment from members of the public regarding today's meeting. The written comment will be entered into the transcript of today's meeting.

I would like to thank all of today's participants for taking the time and making the effort to participate in the workshop. We will now proceed with the workshop, and I call upon Mr. Bill Brach, Director of NRC's Spent Fuel Project Office for the first presentation.

MR. BRACH: Good morning. As Dr. Levenson mentioned, my name is Bill Brach. I'm Director of NRC's Spent Fuel Project Office. If we could have the next -- excuse me, back up to Slide Number 2. In your handout, Slide Number 2 is titled, "Overview," and if

I can start with that one, Theresa.

First, again, good morning. I wanted to thank the ACNW for the invitation in asking the NRC staff to participate and as well as to lead off the discussions for this important workshop. As Dr. Levenson has described, you have a very full and I believe interesting agenda with a broad spectrum of government, government laboratory, industry organization and industry presentations today and tomorrow.

This morning in my presentation, I'll briefly discuss our spent fuel transportation activities, status and some of the past as well as the planned transportation studies.

Slide 3, key messages, let me start off first by saying, unequivocally, that the NRC staff believes that shipments of spent fuel in the U.S. are safe, and they're safe using the current regulations and our current programs in place. I believe that's an important point, let me just stress that one more time: The staff believes that the shipments of spent fuel in the U.S. are safe using our current programs and our current regulations.

Now, this belief is based on NRC's confidence in the shipping containers that we certify and the ongoing research in the transportation safety. And also let me add, as noted in Bullet Number 2 on the overhead, that this confidence, if you will, is based as well on the industry's strict compliance with the safety regulations and the conditions of the certificate and conditions of use that have resulted in a strong transportation safety record.

The NRC ensures that shipping containers are robust. We do this in many ways. First, by regulating the design and construction of the shipping containers. The NRC staff, in our review process, review the designs, we independently confirm the ability of the containers to meet the regulations and the accident conditions through our modeling, analysis and verification of the licensees with the applicant's analysis and testing.

By NRC oversight and principally through the licensee and the user's exercise in implementation of their fundamental responsibility are assuring that containers are built, that they're maintained and that they're used properly and in strict conformance with the certificate and with the regulations.

The NRC also follows an aggressive program to investigate and to assess the continued safety of spent fuel shipments. We do this through a number of avenues, for example, including analyzing spent fuel transportation experience in the records to better understand safety issues and experiences, we evaluate new transportation issues such as the potential for increased spent fuel shipments, increased and changing radioactive material contents of spent fuel packages, as well as looking at population density and density changes along the routes as well as other factors, such as modeling and analytical capabilities to estimate current and future levels of potential risks to the public as a result of spent fuel transportation.

NRC has found that the likelihood of a release from an accident and the associated risks to the public are extremely low. Even though, even so, the NRC continues to maintain our vigilance with regard to our primary mission responsibility to assure public health and safety as an essential part of our oversight of spent fuel transportation. Next slide, please.

Clearly, an interest and focus with regard to spent fuel transportation is derived from the prospects of a national repository being built at Yucca Mountain. I want to focus just briefly on NRC's role with regard to transportation as it relates to the National Geological Repository at Yucca Mountain. NRC's role and responsibilities are guided by legislation -- the Nuclear Waste Policy Act. NRC's primary role in transportation of spent fuel to a repository would be certification of packages used for transport.

Section 180(a) of the Nuclear Waste Policy Act prohibits the Secretary of Energy from transporting spent nuclear fuel or high-level waste except in packages that have been certified by the Commission. The NRC has reviewed and certified a number of spent fuel package designs which could be used for the transport of spent fuel to a repository. We have additional designs and design amendments under review and as well we anticipate there will likely be additional designs submitted in the not too distant future.

There are additional provisions of the Nuclear Waste Policy Act that also apply to transportation. DOE, as noted in the overhead, is required to follow NRC's advance notification requirements. These requirements pertain to notification and coordination with state governments with regard to plans of spent fuel transportation. The second item related to the DOE requirement to fund state and local governments in Indian tribes with regard to response and preparedness activities is an activity that perhaps some of the DOE presenters later, I believe tomorrow, might be in a better position to add or amplify DOE's current plans.

If I could move to the next slide. To provide a perspective, this slide summarizes a picture of the past, the current and the potential future levels of spent fuel transportation. Significant past operations have included, for example, return of reactor fuel to utilities from the closed West Valley Processing Plant back in the early 1980s, as well as current levels that reflect primarily inter-power plant shipments, shipments of some research reactor fuel and other shipments.

And I would note for a number of you all that may have seen these same statistics, while 1,300 shipments is the number we've represented over the last 20 years, it's actually a little bit higher now. As noted, there are roughly ten to 20 shipments per year, and so in a rounding, it's approximately 1,300, but the overall history for the last 20, 25 years for NRC regulated shipments is in that range.

You'll also note on the overhead is a proposed information for the private fuel storage facility. That proposed facility would be located roughly 100 miles west of Salt Lake City while Yucca Mountain is somewhat analogous -- it's about 100 miles, approximately, northwest of Las Vegas. Neither of the facilities have yet obtained NRC license for authorization. A PFS, private fuel storage, has applied, and the matter is currently before the staff, before the -- excuse me, it's being considered in hearings before the Atomic Safety Licensing Board. The private fuel storage facility is planning to use the Holtec High Star, High Star and dual-purpose cask system at their facility, and I believe Dr. Chris Singh from Holtec is on the agenda later and will be discussing in much more detail the Holtec dual-purpose dry cask storage system.

The Yucca Mountain facility is roughly twice the size in the way of capacity of the private fuel storage facility. The Nuclear Waste Policy Act limits the 70,000 tons of high-level waste at Yucca Mountain to approximately 73,000 metric tons of commercial sector spent fuel. You'll note on the overhead as well the statistics with regard to the planned number of shipments. A private fuel storage facility plan to operate for a 20-year period would have approximately 50 shipments per year, as noted with forecasts for shipment. The Yucca Mountain facility, the preliminary information we have at this point from the Department of Energy is that approximately 175 shipments on an annualized basis, 130 by rail and approximately 45 by truck. This overhead gives a general summary, if you will, a comparison of the planned shipment profile for these two sites in the coming years.

The NRC routinely conducts studies to review the adequacy of the regulations. For transportation regulations, we have completed three major studies to date since the 1970s, with the most recent having been completed in 2000. In addition, our current major activity or effort underway is the package performance study, which I'll discuss briefly in just a minute.

After completing the final environment impact statement on the transportation of radioactive material by air and other modes, commonly referred to as NUREG-0170, the Commission, NRC Commission, concluded in 1981 that its transportation regulations are adequate to protect the public against unreasonable risk in the transport of radioactive materials, including spent nuclear fuel. I will note that I believe spent fuel was one of about 25 radioactive materials addressed in NUREG-0170.

The Commission also concluded at that time, however, that prudence dictates that regulatory policy concerning radioactive materials be subject to close and continuing review. In the ensuing years, the NRC has conducted additional transportation risk assessments in other studies that confirm our earlier finding on spent fuel transportation safety.

In the mid to late 1980s, to better assess response to spent fuel and spent fuel casks to severe accident conditions, NRC sponsored an examination of collision and fire accident conditions. Lawrence Livermore National Laboratory conducted this effort. It's frequently referred as the Modal study. Larry Fischer from Lawrence Livermore National Lab is also on the agenda and will be discussing aspects of the Modal study in a little bit more detail.

From the Modal study, the NRC staff has concluded that the Modal study -- excuse me, has concluded from the Modal study that NUREG-0170 clearly bounded spent fuel shipment accident risks, and by the Modal study we concluded that they were bounded by a factor of approximately three. Next slide, please.

Continuing with the transportation studies, in March of 2000, NRC published a report entitled, "Reexamination of Spent Fuel Shipment Risk Estimates." It's commonly referred to as NUREG/CR-6672. This study focused on a risks of a modern spent fuel transportation campaign from reactor sites to a possible interim storage facility, such as the private fuel storage facility I just mentioned, or to a permanent geological repository, for example, the Yucca Mountain facility.

NUREG-6672 was initiated in 1996. The NRC had recognized that, one, there was going to be a significant increase in the number of spent fuel transportation activities over the coming decades, and I believe that was represented in an earlier slide. If you recall, our current operating history, if you will, with regard to spent fuel transportation is in the neighborhood of ten to 20 shipments per year, and it's represented by the information for both private fuel storage and potentially for the Yucca Mountain facility as well. Those numbers increase rather significantly.

The transportation activities as well will be made to facilities along routes and in casks that have not been previously examined in past studies. And the risks associated with these transports can be better estimated using new data and improved methods of analyses. I would mention as well that in NUREG-6672 we were looking at designs of contemporary -- spent fuel packages, excuse me, of designs that are larger in size and have larger radioactive material contents than some of the packages that had been examined in previous studies. The results of the study, the NUREG-6672, also did conclude that the accident risks were much less than those that had been estimated in NUREG-0170, the 1977 EIS.

In 1999, the NRC initiated the spent fuel transportation package performance study. This study is expected to take on the order of five to six years to complete. The study is being developed by staff to confirm their alliance of analytical techniques, to predict cask performance, and as well as a study in significant ways attempting to consider public concerns and input. The study is being developed to demonstrate the robustness of the NRC-certified transportation casks.

The study is using what we've referred to as a public-enhanced, public participatory process and approach to solicit and obtain public input and comments on our tests and on our plans and our considerations that we're looking at in developing the study approach and concept. Our current plans for the package performance study include full-scale physical testing to confirm cask performance and safety during transportation accident conditions.

There also are some additional transportation studies that I'd like to bring to your attention. Many of you, I'm sure, recall the train derailment in Baltimore in July of last year, in July of 2001. We, NRC, are continuing to review this accident closely with the Department of Transportation and the National Transportation Safety Review Board to assess what might have happened if a spent fuel cask had been on the train. NRC's preliminary analyses are very positive and suggest that the transportation cask would not have failed had they been in the Baltimore Tunnel railroad fire. You'll hear more later today from Chris Bajway, also of the Spent Fuel Project Office, on the study and preliminary information we've developed in our review of that fire and the consideration had it included a spent fuel transportation package.

There are other activities as well underway. Recently, NRC and other federal agencies have been providing or have provided joint funding to a project that the National Academy of Sciences, the Board of Radioactive Waste Management, is embarking on to form a group, an expert panel, that will be reviewing the societal and health risks of transportation. I believe that study should be initiated in early -- calendar year 2003.

Also, there have been other studies, tests and demonstrations. Many, I'm sure, are familiar with the Sandia and the British crash tests and the videos, and you may have seen these in the media or in other arenas. I would note that these tests were not sponsored by the NRC. They did not have, if you will, an NRC regulatory purpose for the testing, and they, therefore, are not a part of the basis for our regulatory program. But having said that, I'm not trying to distance myself from those tests or ourselves from those tests, we clearly do believe that those videos, those tests have demonstrated that the casks are very robust in the specific accident conditions in which they were tested. And as well they give added confidence that the regulatory tests are indeed very severe in establishing test conditions and criteria.

Additionally, one important conclusion that you can see from these other studies and tests is that they have demonstrated that the casks upon impact the impact surfaces actually absorb much of the energy of the impact. And those that are familiar with our transportation regulations are aware that our testing criteria require that our drop tests, for example, be onto an unyielding surface so that all of the energies of impact are transmitted back into the transport package.

I've touched in this brief overview a number of the research or study programs and activities that have occurred over the past few years, past 20 years, as well as some that are ongoing right now to address spent fuel transportation. The U.S. domestic standards and requirements, our regulations, were developed using an expert consensus approach, both domestically and through participating with fellow international transportation regulators at the International Atomic Energy Agency. These regulations, we believe, have resulted in an exemplary level of safety and have demonstrated a long favorable history of use, both here in the U.S. as well as internationally.

While risk insights or risk studies have not traditionally been used to establish these regulations, the research studies and programs I've discussed have mostly been of a confirmatory nature, and they have supported the conclusions regarding the adequacy of our regulatory standards.

As technologies have changed and analysis capabilities have improved, we've continued to review our research and findings and conclusions consistent, if you will, with the Commission's earlier direction to us from back in 1981. If you recall, I had mentioned the Commission's conclusion following the EIS is that the Commission had dictated that regulatory policy concerning radioactive materials be subject to close and continuing review, and I believe our studies that we've been carrying out from that perspective have been our efforts to comport with the Commission's earlier guidance.

I would note as well, though, that to date none of the NRC transportation risk studies, if you will, or studies, have included physical testing. They've been primarily based on computer modeling and analysis, and so one aspect we clearly are looking forward to our package performance study, which, as I mentioned briefly, does include aspects of physical testing.

The basic methodology that was developed for NUREG-0170 and its supporting works, including, for example, the development of the radtran code and release assumptions, have, if you will, reasonably withstood the test of time and analysis and have recently as well been used in major environmental impact statements.

Let me conclude by saying the staff welcomes and appreciates the Committee's timely and valuable workshop initiated today to further the discussion of spent fuel transportation with our various stakeholders, and we found past and similar meetings to have been very valuable. Thank you.

MEMBER LEVENSON: First, let me thank you for setting a good example for subsequent speakers by sticking strictly to your time. Thank you.

Any of the ACNW members have questions or comments? Mike? Bob?

MEMBER GARRICK: Probably most of the questions I have will come later, but one of the things you said, Bill, that I'm wrestling with is the position of the NRC relative to the Sandia test, and you qualified it by saying that you're not trying to put any distance between the NRC and the tests, but they're not a part of the NRC program.

I guess I'm questioning just how far that interpretation goes. Generating the steam tables was not a part of the NRC program either, but you use them all the time in your thermalhydraulic work. It just seems to me that that doesn't make much sense. In inevitably has to be a part of -- the results of those tests inevitably have to be a part of the analyses and the investigations that you make about transportation safety. Could you comment on that a little bit?

MR. BRACH: Be glad to, yes. The point I was trying to make is that the conduct of those tests were not tests that, if you will, were part of the regulatory basis on which we, the NRC, are relying with regard to our existing regulations and our guidance, that the tests were -- again, I'm not trying to distance from those tests, I'm trying to explain that the conduct of those tests, the outcome of those tests, the information, the data that was developed as a result of those tests were not a fundamental part nor were they critical to the development or the confirmation of our existing regulatory standards and bases.

MEMBER GARRICK: I have several other questions but I'm going to postpone them later, but there is one I'd like to ask you. I realize that the NRC is focused on the cask and the packages, but do you plan any route-specific analysis just to get some sort of a handle on however small the risk is that it might be affected by the choice of transportation route?

MR. BRACH: There are a couple of aspects. One, the specific selection of routes that would be, for example, used to the private fuel storage facility or potentially to Yucca Mountain as well is not an NRC, if you will, decision, action or direction. Those are guided by other regulatory standards from, for example, Department of Transportation, and those will be selected by, in the case of Yucca Mountain, by Department of Energy in consultation with the states along those routes.

Very specifically, though, with regard to the studies and activities, I'll reference, for example, NUREG-6672, we did in that study pick a few of what I'll call generic but what we believe to be, and of course that also requires the test of time to analyze, to be representative routes that would be used. We selected some routes that are cross country and various parts of the U.S. In selecting those routes, we were looking at length as well as looking at what might be, to the extent we can identify, some of the most challenging or limiting types of conditions of transport with regard to under accident conditions what might be the locality from the standpoint of what might be potential impacts and other considerations. So we're looking at that not in a -- looking at site -- or excuse me, route specific, but we're trying to bound that, if you will, through our generic analysis of looking at various hypothesized routes that could be identified and then analyzed.

MEMBER GARRICK: Thank you.

VICE-CHAIRMAN WYMER: I have one question.

MR. BRACH: Sure.

VICE-CHAIRMAN WYMER: They're kidding about my name wrong on the name tag here.

In connection with the new package performance study to be completed in about 2005, you made a point of saying that there will be enhanced public participation. Now, you've had what appeared to me to be substantial public participation in the past. What does enhanced public participation mean?

MR. BRACH: Let me explain what our participation has been, and then maybe in the eyes of the beholder whether that's enhanced or not. As you mentioned, Dr. Wymer, over the past few years we've had a series of public outreach meetings with regard to the package performance study. We started the process off with a series of meetings here in the Washington area as well as out in the Las Vegas, Nevada area, the Rockville area. The first round of public meetings started with our asking the public, the stakeholders, for input with regard to if we were to be carrying out a fiscal testing program for spent fuel package, what type of testing, what type of conditions, what issues should we be including in the study? And we were really out, if you will, in a listening mode explaining our ideas and plans for conducting a study but in a very general and broad concept but asking for the stakeholders, both state and local governments, industry, industry groups and concerned citizen groups, individual citizens what types of issues do they see.

From that series of meetings, we developed what we called an issues paper, and that issues paper was an attempt on our part to summarize the various suggestions, comments, issues that had been identified to us. We followed them with a second series, round if you will, of public meetings, again, here in Washington area, Rockville area, and also out West in the Las Vegas area to, again, go through the process again of this is what we've heard. One, did we hear you correctly? Have we characterized and summarized the issues, and also we tried to as well put an NRC staff understanding of the issues but also a perspective as to what some of the tests of various conditions and activities may yield or some of the complexities of that testing activity.

And from that process, we then stepped back and our next step is the development of what I'll refer to as the test protocol. And I also should mention we had as well an opportunity -- we established a web page where it could be reasonably interactive, interactions to NRC and folks submitting comments in both of those rounds with regard to suggestions, as well as options for providing written comments.

The step we're in right now with regard to the package performance study, again, from the public perspective and public involvement and input perspective, is that based on the comments we received on the issues paper, we are formulating what we'll call a draft test protocol for the type of testing and analysis that could be carried in the package performance study. We're planning that as we finish that draft, what I'll call again the test protocol, we'll go out for yet another round of public involvement to discuss with the public, the stakeholders, the test plan and to ask for views and comments on that test plan before we move to an embarkment, if you will, of actual carrying out of the tests and activities.

And we're also, as far as the carry out of the study and activities, we're planning that there be fairly full public participation, awareness and knowledge of the conduct of the tests, the tests results that we've gathered, ironing out what those results are, what our analysis of those tests results show and the recommendations they lead to.

So that is -- when I'm using the phrase, "enhanced public participatory process," I'm trying to describe that process that, on our part, is trying to significantly give the public an opportunity to give us input, tell us whether they think we heard them correctly or not or whether they are of the opinion that the tests we're carrying out would meet objectives as they see it or as we represent them.

VICE-CHAIRMAN WYMER: Thank you.

CHAIRMAN HORNBERGER: Do you anticipate any changes in the regulations resulting from the package performance test?

MR. BRACH: Well, I clearly want to be open, that from any study or test we need to be cognizant that the information that we learn we need to apply that information, whether it be to our regulations, whether it be to our licensing process, our inspection process or our review criteria. So from that perspective, we clearly are open as to what the test results may demonstrate.

We, from the standpoint of our understanding of the package designs and understanding of the tests and our modeling of what we'd anticipate in the way of test conditions to be represented through physical testing, we clearly are looking at this and anticipating it to be confirmatory in nature, confirming our predictions and expectations. But, Dr. Hornberger, clearly, we have to have our eyes, if you will, wide open with regard to what the test results tell us and what the implications of those results might be with regard to regulations or our other practices.

MEMBER LEVENSON: I just have one comment that's a little bit of a follow up on John's, and that is I was glad to see you referred to the other tests, because there have been some misunderstandings in the past when people have asked the question like, "Have you ever tested full scale?" The question they were asking was a generic "you," and the response was, "No, we have not tested," and the "we" was a very parochial "we." And I think in discussing technical issues, we need to include all of the available literature and information.

Do any of the other presenters -- first, are there any questions from ACNW staff? Any questions or comments from the other participants in today's session? Still have a couple of minutes, anyone in the public care to raise a question or make a comment? Okay. If not, thank you, Bill.

Our next presentation is by Doug Ammerman of Sandia who will summarize the laboratory research, as understood to be with a capital L. This is the research at Sandia National Laboratory, it may or may not be actual laboratory type research. Doug?

MR. AMMERMAN: Sandia National Laboratories is a DOE facility that has been involved in areas of national interest since its inception in 1948. Our primary mission has been -- oh, sounds much better. Let me start over.

Sandia National Laboratories is a DOE facility that has been involved in areas of national interest since its inception in 1948. Primarily that interest has been nuclear weapons, but the expertise that's been developed as part of our nuclear weapons experience has led us into other areas of system level testing. Next slide, please.

Our presentation will go over past significant test programs at Sandia National Laboratories, starting with the 1970s Crash Test Program that Mr. Bach alluded to, talking about some certification testing that we did for DOE on the defense high-level waste and also on the certification testing that we did for DOE on the TRUPACT-II. It's not a spent fuel package. That particular package is for transporting true waste, plutonium-laced garbage, essentially, and those are done in full-scale tests. Then I'll talk about analysis methodology, how we determined the response of packages using analytical techniques, both through structural modeling and thermal modeling. Finally, I'll go to linking analysis that we've done to testing, both code verification and validation and then examples, side-by-side comparisons of analysis results with test results. And, finally, in my conclusions slide, where are the gaps, what do we need to know more than what we currently know?

Sandia has since its beginning -- next slide, please. Sandia has since its beginning been involved in systems level testing. Like I said earlier, initially those systems were nuclear weapons, but systems level testing expertise applies to a lot of different fields, and it's been used in the area of transportation package testing for about 30 years. Of course, different programs have different goals and different purposes. These goals and purposes define the way the tests were carried out. Some of the tests were, if you will, engineering tests, trying to improve our state of knowledge; other tests certification tests, trying to say do these packages meet the requirements put out by the NRC? Some of the tests are demonstration tests, just trying to demonstrate that this package will survive in an environment that's not necessarily the regulatory environment but a severe environment. Next slide, please.

The 1970s Crash Test Program was perhaps one of the most visible testing activities carried out on spent nuclear fuel packages. The purpose of this Program was to assess and demonstrate the validity of analytical tools and scale model techniques for predicting the response of packages to accident environments by comparing the predicted results with full-scale actual test results, also to gain quantitative knowledge regarding extreme accident conditions by measuring response of full-scale packages under actual crash conditions.

Part of the issue with the regulatory position is that it's a hypothetical accident condition, doesn't necessarily correlate very easily in the mind's eye to real test conditions. One of the purposes of this Program was to show that indeed the hypothetical accident conditions of the NRC regulations do provide adequate safety in actual accident conditions. In this Program, there were mathematical models developed, including some very crude computer scale model testing and finally the combination was full-scale tests. Next slide, please.

This test program included some instrumentation on the scale and full-scale hardware to measure accelerations of package and transport systems, including the conveyance that was being used and in the case of one of the tests the -- or actually a couple of tests we also put instrumentation on the targets; strain gauges to measure strains on various cask and transport system components.

One of the not necessarily requirements but applied requirements, if you will, it's not part of the NRC regulations but it's been implied by the certification processes, that we like to limit the amount of plastic deformation to packages. Strain gauges are a way of measuring that plastic deformation. In addition, there was high-speed photography to record cask and transport system response, and you'll see some of the results of that in the next few slides. Next slide, please.

One of the tests, and this is the one that I personally view as the most spectacular test, was to simulate a grade crossing accident. A truck transporting a spent fuel cask was stopped on crossing a railroad track and slammed into by a locomotive. It was an actual truck in transport trailer that was used at that time for transporting it. One of the criticisms of this particular test has been that the center line of the cask was higher than the frame rails or not equal to the frame rails of the locomotive, and the cask then rode up over the train. Why don't you click on the picture there and you should be able to see the actual test taking place. And you see the cask gets thrown up into the air. Well, that's only partly the result of the configuration of the test. Recently, the American Association of Railroad Test Facility at Pueblo, Colorado has done some tests with passenger trains colliding with each other, and the same kind of behavior is seen. The locomotive essentially plows underneath what it strikes.

Like I said, this is a very spectacular test, and it demonstrated in that 80 mile per hour impact that the regulatory impact, which is a 30 mile per hour does provide a large deal of safety for these packages when you consider that the railroad target goes into a rigid target. In this particular impact, it was by something that people consider pretty rigid. I mean if you want to go and hit something, a train is a pretty bad thing to hit or to have hit you. There's not very many structures out there in the transportation world that are viewed to be more stiff than the front end of a train, but you can see from that picture that that train absorbed a lot of the energy of that impact. There was lots of deformation to the train.

The results of that test are documented in SAND79-2291. Anybody who wants to get a copy of that can obtain that report and read about in detail what's happened in that particular test. There were 18 high-speed cameras, and you saw the footage from a couple of them there, seven strain gauges on the cask body, four piezoresistive accelerometers on the cask, one accelerometer on the locomotive, and the data was acquired via a telemetry system to a remote recording site. So that's why you don't see any cables coming off of that cask, as is typical in the way that we do transportation package testing. You see an umbilical line of cables that are used to get the data off of the testing to a recording system. Next slide, please.

Actually, there were two tests in this particular configuration, involved a truck carrying a transport cask. Would you click on the slide, please, to play that movie? The first test was at 60 miles per hour.

(Movie played.)

MOVIE MODERATOR: In the first test, a truck carrying a 22-ton spent fuel cask impacted a 690-ton concrete block at 60 miles per hour. Here's the impact in slow motion.

(Movie stopped.)

MR. AMMERMAN: For the second test, we had to get a new driver.

(Laughter.)

The two tests were at 60 miles -- next slide, please -- were at 60 miles per hour and 84 miles per hour. The results of those tests are documented in SAND77-0270. Again, that's available to anybody who wants to get a copy of it. This test was monitored with about 14 high-speed cameras, photorays between 400 frames per second and 3,000 frames per second, five accelerometers on the cask body, strain gauges on the cask head and pressure transducers placed inside the cask cavity. The results of both of those tests, the first test, the 60-mile per hour test, had such little deformation to the cask that we said, "You know what? That was no big deal, let's go out and do it a faster test," and so we did the second test, which was 84 miles per hour. Even that test had very little deformation to the cask, and the package remained essentially tight. Next slide, please.

The next test type was a rail transport cask. In this particular instance, we just used the rail car that was used to transport that cask and not the whole train for the impact. Typically, you would have the mitigating structure of cars in front of the car being tested to absorb energy as well, but in this particular test, if you click on the slide, please, the car was slammed into that same --

(Movie played.)

MOVIE MODERATOR: The 74-ton shipping cask, carried by a cask rail car, crashed into the concrete block at 81 miles per hour.

(Movie stopped.)

MR. AMMERMAN: You can see that the

deformation of the rail car was extensive. The cask did not actually come completely out of its carriage, and, again, there was no significant leakage on that cask. Next slide, please. Documentation of that test is available on SAND78-0458. This was monitored with numerous high-speed cameras, up to 3,000 frames per second framing rates, placed above, on the sides and at various angles. Active accelerometers were placed on the rail car frame, the rail car cage cover, which you can see gets extremely damaged in the test, on the cask and also on the target.

One of the things that we tried to learn from that is that concrete target that you see there that that rail car impacts into, and the truck in the previous slide, is not a rigid target. It's a massive block of concrete, but there is energy absorbed by that concrete. It does not have a steel face on it as is required or is typically required for the certification tests. Strain gauges were installed on the rail car frame, cask body and to the rods inside the cask. Next slide, please. Thank you.

In addition to these impact-type tests, that test program also involved a thermal test. The same rail car that we just saw impacted into the concrete barrier was placed into a full-engulfing fire and burned for a period of 90 minutes.

(Movie played.)

MOVIE MODERATOR: After 90 minutes, three times the duration of current qualification test criteria, surface temperatures exceeded 1,400 degrees fahrenheit, but inside the cask where the spent fuel rods would be contained temperatures were below 300 degrees, not enough to melt the spent fuel rods.

(Movie stopped.)

MR. AMMERMAN: Next slide, please. That particular cask in the fire was instrumented with numerous thermocouples. As you can tell from the narration on the film clip, some on the inside, some on the outside to measure the thermoresponse of the cask. Next slide, please.

What have we learned from this Crash Test Program? The results indicated that current, at the time late '70s, analytical and scale modeling techniques could predict vehicular and cask damage in extremely severe accident environments with reasonably good accuracy. In addition to this full-scale sound clips there are clips of the scale model tests of some of those casks, and the difference in response or the similarity in response is amazing, except for if you have something that will reference the scale. And I notice the fact that the scale models look a little bit toy-ish, if you will, not in the same degree of complexity as the full-scale ones. It's very difficult to tell that one of those is a scale model test and one of them is a full-scale test, the response is so similar.

The data collected on responsive transport systems and accident environments was valuable. It demonstrated the fact that these casks are extremely rugged and capable of surviving very severe accidents with much higher velocities than the regulatory 30-mile per hour impact velocity. Next slide, please.

Is there any additional information that can be gleaned from these tests? The analysis computer software that we have today is much more robust or much more capable than it was in the 1970s. We all used 2-D final analysis and lump parameter models, such as spring mass models at that time to represent the casks. Today, we have detailed 3-D final element models that can model many of the components of the packages as well as the global response.

Some of the data from these tests could be used to benchmark the present-day codes. For example, the locomotive cask grade crossing test is a good candidate for that. One of the difficulties of that, though, is that in order to do these detailed final element models that we have today, we need to have detailed information about the packages that were tested or are being tested and the target or in this case the locomotive, the geometry of them. Since those tests were done so long ago, we can't go back and say what are the material properties of the different materials that are involved in that impact? What is the exact geometry of the cask? We can use the drawings of the cask, which maybe are still on file here at the NRC someplace, since those were certified casks at the time. Well, they weren't certified at the time of the test but they had been certified previously to that to get a general description of what the geometry was but tolerances, gaps that are produced in the packages as a function of use, or just fit-up and things like that, we don't know that information.

Some of that information is important in determining what the response is in events such as these that you see here. And even more so, more problematic, is what is the properties of the locomotive. The QA on locomotive design I'm sure is not as stringent as the QA on cask design, and the information on that particular locomotive may be very difficult to get as to even what the geometry of it was, the exact geometry.

Also, since the 1970s, there have been tremendous improvements in data collection, instrumentation and sensors. We're able to obtain much more information in tests that are done today than was possible in the 1970s. Next slide, please.

Another test program, extensive test program conductive at Sandia in 1986 was the DHLW Cask Tests. The purpose of this test program primarily was to do certification impact and puncture test sequence, to provide test data on accelerations and strains to compare with analysis results. It's kind of the same kind of thing that we're looking at today, can we compare tests and analyses? To define the damage state of the cask as input into the hypothetical fire analysis, there was not a fire test because it was a half-scale model. Half-scale fires don't work really well, and so this particular package was intended to be certified in a fire environment only by analyses, and so we needed data on what the deformed shape of the package was to start that analysis with. The test sequence included five 30-foot drops and two puncture spike tests. Next slide, please.

For these tests, there was rather a lot of instrumentation. Accelerometers on the cask varied from six to 15, depending on cask orientation. Strain gauges varied from four to 24. Strain gauge bolts, some of the closure bolts were replaced with bolts that had strain gauges mounted on the inside of them so that that bolt acted like a load cell, could measure during the test what the load on that particular bolt was, and it varied from zero to eight of those. The side impact test didn't have any strain gauge bolts and then the end impact and corner impact tests had up to eight.

In addition, there were LVDTs, linear variable differential transducers, to measure the displacement between the cask lid and the cask body to give -- to see if the analysis that predicted that there would be no deformation of closure was indeed correct. And also since you can't really measure leak rates in scale model testing and there's not a straightforward correlation between leak rates and a scale model test to leak rates in a full-scale package, this information would provide us information to say indeed was the response of the closure such that the package should remain leak tight in the full scale, because you can scale the strains in the deformations. Next slide, please.

Here you see one of the tests. This test was done at minus 31 degrees centigrade. The target was minus 29 but we had -- because the package was warming up while it was hanging up there in the air, it got a little bit colder and we actually ran the test at a minus 31. And you can see the damage to the cask. It curls up the impact limiter there at the end. This package is a little bit different than a spent fuel cask. This is a -- DHLW stands for Defense High-Level Waste. The purpose of this package was to transport vitrified high-level waste logs, essentially a stainless steel canister filled with glass that contains high level waste. It had kind of a unique design, and that doesn't have an impact limiter around the end. For the end drops it had a ring impact limiter, and not in this test but for the sides tests there was a typical, if you will. honeycomb impact limiter to absorb the impact energy. Those impact limiters are done in this test.

The results of that test sequence indicated the package was leak-tight after each test, closure deformations were very small. The various tests where the closure deformation was measured was 0.004 inches, and that was a dynamic measurement, so that wasn't at the end of the test, that was at peak during the test. At the end of the test, all the closure measurements were back to essentially a zero strain or zero deformation. The peak strain measured was 0.0033. Recall that yield strain levels for stainless steel are about 0.0015, so this is barely above yield, although that strain measurement wasn't done during the impact limiter region, it was up in the closure or up in the container boundary of the cask. Strains in the impact limiter are considerably higher than that. Peak acceleration measured was 2,200 Gs on a half-scale, which would be 1,000 Gs on full-scale. This package is a very stiff package, and so the acceleration levels are much higher than are typically seen in spent fuel casks. And the analysis results were generally conservative. Next slide, please.

What can we learn from these tests or is more information available from these tests that we can use to enhance our current level of knowledge? This test series was very thorough, and it can be used as a demonstration of the types of instrumentation information that can be obtained from a drop test. Recall that there was strain gauge data, accelerometer data, load cell data and deformation data that were acquired dynamically during the test. Any future testing, such as what Bill suggested that we're going to be doing in PPS, should probably include all those types of instrumentation.

The tests were performed in 1986 and it would be difficult to resurrect any of the digital data that was obtained from the test. So to compare test results to new analysis results wouldn't have the fidelity that you could get if you were doing a test today. But the test results could be compared to modern analysis results, as I say, but with slightly lower fidelity than current test results.

CHAIRMAN HORNBERGER: Why would it be difficult to resurrect the data, you didn't archive it?

MR. AMMERMAN: Yes. It's archived on 9-track tape. Now, my computer doesn't have a 9-track on it, and there are very few of them that do. I'm not saying it would be impossible. I think that Sandia still has 9-track tape readers. I don't know if there's any modern operating system that can talk to those machines or not, which is why I say it would be difficult. I think it's possible.

Another test sequence that was performed at Sandia was a full-scale test in the TRUPACT-II.

These tests were carried out in 1989 and actually some earlier ones earlier than that in 1988, the initial ones, and some of the tests maybe actually spilled over into 1990 even. The purpose of those test was certification test sequence -- drop, puncture and fire. This package was certified by full-scale testing, so there was very little analysis that went along with the certification process. Multiple tests of each type were performed because the regulations require that packages be tested in the most damaging orientation. However, what's most damaging to one component of the package may not be the most damaging orientation for some other component of the package, so there were quite a few tests done in this sequence of tests.

Because it was not a need to compare test results to analysis results, there was very little dynamic instrumentation taken on this test sequence. However, post-test leak checks were performed after test and the package remained leak-tight, and there was also photometric coverage. Next slide, please.

Here you can see a couple of the tests -- let me click on this movie. This was a 30-foot CG over corner impact test. This is kind of just like testing, you sit around all day waiting for something to happen. And the impact on the closure and to the package. Some of these tests were also conducted, and here you see the fire test. The large object on the left-hand side of that fire is something that was done. We were trying to -- we had a big fire going and we said, well, let's do some characterization of the fire environment too, and I'll talk a little bit more about why characterization of the fire environment is important as well.

As I say, some of the tests for the TRUPACT-II were done at elevated temperature. That particular package has polyurethane foam as an impact-absorbing material. It has significant temperature-dependent material properties. Some of the tests to that package were done with the package hot, some of it done with it cold. Next slide, please.

The results of the TRUPACT-II testing were that the package remained leak-tight following all tests, but the relatively fluctual package experience was visible deformations, which I think is one thing that's important if we're going to do a benchmarking type of study, we want to have something that people can see. If I test a spent fuel cask to the regulatory environment, the cask body itself is going to have no deformation, which is the way we design packages. That's the intent, all the deformation is in the impact limiter. I'm not sure if that's sufficient to convince the public that we know how to analyze a package for environments that are more severe than the regulatory test environment and to be able to predict by analysis when the package is going to start to leak or to fail. Next slide, please.

Is there any additional information that can be gleaned from these tests? The lack of instrumentation during the test sequence makes it difficult to compare test results to analyses. You can compare deformed shape, but that stuff is not archived really well. We can't go up and say, well, we have more detailed analyses now than what you did when you did the test. Let's go out and measure what the package is and say how well that analysis compared to the tests. Measurements that weren't taken at the time of the test are probably not available at this time.

The extent of the test sequence, and you didn't really see from my presentation, but there were I think a total of 14 drop tests performed on the TRUPACT-II using two different test units. It demonstrates the expense of relying on testing for certification, which is one of the main reasons why these kind of people over here, the package vendors, typically use a combination of testing and analysis to do their certification.

So let's talk a little bit about analysis. Cask vendors rely on analysis to some extent to demonstrate package response to the hypothetical accident tests, and that extent for some packages is more than it is for others. Even the TRUPACT-II which was certified primarily by tests there were analyses done as well to demonstrate compliance with some of the requirements of the 10 CFR 71. Other packages are certified without any testing. A good example of that is the bus cask, which is a DOE package. The package was never tested, it was completely certified by analyses.

Conservatisms introduced into analysis methods or assumptions within those analysis methods for design certification are not always applicable for test predictions. When I'm doing design I'm going to use minimal material properties, for example. The real testing isn't going to have minimal material properties, it's going to have something close to nominal material properties. The behavior of the package is going to be different if it has -- if it's built with material with minimum material properties than if it's built with material with nominal material properties. If I'm going to do a test prediction, I need to know exactly what the material is that's actually in the test unit. I can't go to the ASME code and say this particular steel has a yield strength of, for example, 30 KSI. It's not adequate for doing a pre-test prediction of the behavior of the package. I need to know what the stress/strain curve is of that particular material. And so any detailed program, such as PPS, that we're proposing is going to require actual coupon testing of the real material as being used in the package, as it's being fabricated most likely, and recording of the complete stress/strain curve, not just -- I'm sure that when people design packages, when they have them built, one of them who covers the fabricator is you pull coupons and you do tests. But what's recorded from those tests? Yield strength, ultimate strength, perhaps elongation, maybe, and less likely this, percent reduction in area, and chemistry of the sample.

MEMBER LEVENSON: Let me interrupt for a second. I understand what you're saying if what you were doing had only pure scientific interest but it's been stated that the purpose of the test is to demonstrate to the public that nothing happens to the cask, and I don't understand why you need all of that detailed information for that purpose.

MR. AMMERMAN: Our risk analyses that we have done, for example, 6672 that Bill talked about earlier, use computer analyses that demonstrate the response to the package to environments that have never been tested. In order for somebody to have confidence in those computer analyses, it's my belief at least that we have to go out and do a pre-test prediction of the response of the package to an actual test. In order to do a pre-test prediction, even to the regulatory test where there's very little plastic deformation, I still need to know mature properties, I need to know when yield, for example, comes about.

I can't use minimal analysis because then if I don't use the real material properties, my analysis predicts a different result that's shown in the test. The public says, "Look, you cannot predict the test results. How do we know that the analysis that you did for your risk assessment is correct? What confidence do we have in the analysis that's done to demonstrate that the risks are small, that people like DOE rely on when they do an EIS to say that there's no impact of transporting or not -- a significant impact of transporting 63,000 metric tons of fuel to Yucca Mountain?"

MEMBER LEVENSON: But that would make sense only if your analysis had zero conservatism in it, because if it does not have zero conservatism, the test is only going to confirm that it is conservative. It's not going to demonstrate how conservative. So what you're saying makes sense only if you tell me that your analysis is designed to have zero conservatism. I'm not sure that's very acceptable for regulatory use.

MR. AMMERMAN: And that's the reason why that second bullet on this slide, for regulatory use it's not acceptable. I want to have analyses that has conservatism for regulatory use. The certification process is going to require conservative analysis, but if I'm doing test predictions and I want to get the right answer as opposed to a conservative answer, you're right, I'm going to do an analysis with no conservatism.

MEMBER LEVENSON: Are you telling me that these tests are not going to be usable for regulatory use?

MR. AMMERMAN: No, they'll be usable for regulatory use but that's not their -- no, let me rephrase that. They're not going to be usable for certification. They're not certification tests. They're going to be used to demonstrate that the process used in certification provides safety. The responsibility for demonstrating that packages meet the certification requirements lies with the package vendors. They do analyses to demonstrate compliance with certification. The analyses that Sandia is going to do as part of the package performance study is not for certification.

MEMBER LEVENSON: Excuse me one second. Two of our members are leaving, not because of your talk but because they have to go talk to a commissioner. That has a little bit of a priority. I'm sorry, go ahead.

MR. AMMERMAN: Well, we'll excuse them, I guess, then. As I was saying, the responsibility for demonstrating regulatory compliance is up to the vendors, and NRC reviews that analyses and makes sure that they do a good job of that and that their analysis is correct and that their package does indeed meet those certification requirements. The responsibility of the package performance study of an organization like Sandia National Laboratories in this particular instance is to demonstrate reality, not conservatism. Next slide, please.

To do the structural model, we use the -- Sandia uses transient dynamic finite element codes with explicit integration of the equations of motion. Such codes are called shock dynamic codes. First code of this type was HONDO, which was developed at Sandia. Lawrence Livermore developed a follow-on code with more capability called DYNA. That particular code has been commercialized and is available to anybody in the commercial sector who wants it. PRONTO is another code developed at Sandia. It's the code that was used to do the analysis that are in 6672. That particular code is export controlled and therefore has very tight distribution requirements on it, it's not available commercially. ABAQUS/Explicit was written, actually, by the same people who wrote PRONTO. They left Sandia and went to work for HKS and developed ABAQUS/Explicit, which is commercially available. And currently, or just recently, Sandia has developed a code called PRESTO, which is the newest code in this family. PRESTO, unlike the previous codes, was written from the start for parallel analysis using parallel computers and so it's a little bit -- at least I'm told that it's going to be more robust in that environment. Next slide, please.

For thermal modeling analysis, Sandia uses both computation fluid dynamics codes and fine element codes to solve the fire dynamics and the heat transfer problems. CAFE, which stands for cast analysis in fire environments, was a code developed at Sandia designed to model large fires engulfing a package. And it's coupled to P/Thermal so that the CAFE part of the code models the fire environment. P/Thermal models the heat transfer within the cask. P/Thermal is a fine element code which is commercially available.

SODDIT, Sandia One-Dimensional Direct and Inverse Heat Transfer is what SODDIT stands for, is a code that's used when we're doing fire tests. We cannot measure what the incipient heat onto the package is, how many kilowatts per square meter, for example, is being imparted to the package. There's not a gauge that measures that type of information. So what you do is you measure surface temperatures on the package and you use a code like SODDIT to calculate what the heat transfer rate is to the surface of the package. Because it's a one-dimensional code, it's essentially assuming that the test unit is a spherical -- has a spherical geometry. It has some limitations, therefore, when applied to a cylindrical geometry, such as a cask, especially up in the closure region.

Vulcan is a computational fluid dynamics code developed at Sandia to solve a broad range of fire problems, unlike CAFE, which is designed to solve a much broader class of fire problems, for example offset fire is a good example. A tunnel fire would be another good example.

COYOTE is a fine element code developed at Sandia for solving heat transfer problems. It's a very robust code for solving a large class of problems. But it's kind of a legacy code, if you will. It's being phased out in favor of the next code on the list, CALORE, which is the newest Sandia fine element heat transfer code. The advantage of CALORE, or one of the advantages of CALORE, is it's been developed in the same architecture as the impact code, PRESTO. Those two codes talk to each other completely so you build a model in PRESTO, subject it to impact, you can take that deformed shape now that you've gotten from the impact calculations and use CALORE to apply a fire environment to it.

How do we know that these analysis codes are giving us the correct results? One of the methods is code verification validation. Verification validation provide high confidence, at least in the scientific community, to the computational accuracy of simulations, demonstrating the predictive capability of the codes and their underlying models. Verification is the process of determining that the code is correctly implementing the mathematical models that are used to describe the physical process. That's saying does the code solve two plus two and get four?

The validation is the process of determining do I have the right code correctly. The validation process tells me that two plus two is what I want to solve, not two times two. The combination of verification and validation tells me, and I need to do this over a broad range because in that example I gave you two plus two and two times two both give me the right answer. The code solving two plus two that gets four, that's the right answer for two times two. I need to do that over a broad range, because one times three is not the same as one plus three. That's the process of validation. Validation makes use of physical data, for example comparing tests to analyses, and also does code-to-code comparisons -- does my code get the same answer as somebody else's code? Next slide, please.

Here's an example of the -- I told you

that the analysis and the test results agreed fairly well for DHLW. Here's an example from a corner impact test. On the left you see the test result, on the right you see the analysis result. And they agree, as you can see, quite closely. You probably can't read what the strain level is on that on here, but the peak strain I think there is about maybe 70 percent. Large deformations in the impact limiter. This is that ring impact limiter that I was telling you about. High level of strains in the impact limiter, very low strains measured from strain gauges up in the containment boundary. Next slide, please.

A little more detailed analysis of a -- essentially, this was a -- SETU stands for structural evaluation testing. It was nominally a third-scale rail cask designed to be minimally acceptable, to just meet the requirements of the ASME code, have stress levels at the allowable limit from the regulatory impact test. It was then tested at speeds up to 60 miles per hour. This particular test was seven degrees off a vertical impact, and that test result is compared to the analysis on the right. You can see that the analysis does a very good job of predicting the deformed shape of the test. It also -- that test had many accelerometers, strain gauges, strain gauge bolts and LVDTs on it. And the analysis also predicted the response of those gauges quite well. Next slide, please.

In addition to modeling impact events, we also model thermal events. This is an example of the CAFE fire analysis code. On the left, you see a test fire that was used to benchmark this particular code with, and on the right, you see the code results, again, agreeing very closely.

Finally, where are the gaps? What don't we know? Certification tests, for example, DHLW and TRUPACT-II, do not involve significant plastic deformation in the closure region. That's by design. We wouldn't want to have a package going out there that had plastic deformation in its closure region transporting fuel, if it had that, in the regulatory environment. Our risk assessments, though, predict when we're going to get package deformation in the closure region. Do we want to have benchmarks that show that we can predict that response accurately?

The SETU tests were not full-scale tests and did not involve the complete cask system. It was close. I mean it had a closure, a bolted closure, it had a lead steel wall, but it didn't have some of the other components that packages have. It didn't have test parts, it didn't have drain valves, it didn't have neutron shielding. Its impact limit was designed only for end impacts or nearly end impacts, it didn't have a complete impact lender system. That was done so that we could do a good job of comparing test and analysis results. It was done so it was easy or relatively easy to do the analysis. It's not as complex of a system as a real cask.

The Crash Test Program in the '70s had little instrumentation to compare analysis results and also it used cask designs that were obsolete at the time that they were tested almost 30 years ago. So that's not an accurate portrayal of what kind of packages are being used today to transport spent fuel.

There's no data available on surface heat flux incipient onto a rail cask-like object in a fully engulfing open pool fire. Tests have been done with that slide that I showed previously, that calorimeter. That was almost the size of the truck cask. So for smaller objects we have that on what kind of -- what the fire environment looks like. A rail cask has a lot of mass, it has a high thermal capacity. That thermal mass affects the fire dynamics. We don't have any data on how well we can model that interaction between a massive, large cask and a engulfing fire.

There's also no data available on the response of spent fuel to severe transportation environments. We have some tests that indicate what the response of packages are, and actually that Crash Test Program had spent fuel in it, but we don't even know what the environments that spent fuel saw in those tests was, so we have very little data on how does spent fuel behave in accident environments, especially how does it fail in accident environments.

In a certification process, NRC typically assumes that in the hypothetical accident conditions 100 percent of the fuel has failed, which is why typically packages are designed to be leak-tight following the certification process so that they can demonstrate that they have no release of an A2 per week.

There's also no demonstrated comparison between the analysis used in risk assessments, for example, 6672, and full-scale, high-speed impact and fire tests. Package performance study is aimed at addressing that, especially that last bullet. We need to have comparisons for impacts that are a threat to the package. We know what the response of the package is to the regulatory environment. We want to see what the response to the package is to environments that are more severe than that. Thank you.

MEMBER LEVENSON: Thank you. Ray?

VICE-CHAIRMAN WYMER: Yes, I have one question. It has a couple of parts but it's basically one question. You say there that there was no data on surface heat flux incipient on the rail cask-like object in an open pool fire, but in fact you said earlier that you had a 1,400 degree fire and it got to 300 degrees inside the waste package. Isn't that data?

MR. AMMERMAN: We have data on temperatures in that particular test, but we have -- like I said, to relate temperatures to heat flux is not an easy thing. That particular test package was tested with its rail car included, which severely affected the heat flux onto the package. And in a real accident, that's probably the configuration that you would have. For most fires, the cask would remain on its conveyance. What happens is that the conveyance provides thermal shielding, protects part of the package from the fire environment. In that particular case, there was a cage all the way around the package, so that provided a great deal of protection to the cask.

It's not conservative and that's the

reason that the NRC doesn't do that in certification process to assume that the package is going to always be on its conveyance. So the plan is for the package performance study to test the package without its conveyance, so the impact has to be only of the package, not of a package plus tractor trailer or package plus rail car. The fire test also will be a bare package sitting in the fire environment as if somehow the tie-downs had failed and the package had come off of its conveyance mode.

So, yes, there is some data available, but it's very difficult from that small amount of available data to infer what heat flux is.

VICE-CHAIRMAN WYMER: Now, what you said was true and accurate, but it was misleading, I thought, because the suggestion earlier was that you had actually exposed the package to a 1,400 degree centigrade and in fact you hadn't.

MR. AMMERMAN: We had exposed a package plus conveyance to a --

VICE-CHAIRMAN WYMER: No.

MR. AMMERMAN: -- an engulfing fire, not necessarily a 1,475 degree fire. Real fires tend to be actually a little bit hotter than that, and so the fire environment that that package saw may or may not be more severe than the regulatory environment. Same with the crash environments.

VICE-CHAIRMAN WYMER: But it wasn't 1,400 degrees.

MR. AMMERMAN: Well, I'm guessing it was -- the surface of the package got to 1,400 degrees, so obviously it saw an environment. Now, did it get to -- was it at 1,400 degrees for 30 minutes like the regulatory fire -- actually, 1,45? Probably, yes, because that was a very long duration fire, it was a 90-minute fire. And so the protection offered by the conveyance probably didn't -- and this is one of the difficulties with using that test as a benchmark, I say it probably didn't because we don't know -- protect the package to the extent that it didn't see even an environment as severe as the certification environment.

The same is true with the impact tests, in the crash tests of the truck casks, for example. The tractor absorbed some energy, the front part of the trailer absorbed some of that impact energy. By the time the cask actually hit the impacting surface, which wasn't the rigid surface, it wasn't going at its initial velocity of 60 miles per hour for the first test or 84 miles per hour for the second test; it slowed down. Those environments may or may not have been ex-regulatory.

VICE-CHAIRMAN WYMER: Was the 300 degrees internal temperature the peak temperature? Is that what it rose to or was that the temperature at the time you started squirting water on the fire or what?

MR. AMMERMAN: Well, I don't believe that that fire was extinguished and the cast was artificially cooled. I think that that 300 degrees was the temperature of the internals at 90 minutes.

VICE-CHAIRMAN WYMER: Oh, not necessarily peak.

MR. AMMERMAN: Not necessarily peak.

VICE-CHAIRMAN WYMER: Because it would have coasted up from there.

MR. AMMERMAN: Right. Because of the thermal leg, it would have gone up beyond that.

VICE-CHAIRMAN WYMER: You don't know how far.

MR. AMMERMAN: I would be willing to wager that it's documented in that Centigrade part that I talked about but I don't know.

VICE-CHAIRMAN WYMER: Okay. Thank you.

MEMBER LEVENSON: John?

MEMBER GARRICK: One of the things the

Committee's been struggling with looking at the transportation problem and the tests in particular is this issue of the information that you're getting being for the benefit of demonstrating safety versus being for the benefit of the science that you're trying to deal with. And our obsession, of course, is with the safety and demonstrating the safety. One of the things that concerns me here is that you're delineating a lot of things that you didn't do, and part of this is a lead up to the package performance study that is coming out and that you're not going to make the same mistakes this time around, you're going to do all those things. But I suspect in ten, 20 years from now, we'll be looking back on the package performance results with the same kind of concerns because of the advances that are made and so forth.

So the question I have here is trying to get a handle on how this information is used. I was at the 1970s test, they were very impressive as a demonstration of transportation safety of the cask, and as I look at those tests and compare it with other engineering issues that exist and the gaps between demonstration tests an the designs, I suspect we build a lot more things with much less testing and much less data than we're building these casks, and yet we seem to downplay the fact that in spite of the fact that we had accelerometers and strain gauges and high-speed photography and target instrumentation on the 1970s tests, we're not able to convince ourselves, at least from an analysis standpoint, that they were very useful. And I just have a great deal of difficulty with that.

And I guess I'd like to ask a specific question. Can you tell me how these tests have been used in the models that people have been using, say the three risk studies that have been performed?

MR. AMMERMAN: I would say that they've been used very little.

MEMBER GARRICK: And I think that's amazing.

MR. AMMERMAN: Yes.

MEMBER GARRICK: I think that's absolutely amazing, and it doesn't give me a heck of a lot of confidence that the package performance study is going to reap a great deal of benefit when you have a history of those very impressive tests and quite a bit of instrumentation, certainly at the time. And then you look at the risk assessments that have been performed, which are pretty crude and are not very well anchored to those tests in terms of having a scientific basis, and you really wonder where this thing is going. You start out by saying that we have enough evidence in front of us now to be high confident that the casks that we use today are safe, and then we immediately -- and this is not very reassuring to the public, I'm sure -- then we immediately give a list of gaps and things that don't exist.

These gaps, in my opinion, are probably mostly relative to the science and very little relevance to the safety. And I just wonder if there isn't a way we could do a better job of presenting that picture; that is to say showing the separation between what is for the good of science and what is necessary to give the public high confidence in the safety of the cask.

It's like some of the analysis I saw in the package performance study justification of not taking any credit for energy absorption in anything except the cask itself. Well, I suspect if you did a very meaningful analysis of energy absorption partitioning based on the 1970s tests, you would come up with some rather dramatic pieces of information about how the energy absorption is allocated in these kinds of events. And I don't know whether that's been done or not but it seems to me it's something that could be done and would be extremely useful.

So I have a whole lot of questions about this business and the lack of a history of continuity between the tests and the analyses and particularly the risk analyses. The risk analyses that I saw, for example, had very little information in them to portray the uncertainties that are involved and to really give an accountability of what we should be worrying about. Because the risk is in the uncertainties, and yet those assessments do not present the results with any kind of uncertainties associated with the critical parameters except in the sampling process that was performed in the course of doing the analysis.

So I think there's a great deal that needs to be don here to put this whole act together in terms of getting the right message out to the public, on the one hand, and then on the other hand, allowing the science to move forward as necessary. But I'm not very impressed with the way the test data that's been generated so far has been kind of buried and not manifesting itself in the course of the kinds of analyses that are what we're interested in doing today, particularly if we mean what we say relative to being risk informed. And I just wondered if you had any comment about that litany of concerns, because I'm frankly not very impressed.

MR. AMMERMAN: To start out with, we have struggled both at Sandia and at NRC, I think, with the dual purposes of the package performance study. Is it a scientific study intended to address the shortcomings or gaps, let's say, in our understanding of the science or is it, on the other hand, a demonstration program to demonstrate safety? And to what degree can we marry these two purposes together and come up with a program that addresses both issues? It's been a very difficult struggle, because sometimes what this side wants is counter to what this side wants. I'm not certain that we have in our currently proposed program achieved the correct balance.

That's one of the reasons why we're having this next round of public meetings to talk about the test protocols. We'll go out and say, "These are the tests that we're planning on performing." Did these tests address the concerns that the community as a whole has, and if not, what should we do instead or in addition to this series of tests that we currently have planned? The results of that series of public meetings, I think, will tend to either tell us that your concerns are legitimate and that we need to do something different than what we're going to do or that we have reached adequate compromise between the two, the dual purposes of the program.

Obviously, there are going to be members of the public that are more swayed by the safety demonstration issue than the science issue, and maybe that's going to push the compromise more toward this side of the fence, if you will, than toward this side of the fence. And, obviously, since Sandia is the organization who wrote the test protocols and has primarily a scientific interest, I wouldn't be surprised that the current plan is a little bit leaning this way toward the scientific analysis or answering the scientific questions.

One of the things that I think is imperative and why -- is that if we can convince the scientific community as a whole that this program was conducted in a rigorous manner and therefore the results of it are correct, if you can say that the results of this are correct and apply them now to a risk study, that gives great credence to the fact that that risk study is also correct and removes one of the stages of doubt, if you will, on the risk study.

MEMBER GARRICK: Well, there's a lot of

very important things that I think can be done. For example, in the reactor safety field, we made some major breakthroughs and better understanding of the safety reactors when we started looking at things like the likelihood of containment failure as a function of the capacity of the containment. And we made some very important discoveries that gave high assurance that these containments, at least some of them, were extremely good and overdesigned and conservative. We want to regulate conservatively, but we want to know what we're regulating from, what constitutes the baseline for conservatism. And in the case of the containments, especially on the large, dry containments, the analysis and the testing demonstrated pretty convincingly that the capacities of the containments were anywhere from one and a half to four times their design basis, and that was an extremely reassuring piece of information that came out of a combination of tests and analysis and risk analysis.

So, for example, if we had something on these casks that was something like a parameter that was the likelihood of release as a function of impact force or energy absorption, I think that would be a very insightful piece of information as to what the containment capability of these casks are. And from a safety and risk standpoint, I think these are the kinds of things we'd like to see much more focus on.

MR. AMMERMAN: And I think that was one of the big differences between 6672 and the prior risk studies. Both 0170 and, to maybe a slighter lesser extent, the Modal study, assumed that the packages failed as soon as they got into an ex-regulatory regime.

MEMBER GARRICK: Right.

MR. AMMERMAN: That they had zero design margin. Sixty-six seventy-two did not make that assumption.

MEMBER GARRICK: Right.

MR. AMMERMAN: It said we will determine or we will attempt to determine what the design margin is of a generic cask. One of the other issues with the risk studies, all of them have been done using generic casks. Is that the correct answer? Maybe not. Maybe what we should do is look at some specific casks. One of the reasons why the -- that generic cask assumption is one of the reasons why the impact limiter was assumed to have zero design margin in 6672. Sixty-six seventy-two said the impact limiter absorbed the energy of a 30-foot drop and no more.

And so for higher velocity impacts, the analysis said we'll just add the energy that the impact limiter absorbed to the equivalent velocity and get a higher equivalent velocity. And at a 60 mile per hour impact speed, that makes that 60 mile per hour instead to be a 67 mile per hour, which is a relatively small delta. And, of course, at 90 -- that's just not true. The impact limiters have tremendous design margin in them. They can absorb much more energy than just the 30-foot drop.

If we were to do an analysis of a real package, and this is one of the things that PPS is going to do, it's going to use a real cask, not a generic cask, not a test model, it's going to use real production cask, and one of the things that the analyses that we've done to write the protocol report, as indicated for the rail cask where the test is going to involve the impact limiter is that the impact limiter has a tremendous margin of design margin in it, and it absorbs much more energy than just a 30-foot drop.

MEMBER GARRICK: My only point is that I would like to see a much stronger relationship between the tests and the analyses, and the nature of the analyses I'd like to see that stronger relationship is with risk and safety, not necessarily just a finite element code or structural or thermal, because all of the codes that you present up there are either structural or thermal. There's nothing up there about leak rate or there's nothing up there about risk, and in many respects to the public, there's nothing up there that really makes the final connection to what they're most interested in, namely whether one of these things is going to break open and release a lot of material. That's my point.

VICE-CHAIRMAN WYMER: I have one sort of half facetious follow-up on temperature. Your drop test was at minus 30 degrees. Did you deliberately choose the coldest day in the winter in order to get the properties of the materials that you wanted or you're just sort of masochistic?

MR. AMMERMAN: Actually, you know, it kind of works out this way, it seems like, that people come to us and want us to do a cold test in the summertime, and they come to us and they want us to do a hot test in the wintertime, I don't know. And so what we do is we put the test in an environmental chamber, we cool it down to the desired test temperature. The air temperature that day was not that cold. As a matter of fact, I don't see any ice around the target area, so I'm guessing that that test was done -- actually, as I recall, it was done in April, so the air temperature was probably at that site someplace in the 70s when that test was conducted, 60s or 70s.

VICE-CHAIRMAN WYMER: So you cooled the cask, then you cooled the plate and then you quickly ran them out there and dropped them?

MR. AMMERMAN: The plate is at ambient temperature, we just cool the cask.

VICE-CHAIRMAN WYMER: I thought you said it was at minus 29.

MR. AMMERMAN: The cask was at minus 31, actually.

VICE-CHAIRMAN WYMER: And I thought you said the plate was at minus 29.

MR. AMMERMAN: No. The plate was at ambient temperature.

VICE-CHAIRMAN WYMER: What was the minus 29?

MR. AMMERMAN: The minus 29 is what the NRC regulations -- okay. What I said is target temperature, which is we tried to get the --

VICE-CHAIRMAN WYMER: Oh, okay, wrong --

MR. AMMERMAN: Yes. Now I understand where your confusion came from. Not the plate, right.

Different target.

VICE-CHAIRMAN WYMER: That's why I thought it was outside. Okay.

MR. AMMERMAN: Okay.

MEMBER LEVENSON: I've got a couple of questions. I'm having real problems separating out this hodgepodge of testing to check certification, testing for demonstration and testing to assure the public, because it isn't very clear to me that these aren't conflicting and they're not clearly not clearly delineated what's for what. And for instance, your list of gaps that has to be for pure science, because the first bullet -- I guess I do consider myself a member of the public, and I feel if you did the tests and there was no deformation, it means the design is conservative. That's a basic gap in pure science, but suppose you have to go 175 mile an hour to get deformation. Would you propose to go there till you demonstrate that you've done deformation?

MR. AMMERMAN: No. I would say --

MEMBER LEVENSON: And by the way, 175 miles per hour you know was a number in the draft plan for PPS, so this isn't something I made up.

MR. AMMERMAN: Actually, I think that there's no need to go -- from a demonstration point of view, there's definitely no need to go to impact velocities that are higher than the accident record. And when we developed the initial plan for package performance study was before we had done any reviews of the accident record. We were relying on the accident record as portrayed by the Modal study, and I think that they only had impact velocity up to 150 miles per hour in there.

If we say that the spent fuel transportation experience is maybe not going to be the same as the global transportation experience, for example, freight trains don't go 150 miles per hour. There may be train accidents at that velocity but they're not from freight trains. They would be from passenger trains. Those are the higher speed trains. So the only type of accident that would involve that kind of velocity is a train-to-train collision. And to use that impact speed for other types of accidents is probably not a smart thing to do, if you will.

But the accident record definitely does show impacts up to 90 miles per hour for both truck and train collisions, and so where do you draw the line for demonstrations and safety purposes, maybe someplace less than that. If you want to say that our analytical capabilities are adequate to predict failure, if that's the goal to say that our analytical capabilities can predict failure of these various components, then that may drive your velocity to a higher number in order to demonstrate the test shows that you had failure of that particular component and we predicted it correctly.

MEMBER LEVENSON: Well, I guess I'd be more interested in feeling comfortable that your codes could predict when I wouldn't have failure than accuracy on predicting failure if failure is beyond reality. This is kind of a generic issue.

MR. AMMERMAN: Yes.

MEMBER LEVENSON: You raised the question of rigorous and I think that's a little bit of a red herring because I have a great deal of respect for Sandia and I don't have any doubt that all the testing they do is rigorous. That has very little to do with the conditions you pick for doing the tests.

I have a follow-up question for George. He's not here so he's not a member of the ACNW at the moment but he is a taxpayer, and his question is isn't it significantly cheaper to extract the data from the old tapes than --

MR. AMMERMAN: Yes. It is significantly cheaper, but -- and one of the things I didn't put on my slide but it is a consideration is would you have confidence in the fact that my analysis matched the test results, that I already knew the test results as opposed to predicting a test result before I did it? There's a much higher -- I contend that there's a much higher level of confidence if I predict a test result than if I match a test result.

MEMBER LEVENSON: But in this case you don't have the data yet, so you can predict it and then go extract it, so that's not an issue in this case.

In your DHLW test, you said the analytical results were generally conservative. Was this by a factor of 50 percent or two orders of magnitude or how far away are we? See, the assumption on the regulatory side is that the regulatory requirements already have conservatism in them, and I'm just curious how many more times we're adding more conservatism.

MR. AMMERMAN: The DHLW analysis results -- and part of the reason that they were conservative is because the analysis results were not pre-test predictions. They used minimum material properties, the test unit had real material properties. They were on the order of maybe ranging from conservatism factor of 1.2 up to maybe as high as four. Now, it depends, of course, on what you say is a conservatism. What are you comparing? And that's one of the difficulties whenever you try to compare analysis of test results. If I say that the test result the answer was 120, the analysis result answer was 150, the allowable was 100, the conservatism in my test was 20, the conservatism in my analysis result was a 50, so is my analysis result two and a half times conservative relative to the test result? It's difficult. You have to be very precise in describing what you're comparing to when you say the analysis showed a conservatism of X.

MEMBER LEVENSON: Okay. Well, that, of course, is back to John's question: If you're not carrying the calculation out for some indication of risk, you don't what the conservatism means.

MR. AMMERMAN: And one of the things that I think that has been lacking in past risk studies is what John suggested is what is the sensitivity of things? Sixty-six seventy-two did some, as you said, in the sampling of parameters, but probably the most important parameter is what is the package response? And there was no sensitivity study at all done on package response. How sensitive is the response to the fact that minimum material properties versus real material properties? How sensitive is it to impact orientation? We did an analysis at CG over corner. What happens if you're two degrees off of that? A whole host of issues with respect to sensitivity to analytical results of the package to the impact environments. We could spend the manpower that's in this room for several years, though, to try to nail that answer down precisely.

MEMBER LEVENSON: I know, and that's one of the things that bothers me a little bit. I'm going to do something I don't very often do in public and that's maybe defend what the NRC staff does about something, but their use of minimum properties, which you're kind of poo-pooing a little bit, seems to me is the only thing that in a regulatory safety world makes any sense at all, because, for instance, you want exact dimensions and exact properties. I used to live next to where locomotives were built and I can tell you that each one is a custom one, there are no two that are absolutely identical. So are you proposing to test all the locomotives? I mean I think you have to work with some kind of bounding.

And here, again, we're basically coming into conflict between is this test confirmatory for safety or is it to get additional data for scientific research, which is an admirable objective. I spent 45 years in research, I never had enough data for anything. But in the real world -- which doesn't -- which like John, I have some real problems with defining as gaps, which we're interested in safety gaps, which are gaps in scientific information and may not be relevant for risk. Any of the staff, ACNW staff members want to comment?

MEMBER KOBETZ: Doug, I know you were saying that with the casks that you tested in the '70s you didn't know a lot about the fabrication tolerances and things like that, but can you tell us anything about the design margins and design characteristics and how they compare to today's casks? I mean was it stainless steel shell, was it a carbon steel shell, was it bolted closure, was it welded closure, was it a cask inside a cask?

MR. AMMERMAN: They were stainless steel casks with bolted closures, very similar in concept to the packages today. They were all designed for wet transport of fuel, in other words, fuel with cooling water in the cask cavity as opposed to today's packages which are designed to transport fuel dry with inert gas in the cavity. That was probably one of the big differences. The closures were not really as robust as modern closures are. You can even see that in certified packages that are still certified. The ones that are older have fewer closure bolts than the newer cask designs, typically. So that is an area that we're still progressing toward increased safety.

MEMBER KOBETZ: So they were with water in them?

MR. AMMERMAN: Yes.

MEMBER KOBETZ: And their closures were not as robust as they are today?

MR. AMMERMAN: They were tested with water, and the closures are not as robust. And, actually, the requirements weren't as stringent, I think, in those days. I mean the interpretation. The requirement was to A2 per week and in some of those tests there was actually some leakage of that water. There was a burp, if you will, of the closure, and some of that cooling water was released, a relatively small amount. And then the closure, of course, after the dynamic event was over, came back to its initial position and there was no more leakage.

That probably would not be acceptable today. The way that package closures are designed today is such that the dynamic impact that's on the lid does not relieve completely the pre-load that's in the closure bolts, and so that there will not be a burp.

MEMBER KOBETZ: Is all that describing those two Sandia reports?

MR. AMMERMAN: The fact that the tests resulted in the leakage of a small amount of water is in there. The fact of why that is and what's different today is not in there.

MEMBER LEVENSON: Any other presenters have a question or comment? Identify yourself first for the court reporter.

MR. BRACH: Bill Brach, NRC. I think it's worthwhile to make just a couple of comments on the package performance study. That's been a topic of much of the presentation as well as the discussion. I think the characterization of, if you will, the competition or the interplay between science and safety is important to recognize here, earlier comment about the speeds. So, clearly, from NRC's perspective, the package performance study and the tests, if we carry the tests out, need to be considerate of water realistic testing scenarios that an actual spent fuel transportation package might encounter as it's being transported, whether it be by road or by rail. So the consideration of the realism of the scenario has to be and it's fundamental.

Also, a discussion with regard to the kind of, if you will, the science versus the safety. In earlier discussion, questions to Doug with regard to the material properties -- of the materials used in fabricating the cask design. I think Doug's comment or response was from the perspective of a concern with regard to the modeling and analysis that's done and the accuracy of that modeling in predicting results so that the results when compared to actual physical tests would have as accurate a comparison base as would be possible. And I think we look at too again the extent to which the science or the safety basis would leave that to the extent to which information is needed or sufficient to be carrying out the tests for the comparison.

We'd know clearly that the safety responsibility we at NRC have is dependent upon relying on the safety and the technical analysis and basis that we make reference to, so we need to be sure that we're bridging that gap, if you will, so that the safety mission responsibility, we must exercise that we're comfortable and confident with regard to the technical and the science basis that we're relying on.

But I think the comments and questions

that we've been discussing in relationship to the package performance study and the physical testing are I think representative of the type of interchange and input we're going to be looking for when we provide the draft test protocol, both to the Committee ACNW, as well as to stakeholders in the earlier public meetings that I've mentioned as far as helping us as we take the, I'll call it the draft, and it seriously will be a draft, a draft of the test plan.

And we are trying to finalize that plan with regard to what specific testing activities, information, knowledge of materials, et cetera, are needed and appropriate as well as the various test conditions for the actual conduct of the test. But it looks like the interaction we're having is as well what we're looking for in our outreach activities as the package performance study progresses to help us shape and be carrying out tests that -- responsibilities but also provide a basis from both a science and technical basis that we're comfortable and confident that we can rely on that basis for our safety decisions.

MEMBER LEVENSON: Let me ask one quick question of you since you raised this issue in a way. Will you be viewing these tests symmetrically? And by that I mean now on regulation you assume 100 percent fuel failure. The result of these tests it confirms what is somewhat the previous experience that there is no fuel failure. Let's be utilized to revise regulation based on --

MR. BRACH: In response to Dr. Hornberger's earlier question, we'll need to -- actually, we need to look at what the results of the tests tell us and demonstrate. As Doug has mentioned, much of the modeling and analysis and actual testing has demonstrated that there's been no breach of a container. So from that perspective, the container that contains the radioactive material, as maintained as leak-tight, whether there's 100 percent fuel failure in the accident or some other lower percentage, we need to step back and look at the results.

MEMBER LEVENSON: No. I'm asking a more generic question that all of this will provide upgraded information. Will it be looked at whether it's greater or less than existing situations?

MEMBER GARRICK: One aspect, and this goes back to some of the underlying, I'll say, risk-informed or performance-based considerations, we'll indeed take a look at what the test results and test information tells us in relationship to our regulations and our review approach. And if there are aspects of our regulatory process that we need to relook at, both from a risk-informed perspective, and if the margins are such that more than might be reasonably expected, we'll have to look at what those test results tell us from that.

MEMBER LEVENSON: You know, Bill, that you are on the right side of this Committee when you say you're moving toward a risk-informed approach.

We're running five minutes late but that's pretty good for this morning, so we'll take our 15-minute break now.

(Whereupon, the foregoing matter went off the record at 10:41 a.m. and went back on the record at 10:57 a.m.)

MEMBER LEVENSON: We'll restart the session. Before we start the next speaker, I sort of cut Doug off a little bit at the end, and he might want to make a final comment or statement.

MR. AMMERMAN: Actually, I wanted to make one clarification, and that is that my last slide -- and it says, "Where are the gaps?" -- it doesn't really say what the gaps -- what are the gaps to what? And it's to determine what the level of safety is, what the margin of safety is in packages, not to determine if the packages are safe.

We have no doubt that the packages, as currently designed and certified, are safe. We just don't know what that margin of safety is, and that's where those gaps are. What more information do we need to know to determine that margin of safety?

MEMBER LEVENSON: Thank you.

We'll move on to a summary of work at Lawrence Livermore. Larry Fischer?

MR. FISCHER: There we go. Okay. First of all, I'll talk a little bit about myself, so that you know how I fit into this industry. Actually, I got into the transportation industry on spent fuel while I was working for GE, and that was in 1979. I was the manager in charge of the --

PARTICIPANT: Your microphone is not on.

MR. FISCHER: I put this on earlier to try to get around this, but thank you.

Okay. I just wanted to say a few words about myself, so that you know where I'm coming from a little bit, and that I worked for General Electric. In 1979, I was the manager in charge of the IF-300 cask, and I did a lot of work also out of Morris, Illinois. I was stationed in San Jose, and I went through the consolidation report on the IF-300.

And I actually downgraded the IF-300 because we supposedly were going to ship fuel wet. Processing went away, didn't make any sense. We had a lot of problems with our pop-it valve shutting, and so we just came up with initially a burst this type, and then finally we ended up just with a blind flange and showed that the cask would be safe. And, of course, we went from water to helium.

And then I came to Lawrence Livermore, and I've been here about 20 years. And I've worked primarily on NRC and DOE safety-type programs.

Next slide?

Okay. I wanted to let you know that since I work for Lawrence Livermore, we had a similar a similar situation that came up and that nuclear testing was suspended in 1991. And so it meant no more big ground/underground testing going on. And we had to be able to certify that our weapons would work when they're supposed to work and not work when they aren't supposed to work.

So they had to be highly reliable. We had to understand how they worked, and some of the physical basis. And so we went towards a science-based type technology in trying to understand our weapons, because we could not go out and do a full-up test. We could only do component tests and what we'd call subcritical tests.

And we also had an aging problem with our stockpile, because we were no longer allowed to design new weapons or bring new ones in. Always before we would have a new weapon in about five to 10 years' period, and so then the older weapons would be retired. So this was a big dilemma for us in how we were going to do this.

And so it came about that we developed what we call a stockpile stewardship program where we certify that the weapons are operable in the right manner. And one of the cornerstones of this program was the development of high-speed computing, greatly expanded memory, and multi-scale, multi-physics computer modeling.

And this is just an example of where we are today. This is our ASCI White computer. It's a 14 TeraFlop computer. We're already building our 100-TeraFlop machine. We will do full simulation of nuclear explosives and other types of things.

Now, we go multi-scale, multi-physics. We go down to the nano level. That's not, obviously, required for this type application, but I want to say that there's a lot of capability there to go down to the nano. That is below the micron. In fact, some of the stuff, they go down to the atomic level. So we now have these capabilities.

Next slide?

Okay. I, first of all, want to go through the background a little bit. I'll go a little bit more into how we got to where we're using all of this high-speed computing. Then I'm going to talk about four different projects that I led in the past. There was the modal study, shipping port reactor shipment -- that was actually a DOE project.

The plutonium air transport certification -- that's of interest because it was very high velocity types of things, and we did do both testing and analysis for that. And then, on the other extreme, we went to low velocity impact testing and solid billets onto concrete pads for the storage program. And then I'm going to do a quick little summary with some conclusions or recommendations.

Next slide?

Okay. The lab Lawrence Livermore came into existence 50 years ago. In fact, it's our anniversary as you saw on the first slide. And we've been combining testing and analysis over the last 50 years in order to evaluate and understand physical phenomena.

We developed, in the late 1960s or early 1970s, computer codes for structural, thermal, and nuclear transport analysis, very similar to what Sandia did, except we were -- got a lot into the nuclear transport analysis because of the weapons program.

And we learned earlier that we had to combine tests and analysis to benchmark computer codes in order to evaluate our system performance. Also, postulated accidents, natural phenomena, and sabotage, because you can't go run thousands of tests for every situation.

So what we would do is go out and benchmark our codes, try to find out how well they work, and then we would then apply them to a whole variety of situations and environments, and so forth, to see how, whatever enters the system, how it would respond.

And this includes seismic, and so forth, so we set up that methodology or paradigm, whatever you want to call it, to combine the two together, because you can only run so many tests but you're interested in much more than just what you tested.

Of course, massive parallel processing has come along, and so we have exploited that. Also, the multi-physics modeling has developed over the past 10 years or so. And so now we can do a lot of things we could not in the past, and it really reduces the need for large-scale modeling and multiple tests.

Next slide.

This gives you an idea how the computing world has exploded since 1952. We had a Univac out at the lab, and we had 1,000 Flops per second -- 1,000 Flops per second. Of course, this is an old tube-type machine. And then, once we got up to CDC and 3600, well, by this time, we were going to solid state with transistors, and so forth. So we made a great jump in going from 52 to 72.

And suddenly we're starting to talk about going into MegaFlops. And then there's a CDC 7600. I'm sure many of you remember that machine. Then we went through the CRAY type, I think. And then finally we went into the multi-processing, massively parallel processing.

We're now up around 14 TeraFlops with ASCI White, and that's been online for about two years now. And we have under construction our 100 TeraFlop machine. It looks like a huge double parking garage, and it's all going to have computers and servers in it. It's really an unbelievable structure when you look at it to just think it's going to contain computers.

Also, very important is the fact that our desktops and workstations have gone up greatly, and we can see that a Macintosh G4 and Pentium 4 is equivalent to like our CRAY YMP of just a few years ago. It's incredible, and we can see that this is going to make another jump, because we now have the extreme ultraviolet light -- lithography coming online, so we're going to see this thing jump another factor of three or 10, maybe even a factor of 100.

Well, that's great to have all that capability. But if you don't have the codes to use it, nothing happens. So as part of this thing, we had to go out and improve our codes, and we've been doing that over the years. We started out with simple things like paper-scaler type of setting. It's cards -- remember the cards? We used to drop them and forgot to number them, and then we had to go and scramble and have to redo them all.

Also, we got into paper and teletype, and then finally microfiche. And by this time, we're getting to 2/3D type of codes. And next we went on up and got some good graphics and then some more improvements in our 2/3D codes -- that is, our capabilities, just having a 2/3D code that doesn't have slide lines and that kind of stuff, and a lot of good materials, models, doesn't do you much good.

So you've got to have the so-called sub-routines or materials modeling that fit in with those codes. And then we came out with our L code, which does not only structure but also fluids, interactions, and the different types of contacts between surfaces, so that we could do better analysis.

And, finally, we're up here where we're doing massive parallel type of stuff, 3D rendering or simulations. And I'll show you one simulation today. Unfortunately, it's not on a cask. It's on a dam. And the codes go on up to great improvements, again, in the materials modeling with the multi-physics and auto contact and auto meshing, and so forth.

So these models have gotten to look more and more like actual tests, once you get down to it, if it's done properly -- and, of course, that's why you do some benchmarking.

Okay. Modal study was the first thing that we did for the NRC, and it was the first time that we used quantitative computational modeling and analysis to evaluate responses of representative casks to severe accident conditions to estimate the radiological releases.

And the overall objective of the modal study was to look at NUREG 0170. There was complaints from intervenors that they didn't look close enough at spent fuel, and at that time all we did is severe, extremely severe, severe, and so forth, and it was a qualitative type of judgment. It was not a quantitative thing that tied from the cask design to the estimated radiological release.

And so what we wanted to do -- evaluate the safety of the cask provided under severe accident conditions. And this has met conditions that went way beyond the regulatory test conditions to show that there is significant margin built into the cask. And what happens is that under regulatory conditions the cask remains essentially in elastic mode.

So we knew there was a lot of capability in it for deformation and to exceed very high loadings, and especially if they're using ductile materials, such as 304 stainless or high grade, small grain steels. Then we knew it could actually deform, store up a lot of energy, and not fracture or break. That it had what we would call a graceful failure versus a catastrophic failure. And so that was the way we went into the study, and it pretty much went the way we thought it would.

We used a CRAY 1 machine at that time -- it was a one GigaFlop -- to form our analysis. We did primarily 1D and 2D analysis, because the costs were very high and the time limited. We spent about 25 to 30 percent of our budget just on computer time, believe it or not, and that was very expensive for those days.

We did do one single 3D analysis in order to show that by doing a 2D analysis that the results were comparable. In fact, we were conservative.

And we did have a problem, then, and we are constantly attacked for it. We did not have any benchmark for the code for cask. We had weapons that we'd benchmark, weapons components, and closed form solutions. So that was a bit of a gap at that time.

Here are some results. You can see what we used. We would have liked to use a more refined one, but, again, it's a problem of cost and computational time. So we used this one for the railroad cask, and we did do finer measures in order to see if this one was adequately representative and it didn't put in a lot of error.

And we decided that this one was a good compromise between getting good results and satisfactory results that were not misleading. And this was a 90 mile an hour impact onto an unyielding surface, and you can see there's lead slump. This was a lead cask.

The next slide shows where we did the 3D model. We used the truck cask for that, because it was smaller. And we impacted at 90 miles per hour and put the impact limiter on it. We wanted to see how the impact limiter interacted with the cask, and as it came on down and we could see it starting to collapse here, and collapse a little bit more. By the way, the impact limiter flew off in this particular analysis.

But anyway, the result here with the most deformation matched up well with the 2D model. So we felt satisfied that we were getting valid results.

The next project I worked on was the shipping port reactor vessel. We, by this time, had our CRAY YMP, and that's the one we used in 1988 in order to run these analyses. We used computational analysis with scaled modeling to obtain certification for the shipping port reactor package for shipment. This was a DOE certified package, not an NRC one, but a DOE one.

The other thing, too, is that the shipping port reactor had no fuel in it, and so it was what we call a Category 2 package, which is -- the requirements are less stringent than that for a Category 1 or spent fuel package.

And so we proceeded to try to incorporate the important features in a 1/10 scale model. This thing weighs 1,000 tons. We would have liked to use a larger scale model, but when you're down to -- when you're looking at a 1,000-ton drop test, it's way too high. So we backed off onto a 1/10, which was around a one ton type of system. And we got really quite good at --

MEMBER LEVENSON: Do you really mean 1,000 tons?

MR. FISCHER: What?

MEMBER LEVENSON: Do you really mean 1,000 tons?

MR. FISCHER: Yes. It's a reactor vessel. I'll show you. It's a reactor vessel. I'll show you. Yes, yes. It was a big one. I'm trying to show that we can do big things, small things, and things in between, basically.

We got what we thought was fairly good agreement, given that the size of the package and the instrumentation, and so forth, and the state of the art at that time. We got much better as time went on. But we were able to get a 30 percent agreement between the scale model testing.

And then using that benchmark Dyna code with -- which used the 1/10 scale data, the -- we then dropped the full reactor package in three, four different orientations, a bottom drop, a side drop, and a corner drop.

And we were able to show that we met the regulatory drop requirements with good safety margins. That means that the package would not fail and that also it included a 30 percent difference in our benchmarking. So we wanted to make sure that we included that as part of the margin, and so the package was able to get certified.

Here's a -- next slide?

CHAIRMAN HORNBERGER: Just a quick clarification on that. So when you say a good safety margin, that --

MR. FISCHER: That means --

CHAIRMAN HORNBERGER: -- some quantitative measure, a factor of three or --

MR. FISCHER: That means like a factor of one and a half.

Now, this was only a Category 2 package. Usually, we'd like to have more like a safety factor of three on a Category 1. So there is a difference.

This is the test that we ran. It was dropped, and you can see we had about a six and a half inch flat spot on it, and then this was the analysis we ran. And we predicted about a five inch flat spot on it, and some voiding here. And when we cut it open, we did find some voiding here. That was a big surprise that we were calculating that. And then actually when we cut the package open we did see that.

And then the next slide is the reactor package. As you can see, it's over 40 feet long and about 18 feet in diameter. We had to put a new lifting beam on top, and we had to put the screws in here, or the bolting, long bolts. And we put in 16 of those, and we took out some of the closure studs on the reactor and used those, and there are 28 of those left.

We had some insulation in between, and this was all filled up with grout. And then this was also filled with grout, and the bottom was filled with grout. That was all modeled.

Next slide?

Okay. This is the actual finite element

model we put together. Here is the grout inside of the reactor pressure vessel. Here is the pressure vessel itself with the nozzles. Here is the head closure, and here's the insulation that was in between. There is a ringer around it, and then there is concrete in between the reactor vessel and the thermal shield.

These are the bolts. We actually modeled those, so that we could see if they stretched or bent. And this was the lifting beam. So that was all modeled.

Now, I've also had some problems in retrieving old files. Unfortunately, we ran all this on the YMP computer. It's a classified compute, and nowadays it's hard to get unclassified work off of classified computers.

We are downloading it, and we will go ahead and run some of these new drops, and so forth. But it got a little too tight to make it for today. But we did have good results. And like I said, it did pass the certification test.

The next one I want to talk about is PATC tests. That is, the plutonium air transport package or certification package. This was -- believe it or not, was done on a Silicon Graphics, Incorporated workstation. Guess what? We owned it. It was cheap to run. We did not have high cost of trying to run it on a CRAY YMP, and we had complete control of the machine. We did not get bumped for weapons work or other higher priority work. We were in control of our own destiny.

Obviously, it took us longer to run it on this machine, but it was a 200 MegaFlop type machine with double precision. And so we were able to do all other computational analysis with this machine. These were very high impact velocities, went up to over 600 miles per hour, or about 950 feet per second.

We made up a 1/6 scale model, because we knew that we had to benchmark the model against our code, or our code against the model. And we used grout for the impact limiter, because we had experience with the grout, with the shipping port package. And it was well characterized, and so we felt very comfortable using it as an impact limiter, rather than crushing it. It basically deforms and moves mass to the side, and that's how the energy is absorbed.

We put a little aluminum ball inside to get the peak G's, to see what type of G-forces this was subjected to. And then we did tests, impact velocities, from about 17 to 157 meters per second on a steel surface, basically an unyielding surface, and then we did a couple of shots on a concrete surface which was -- there's a typo here -- it was -- 288 was the other number.

We got good agreement with the impact limiter deformation -- was demonstrated between the scale modeling and computational analysis. Whereas with the peak G thing it was within a factor of two or something like that. We always seem to be having little problems with correlating accelerometer test data with our analysis. But the next project we did we resolved that, so there is hope.

Next slide, please.

Okay. Here it shows a picture. This is the model that we built. We shot this out of a six-inch Howitzer gun. It was a Navy gun that we had in our bunker, and we just loaded it in just like a regular old shell, put in some powder and shot it out against these targets.

And these are the way they looked, and the little ball was right in here in the containment vessel. It was high strength, whereas this was the grout with the deformable 304 stainless steel package. And this is where it went at 516 feet per second onto an unyielding surface, and you can see it got pretty close to the end.

And we were trying to determine what the equivalent velocity was for an unyielding surface versus a soft rock type surface. In this case, we used the grout.

And this is the 288 or 945 feet per second. You can see that we didn't quite hit it straight on. This is one of the problems with shooting it out of the gun. You don't get exact straight-on hits, and you can see that a little bit here, too, that it's flattened a little bit off to the side. And this one it tilted a little bit this way.

So having gotten that -- next slide -- how do we match up with our analysis? Now, we used essentially the same grout, same computer model for the grout that we had used for shipping port. And so this is where, you know, it was really amazing how well we could still benchmark this thing.

You can see there is the little ball that was -- the little aluminum ball, and here is the mesh here. And it kind of -- it looks like it lined right over the top of it. Again, we got very good correlation with deformation, but we were still having problems with correlating with acceleration.

And then here's the other one that was 900 -- 288 meters per second on a soft rock, and you can see it's right near the end here. Now, this is symmetrical, whereas the other one was not, because it can shoot it straight.

Next slide.

Now we got over to billet testing. We did this also for the NRC. Again, we went to the SGI workstation, because of the cost consideration and the fact that it was conveniently available. And the thing that we're looking here at was primarily tipover drops onto a concrete pad. This is for storage casks.

And when we use an unyielding surface it -- the answer always came up you've got to put an impact limiter on top of the cask. And what the problem there is is that, number one, they are expensive. They are difficult to put on, and you expose people when they're putting them on.

The other thing is that you're going around and monitoring the cask. You have to some of the times take them off in order to get access to the monitoring equipment.

So it would be very desirable to take these impact limiters off or not require them. And so the thought was that the concrete can, of course, absorb energy and could maybe eliminate the need for an impact limiter. So that was the thing that got this testing going.

Now, we decided to use a 1/3 scale model for the storage cask. It was just a steel billet. It was very cheap. And we used a reinforced concrete pad, meaning we had concrete with rebar in it. And all of this was 1/3 scale. The actual rocks and sand, and so forth, is all 1/3 scale in order to try to get a valid test.

The next thing we did is very precision, well calibrated accelerometers. And then the most important thing is we developed a methodology for determining the cutoff frequency. There had been problems in, where do you cut it off at?

If you cut it off too high you get too high of G-forces. That is, you are not really putting that much energy into the cask system. You cut it off too low, well, then you're actually having deformation or energy being deposited into the cask, and you're coming up with too low of decelerations.

This is very important with respect to the spent fuel basket, because these forces, as it goes to the spent fuel basket, and the spent fuel basket is the most fragile part of the whole design, because it has heavy spent fuel in it, and they try to make the basket as light as possible. And so it could buckle or bend, and also the fuel can be affected itself.

And so it was very important that we know the exact G-forces that are being translated not only into the cask but to the spent fuel basket and to the fuel. And so we developed a methodology for determining the cutoff frequency by looking at the different modes. We also worked with our weapons people on this to make sure that we were up to speed with them, and they were going through the same sort of thing, how do you have these things correlate?

And we then did a computational analysis to benchmark the Dyna 3D code. We got good to excellent agreement, as demonstrated between the scale model testing and the computational analysis, and I'll show you a little bit more on that.

MEMBER GARRICK: Larry, can you comment briefly on that? What were some of the most critical requirements of the computational analysis for getting that good agreement?

MR. FISCHER: Okay. That's going to be the next slide.

Anyway, when we got done and we had this benchmark, we then looked at a full-size cask. It was a very typical cask. And we did a tipover without an impact limiter on it, and it passed the test. And, of course, we could come up with examples where it was a tall, skinny cask. It wouldn't make it. It would have to put an impact limiter on it.

But most casks they did not need an impact limiter, and so it could tip over onto concrete and the basket could take the forces.

Okay. Next slide.

This is where we show -- okay. What we discovered -- in this case we did a Foray analysis, and we also did the -- performed it on the data, too. And this was after we did a considerable amount of analysis on determining the response of the cask, and what frequency would be best to cut it off and capture anything that could deposit a significant amount of energy versus just ringing, because the ringing does not do any damage to the cask.

And so we determined 450 Hertz was the correct one for the billet, and these are the results for the four different tests that we are -- our two tests and two accelerometers. This is what we calculated.

But notice we also filtered at 450. So when you do your analysis, you know, you can get ringing inside your analysis, so you have to use the same Foray technique to cut that off and smooth it out, so that you're not getting a bunch of ringing going on.

And so this was the big thing that we developed in this particular test sequence and could justify why the 450 in both of these. And that was done for all of these, and we had anywhere from 1 to 15 percent agreement.

CHAIRMAN HORNBERGER: Presumably, you could go back to your previous data and analyses and do the same thing and improve your agreement on the acceleration. Is that true?

MR. FISCHER: Yes, we probably could. Yes.

Okay. Next slide.

I just wanted to show you what it -- this is -- again, this is the tipover. This was very crucial, because that's what we were trying to do is get that impact limiter off.

Next slide.

Okay. Here is the actual billet tipover test that we have here on the pad. And we just let it slap down and took the measurements, and then this is the finite element model. We included all of the soil, concrete pad, and the billet for doing all of the analysis. And, again, that was done on an SGI station.

MEMBER GARRICK: How did you decide on the mesh size?

MR. FISCHER: Actually, we did several different trial and error, to see when there would be a difference. When you saw that you didn't have any difference between the previous one, then you probably -- then you know that you've got enough elements.

First of all, it's an experienced analyst who is putting this together, who has done similar type things. But what we do is we also put in larger blocks and smaller elements, and so forth, and then look at the results. Did the results change significantly or not? If it does not change significantly, then you can most likely go with that number of elements.

MEMBER GARRICK: So mesh size has got to be very critical to the --

MR. FISCHER: Yes, absolutely.

MEMBER GARRICK: -- to the ability to have the computational analysis agree with the test.

MR. FISCHER: Yes.

MEMBER GARRICK: And do you have any

specific criteria, other than trial and error, for determining that?

MR. FISCHER: Get a good analyst.

(Laughter.)

If you get a good analyst, they can usually get it right there to begin with. But we always do perturbations in order to see if we've got too big a mesh size, too small a mesh size. Usually we worry about too big of a mesh size.

MEMBER GARRICK: Yes. Yes.

MR. FISCHER: Okay? Yes?

MEMBER RYAN: Just a follow-up. I mean, there's some calculational questions about convergence or lack of convergence when you do that. Is that the kind of approach that you take? I mean, numerically, things might blow up with large mesh sizes, for example. Is that --

MR. FISCHER: It's not a convergence thing. It's, do you see a difference in the answer? Like the G-forces or any kind of deformation occurring or displacement of, say, the concrete pad. Those are the sort of things that are important.

Also, you want to make this large enough so that you have the right boundary conditions for any wave formations, to make sure that you have the right boundary conditions. But, again, this is why we want to have a good analyst that sets the problem up.

But we also go through what we call a design review type of thing. We bring in our people and critique it and say, "Well, did you do this? Or when you did this, what happened?" And so forth. So it's kind of like a mini design review on these complicated models. It usually involves three, maybe five, analysts.

And like I said, the extra check is we do bring our weapons people in to take a look at it, too, to make sure we're using the code properly.

Any other questions?

Okay. Next slide.

This is not a cask.

(Laughter.)

I want to show you what we can do. Actually, we could go back and try to do this with some of the cask things now that we have these capabilities, and a lot of things have been cleaned up. But this is a -- oh, they already started it.

This is a seismic analysis of Morrow Point Dam. One of our young analysts, Charles Noble, or Chad, is the one who did this. It's in -- southwest of Denver, about 250 miles southwest. And we're looking at a 6-1/2 to 7.0 magnitude earthquake, and most of the people in Colorado would say, "Wait. That can't happen. We never knew." And they said, "Well, these will probably return ever thousand years." So you haven't been around for 1,000 years, so you can't say it would never happen.

What is interesting with this dam construction is it is a segmented dam. It's columns that were poured, and then they put what they call interlocking pins. It's actually kind of like corrugated steel interlocked together.

And the reason why it's built that way is for expansion and contraction, because it has to have it for the summertime and the wintertime. And then on the back side they put a rubber sealer, a very tough rubber sealer, so it can expand and contract and not leak the water through.

And so the other thing is is that this one is a little more exciting than the final one. They put the earthquake ground motion right in the bottom of the dam rather than to the ground. And so what's happening is the top moves much more than it should be, but it makes it a little more exciting to see the capabilities of these types of tools, of the friction in between, and be able to get the slide lines and things to move.

And as you can see, we did mesh the water, so you can see the water sloshes.

CHAIRMAN HORNBERGER: Play it again.

MR. FISCHER: Yes, I'm going to have him play it again. Just let me finish the explanation just a little bit more. I want to make sure you understand what's going on.

I live in Los Gatos, and we had the -- Loma Primetta, yes, there we go -- thank you. It's only 10 miles from my house. We used to go up there and buy our Christmas trees, chop them down.

Anyway, it was a 7.1, and I was, unfortunately, here in Washington, and had a tough time getting hold of my wife. And everyone keeps showing what happened in San Francisco, and I wondered what happened in Los Gatos, not in San Francisco.

Well, anyway, I finally got home. The very next morning I got on a plane. And she was worried about all of this water all over the place. Well, what happened, about three to four feet of water jumped out of our pool and went all over the place. So slosh is extremely important, and a lot of people said, "Why don't you do a mesh on the water?" I said, "It's simple. It's called slosh."

So anyway, go ahead and play it again, so you can see some sloshing here and reaction of the dam.

Now, this is amplified 50 times; 50 times it's amplified -- the displacement. So it's really not this bad. So you can see some opening up and sliding between the columns.

Again, there is a rubber seal on the back, so the water is not coming through.

Do it one more time.

(Laughter.)

But this is what you can do. They can do this with cask simulations. We can run one simulation, another simulation. Somebody else wants water -- wants a low side drop, they want a side drop, we want it to go tumbling down, and whatever, we now have that capability to show this to the public and say, "This is the way it reacts."

Now, we can also zero in where are the high stress points, where are the places of concern. You can zoom in and look at those areas. You can always do the graphics, just print them out in place. You can even, if you want to, print out your data sheets for that region, and your computer sheets, so you have single point data.

But the simulation, this was very important to the weapons program in order to see what's going on. There is tons of data going on, and if you don't have a simulation you don't know where to look to see where the potential problems are.

So this is a great new technology that has come about, and it can be done on small clusters of deck machines, Dell machines, or whatever. You don't have to get into our TeraFlop machines for this type of thing.

Okay. I kind of want to summarize what I've been talking about now. And we have -- as I said, today's analytical capabilities allow more comprehensive analysis of shipping packages. We still want to do our benchmarking, believe me. But now we can emphasize, where do we want those benchmarks to be?

We want to understand the package design margin. We want to quantify it, not just say, "Well, it stayed together. It's okay. We don't know how close it is to failure, how safe is safe." Well, if you don't look at the design margin after you've done these tests, you're begging the question, especially with respect to the public.

So there are things we also can do. The

public keeps bringing up, what about metal bending, machining, welding, lead depleted uranium pouring, annealing? What about all of these manufacturing processes? We can do those now. Those models are being developed. They are going to be made available to everyone.

And these are very important, not only in the weapons program but also in the automotive industry and other places, too. We can do detailed analysis of bolted closures requiring large complex computer models. In fact, we can do tests just on the full scale bolt closures, rather than a whole cask. We can devise those type of tests, and then do your benchmark, and then your computer modeling, and look at the closure. How does it act with the side drop and the end drop or low, shallow drop?

We found with some of the drum packages we had about a 15-degree shallow drop, and it would take the lid off. Whereas when it was a CG, over center drop, the lid stayed on. So by doing these simulations, you can determine where the weak points are. What do you need to do to improve it and put more safety in it and put the safety in the right spot?

Of course, using the contemporary high

speeds we can use a lot of these multi-physics types of stuff that's unique to both our labs to be able to do this sort of thing. Of course, we have extra good physics models and that sort of thing to study things. But eventually you're going to have to put this out to the applicants.

And so once we've gone through all of this, we have to come up with a methodology that we hand over to the applicants, like what we did for the tipover accidents for the storage casks. We wrote out the methodologies. They could run it on their smaller machines, and they could come up with believable, good results.

And that's what we're going to have to do is transfer that technology over to the applicants and also that -- even members of the public. If they want to do some of the stuff, they can do it, too.

MEMBER GARRICK: I can't help but ask this. One of the issues in the Yucca Mountain cask is the heat treatment of the welds for the lids on the inner and outer waste package. And the concern there is, of course, that that's the weak link as far as the possibility of stress corrosion, cracks, and --

MR. FISCHER: Right.

MEMBER GARRICK: -- creating a pathway

into the fuel. Is this tool something that could better quantify the realism of that as a pathway?

MR. FISCHER: Can you believe they're doing that today?

MEMBER GARRICK: Well, I hope so.

MR. FISCHER: They're doing it.

MEMBER GARRICK: Okay.

MR. FISCHER: That's exactly why I can say these things --

MEMBER GARRICK: Okay.

MR. FISCHER: -- for us, because that's actual.

MEMBER GARRICK: Very good. Thank you.

MR. FISCHER: Okay. Recommendations or conclusions. I don't know which one to call these, but anyway based on my experience and the things we've done there -- out at their lab, we'd say let's go ahead and perform some kind of drop and thermal tests on typical transportation casks. And let's just use a hypothetical accident conditions, at least mesh the -- maybe they want to do more, but I think you can learn enough about the systems with that.

And they use state-of-the-art instrumentation to record the cask response, especially in the closure and weld regions. And, obviously, we determined the cutoff frequencies properly, and so forth.

Benchmark at least one finite element code against the test for recordings. Use at least 1/3 scale model. Otherwise, you lose too much detail, but you don't have to use a full scale cask, I don't believe.

You do perform drop and thermal tests and simulation for full-size casks in all different orientations, and so forth. You can also do that for the scale model test, and use a high-speed computer system's physics codes for getting the basic things done and a better understanding. And once you feel comfortable with looking at all of those variables, then you provide the methodology and data such that the applicants can benchmark their own finite element codes and perform analysis for their own casks.

And, of course, we would make all of these simulations available to the public, and let them decide what they want. And if they say, "We want another simulation," okay, well, tell us what new simulation you want. And it's a low cost, easy way to do it. You don't have to go out and run another test. And that's the basis of our stockpile stewardship program.

Any questions?

MEMBER LEVENSON: Thank you, Larry.

MEMBER RYAN: No, thank you.

MEMBER LEVENSON: John?

MEMBER GARRICK: Just a couple of simple ones. You mentioned early in your presentation the nuclear weapons transportation experience. How much of that experience is now declassified? That is to say, one of the most convincing pieces of evidence as to the safety of the shipment of nuclear materials is experience.

And, of course, we know about the NRC experience. We know about the DOE experience on non-weapons material. Is the weapons experience data not available now, just in terms of the number of shipments and the incidence associated with those shipments, etcetera?

MR. FISCHER: I can at least make the request. I would think that we could present it such that it wouldn't be classified.

MEMBER GARRICK: Yes.

MR. FISCHER: But I would have to -- you know, we have to go through the usual scrub and --

MEMBER GARRICK: Well, I would think that would be an important --

MR. FISCHER: Okay.

MEMBER GARRICK: -- piece of data.

A second question is: in the original protocols for the package performance study, there were some tests having to do with the fuel elements themselves, to better understand the disposition of the fuel in terms of the damage, and, therefore, to get a better handle on the source term should the cask actually fail.

Is what you have been doing here something that could simulate the conditions inside the waste package as well as the conditions having to do with deformation and penetration of the waste package?

MR. FISCHER: Today I say that that's possible. Right now, we're doing all the nano-type scaling with reactor vessels with embrittlement. And we're getting pretty good results with Bob Oddet out of University of California.

MEMBER GARRICK: Yes. The specific issue is, what's the condition of the fuel under these severe conditions, such that if we have a puncture we could make an intelligent analysis of what the release conditions would be. That's --

MR. FISCHER: Yes. I think that we can model the cladding of the fuel and its shape and the extent of, say, corrosion, pinholes, or whatever. We now have that capability. Already people are doing it in other fields that could help us out.

MEMBER GARRICK: Okay. Thank you.

MEMBER LEVENSON: Ray?

VICE-CHAIRMAN WYMER: Yes. I have a follow-up on one of your answers to John's question, which goes out of what you've presented here today. But he asked what you were doing with respect to stress corrosion cracking, welds and welded areas, and you said, "Would you believe that's going on today?" Do you actually mean that you're modeling corrosion or you're just modeling the stresses near the welds?

MR. FISCHER: We're actually going into the physics and chemistry of stress corrosion cracking at the nano level.

VICE-CHAIRMAN WYMER: So you're modeling the corrosion?

MR. FISCHER: Yes. We're working with Bob Oddet -- a review with those folks. There's a whole field out there. Maybe I could send you a magazine article, so that you know what's going on.

VICE-CHAIRMAN WYMER: Yes, something simple.

MR. FISCHER: Oh, no, no, no, no. No, no.

(Laughter.)

This is definitely for the lay person. No, it doesn't -- it just tells you what's going on. I could make that available to the panel or the board.

VICE-CHAIRMAN WYMER: It seems to be pretty tricky, because the stresses are a function of distance from the weld, and you've got to take all of that into account. I'd be interested to see what you -- I'd like you to describe what you do there.

MR. FISCHER: Okay. Well, it's down to the nano level right now where a lot of these -- show that one slide that was near the beginning, where I showed you the -- the first slide after I did the introduction. That was a nano level type thing of materials, and you can see how it's not homogenous, and that there are a lot of things that are going on.

VICE-CHAIRMAN WYMER: Yes. But it really would have to include some experimental results on various kinds of stress material as input to the code, doesn't it? Or --

MR. FISCHER: Well, we include the stresses on it, yes, and the environment -- the stress to the environment and the material --

VICE-CHAIRMAN WYMER: But then you need experimental corrosion results in those stressed environments. That's pretty tricky stuff.

MR. FISCHER: Yes. Well, we have a very large program with Yucca Mountain on stress corrosion cracking under different conditions. And that's what we're doing now, we're starting to correlate our models with that data.

VICE-CHAIRMAN WYMER: Different degrees of stress. Okay.

MR. FISCHER: Yes. Yes. Yes, definitely. Different degrees of stress, environment, and chemistry, and so forth. Yes.

CHAIRMAN HORNBERGER: If the article is for a lay person, you can send it to me, and then you can send Ray the real chemistry.

(Laughter.)

First of all, I just have a comment. I must say that your presentation to me -- very impressive computational results. And it does strike me that if -- if we can move forward and do a full computation of a thermonuclear explosion, it does seem to me that we should be able to figure out what happens if a cask tips over. So order --

MR. FISCHER: Three orders of magnitude less?

(Laughter.)

CHAIRMAN HORNBERGER: My one question -- in some sense it would be argumentative, but that's okay.

MR. FISCHER: Yes.

CHAIRMAN HORNBERGER: Would it be safe for me to infer from your whole presentation that the purpose for a test on a full scale cask is simply demonstration and not necessarily technical? That is, can I infer that if you do 1/3 scale testing, and benchmark your codes, you're going to be able to learn everything you need to know about safety?

MR. FISCHER: Yes, I believe that. The reason being is that all that you can do with a full scale cask test, unless you do the same thing you do with the 1/3 -- I mean, the full computational, and so forth, you're only showing it for that one cask. And there's more than one cask that's going to be there.

And you have to be fair to everybody. Everyone should have an equal chance for their cask design to be certified and be able to demonstrate that it can meet the overall intent of the regulations and not incur any undue risk to the public.

MEMBER LEVENSON: I have on question related to the fuel. There is obviously a lot of conjecture, if you're going to do fuel testing, what's the right test to do. What are appropriate loads, etcetera? From the analysis you've done, or for what can be done, it would be relatively easy for you people to identify what are the appropriate loads that the fuel itself would actually be subjected to inside casks undergoing other kinds of tests.

MR. FISCHER: Yes, that can be done. Through simulation you determine what the loads are, and then determine what happens to the fuel rod, given the condition of the fuel rod.

MEMBER LEVENSON: But that has not been done yet.

MR. FISCHER: No. But I think now you can do it, that we're in a state where we can start doing that sort of thing. And I don't think you have to take a real spent fuel rod out and drop it --

(Laughter.)

-- inside of a cask.

MEMBER RYAN: One question from several of the comments you've made and several points in your presentation, but, first, I agree with George. It's pretty impressive computing technology.

For example, when you picked 450 Hertz as the cutoff --

MR. FISCHER: Right.

MEMBER RYAN: -- you know, I think about sensitivity analysis and uncertainty analysis and stability of the answer at a given end point. Could you talk a little bit about how you address that? Because from a performance confirmation point of view, sometimes those are the real key issues of uncertainty, stability of a model, and parameter selection.

MR. FISCHER: First of all, we had four experts working on that. It was not just one person. We had Jerry Mock, who had the lead on it, and he determined by human hand analysis what the best cutoff frequency was, and then we had weapons people come in on it. And then we had T.F. Chen, who is the primary analyst for doing all of those analyses. And we also brought in people from a diagnostics lab to help determine that.

Once it was done, we have a methodology. So it's not like we -- you have to come to these guys every time you want something done.

Now, I'll have to point out, they use the same methodology for the cutoff frequency on a full-size cask, which was much lower because it's much larger. So we did not use 450 cutoff for the full-size cask, because that would be ringing, and so forth.

So the methodology goes to the size of the cask, the shape of the cask, and etcetera. It's cask-specific, and the methodology can be applied to whatever you have.

MEMBER RYAN: Sure. No, I appreciate the fact that you have, you know, true experts that can select that value. What I'm more interested in is the question of: does a particular calculation at whatever value you pick have stability? And is it -- you know, what -- how do you assign or assess uncertainty?

In other words, if I changed it from 450 to 440, or 425, how much does the answer change? How much does my ability to predict change? And how do you assess that? You haven't really talked formally about uncertainty analysis, but I'm curious of how you -- how well you know your answer.

I know you're comparing experiment to calculation, but then when you go strictly to just calculation, how do you express confidence?

MR. FISCHER: Okay. Let's, first of all, back up. There is not a stability problem. The code calculates the stable -- the tests are done, and the accelerometers are stable. What the problem is, you've got all of these -- I should have probably brought an example here. You have all of these spikes going up and down, and you wonder, is that doing anything to the cask? Will it damage the contents, especially will that be transmitted down to the basket, down into the fuel?

So you want to filter it, or else you will come up with false results, but it's not going to damage anything.

On the other hand, if you filter it too much, then some loading will go into the fuel. Some loading will go into the basket that could damage it. And so that cutoff frequency has to be determined very precisely. And in that particular case, it was probably about 400 to 500, didn't make too much difference. But if you start saying, well, it's 200, then it's way too low. And if you say it's 700, it's way too high.

So there, obviously, is going to be some judgment involved. But like I said, there are ways of decomposing this and saying, "This is the analytical cutoff frequency," and it should be also for the actual test.

That's been part of the problem with all our accelerometer data. Where do you cut it off at?

And the answer can vary quite a bit, depending on where you cut it off.

CHAIRMAN HORNBERGER: But the point is -- I think you answered it -- is that it doesn't depend critically on an exact value of 450.

MR. FISCHER: No.

CHAIRMAN HORNBERGER: It could be 425. It could be 475.

MR. FISCHER: Yes. Yes.

CHAIRMAN HORNBERGER: And presumably, you can't get a complete square-away filter anyway, and so you have some --

MR. FISCHER: Right.

CHAIRMAN HORNBERGER: -- leakage.

MR. FISCHER: Right, right. Exactly. You've got to accept some uncertainty. Yes. But it's -- but you can get it in the right range, where you feel very confident that it's not 700 and it's not 200.

Okay? Does that take care of your question?

MEMBER RYAN: In part. I appreciate that. I only want to focus on this frequency question, but I'm questioning and just need a little more information about your general uncertainty analysis.

Typically, when you model something, you have a set of parameters, some measured, sometimes some estimated. And in any system model, if you vary those parameters you will get a different result perhaps, perhaps not. And that whole assessment of -- I don't mean stability in the sense of mechanical stability. I mean stability of the calculation that, you know, if I vary parameters I'm going to get some reasonable range of answers. Do you do that kind of numerical assessment of --

MR. FISCHER: Oh, yes. That's --

MEMBER RYAN: -- and how they work?

MR. FISCHER: Yes, that's what's good about this, that you now have good physical models that you understand and can use. So you can do your sensitivity analysis -- given that you don't know the exact answer or the exact conditions, you can now do the sensitivity analysis to see what has happened.

Has it changed the whole answer, like before you said it doesn't fail, and then we change two or three parameters or conditions, and all of a sudden we see failure? Yes, those sort of things can be seen.

MEMBER RYAN: I mean, you haven't reported on that kind of sensitivity analysis today. But, I mean, that's something you routinely do?

MR. FISCHER: Yes. Yes. Well, we did that in all of these tests, actually. Maybe I should have emphasized it more.

MEMBER RYAN: Thanks. That answered my question.

MEMBER LEVENSON: Any questions from the ACNW staff? Any of the other presenters have any questions or comments?

MR. YAKSH: I have a comment.

MEMBER LEVENSON: Yes.

MR. YAKSH: Mike Yaksh, NAC International.

MEMBER LEVENSON: Pull your mike down.

MR. YAKSH: Oh, sorry. Mike Yaksh, NAC International.

With respect to the basket, baskets really are very fragile. They may be a little bit weaker than the thick outer shell, the inner shell, and the nine-inch lids, but I don't really think they're fragile.

MR. FISCHER: Okay. I'm sorry. Fragile, like 70-G capability versus a few hundred G's.

MR. YAKSH: You didn't --

MR. FISCHER: In fact, that's the reason why we went through all of that. We felt that the baskets could take it --

MR. YAKSH: Right.

MR. FISCHER: -- and that's why we did go to the tipover, saying, yes, they are very robust. On the other hand, you'll always ask the question, can a basket take 200 G's? In a lot of cases, they can't.

MR. YAKSH: Some people interpret fragile as like being a real liability, extremely weak, and I don't think they are very --

MR. FISCHER: I apologize. I used the wrong terminology.

MR. YAKSH: Thank you very much.

MR. FISCHER: I used the wrong terminology.

MR. YAKSH: The other comment I have is on the tipover test, over the steel billet. Can't emphasize how important that test was to ourselves and the other vendors here.

There is a particular beauty about that. Steel is a very complex material, and what they did was they used an elastic modulus. And that prevented people from having to go out and perform very expensive soil testing and really provide no additional assurance that the calculations were accurate or more assurance that there were baskets that were much more robust or the design was more robust.

And he is correct about the bounding conditions. These -- what he showed there was a block, and what you don't realize is a lot of times people apply certain bounding conditions, and it may or may not be correct. And one of the things that the NRC reviewed is to question, why did you use this bounding condition? What affect does it have? And you have to justify that bounding condition.

So the report that they did was a very important step for all the vendors in being able to justify and defend that their designs are adequate.

Thank you.

MR. FISCHER: Thank you.

MR. YAKSH: You're welcome.

MR. FISCHER: I'm glad it helped you.

MEMBER LEVENSON: Any questions or comments from anyone in the audience? Come to a microphone and identify yourself.

MR. REZNIKOFF: My name is Martin Reznikoff. I always --

MR. FISCHER: Hey.

MR. REZNIKOFF: Hi, Larry.

MR. FISCHER: It's been a while. Oh, my

goodness.

MR. REZNIKOFF: I always appreciate your honesty. I wanted to find out a little about the cladding and whether you've actually taken cladding that's been irradiated to the kind of levels that fuel is going to be irradiated to, say 45,000 megawatt days per metric ton, and actually tested that cladding for various physical properties.

MR. FISCHER: Yes. I did that when I was at GE. We did it out at Vallecito. We irradiated the cladding up to the levels that it would be exposed in the reactor, and then we went forth and did bin tests on them, and a hardness test, and so forth. We did quite a number of tests, and it is in the IF300 safety --

MR. REZNIKOFF: Is it written up in some paper that you --

MR. FISCHER: It's in the IF300 safety analysis report.

MR. REZNIKOFF: Okay.

MR. FISCHER: Yes, it was very extensive.

MR. REZNIKOFF: And I have a question for Sandia, if I could do that. I was involved on the Advisory Panel of the TRUE study that was done in 1980, transportation of radionuclides through urban environments.

And I was wondering whether Sandia is going to do the same thing, have an Advisory Panel for these actual physical tests. I think that would improve the public confidence in these tests, if the public can have a hand in the design of the tests.

MR. BRACH: I'm Bill Brach from NRC. I mentioned to Doug -- let me perhaps answer that or respond to it. The Package Performance Study Test I tried to briefly describe before has a -- what we've called an enhanced -- but let's not focus on the word "enhanced."

It has a public participatory process that began with the very outset of the study. Moving into the next phase, which will be our providing to the members of the public and stakeholders the draft test plan for public review, comment, feedback to us, as to the test plan, what we're testing, why we're planning, what considerations, what materials, what type of tests, extremes for the test, etcetera, should be considered. That's the process we will be moving to in the next few months.

Following that, part of the process as well will be actually, then, conduct of the test. Our plans are to have the actual conduct of the test, to the extent we can, also have public, if you will, participation from the standpoint of observation -- better phraseology.

Following that, the test results that are obtained, we're planning to make the test results part of the public process, so that the outcome of the test, what the test results are, will be available. Our analysis of those test results would as well be made available. And then, leading from the analysis, what the recommendations, conclusions, findings are we have -- would be part of -- would be shared with and open to the public.

So from that perspective, there is not per se a public advisory committee or council that we're planning or forming. But we've had very much of an open, public, involved, and engaged process from the very outset of the study, where we were asking the basic fundamental question -- if we carry out this test, what type of test and type of parameters and conditions should be considered to all aspects of conduct?

MR. REZNIKOFF: I think that's good -- not as good as an advisory panel, because it's rather discontinuous. You do things, and then you say, "Are we doing it okay?" And then you ask for other input.

And the advisory panel that I've been familiar with had a more continuous role and a greater interplay, you know, with Sandia.

MR. BRACH: Well, let me take that as a comment or recommendation and for consideration.

Thank you.

MEMBER LEVENSON: I want to point out that Mr. Reznikoff was correct in not limiting his questions to the last paper. This is public comment. Anybody can ask questions or comments on any of the presentations this morning.

Before I turn to the audience, again, as was introduced in this last discussion, the urban study, the TRUE study, was not mentioned by anybody this morning. And, I don't know, Bill, are you in a position to give a two-minute summary? Because is it or is it not something relatively important? Should it be part of this workshop record?

MR. BRACH: I have to explain my lack of full knowledge of the study. I apologize. If appropriate, maybe I could check with staff and come back later during the conduct of the workshop, if that's appropriate.

MEMBER LEVENSON: Any other questions?

MS. GHEE: Thank you, Mr. Chairman,

members of the committee. I am Lisa Ghee with Public Citizen.

And I wanted to make three general comments, first of all, related to the presentation, yet again, of the Sandia videos from the full scale tests in the '70s. And I just wanted to I think clarify for you an element of the public concern here that I think hasn't been fully acknowledged, and just draw an analogy perhaps.

If, for example, a member of the auto industry were to present a new car design for certification based only on analytical models of crash testing confirmed through physical tests done on obsolete models three decades ago, that would certainly not meet with regulatory approval, much less be worthy of public confidence.

And I think it is critical to have those tests from the '70s updated through the planned package performance study, but I hope that the NRC will make it clear in its presentation of the PPS also of its limitations, that this is not a change in the regulatory requirements that would -- this is not a requirement for physical testing of the casks that the NRC certifies. Rather, it's a one-time confirmatory test still taking into account the boundaries of the test parameters, of course.

And I guess that brings me to my second point, which is that if we are to be limited to a one-time confirmatory test, we would be very happy if this committee would recommend that the PPS consider test to destruction, because, you know, just taking for example, the fire test that I've heard -- the contemplated parameters of the fire test, a 90-minute fire at the regulatory temperature, it's three times longer than the regulatory requirements, but still much lower than actual -- some actual fires that do occur in the transit of materials that are already on the roads.

And I don't want this comment to be dismissed, as often it is, as a situation that's highly improbable, because all of these -- as a member of the public, the issue of -- or the weighting of these risks by low probabilities becomes irrelevant, because we all know that unlikely accidents do happen on the roads and rails.

And at the moment when that unlikely accident happens and results in a catastrophe in my neighborhood, it's not very comforting to know that it was unlikely. And I think that given the large, unprecedented scale of transportation that's being contemplated to Yucca Mountain, the test to destruction are, more than ever, necessary.

Finally, there has been a lot of discussion here about the need for extra regulatory tests to test the performance of casks beyond the requirements in the regulations. And there seems to be a widespread acknowledgement that the regulatory parameters drastically underestimate the accident conditions, again, on today's roads and rails.

And, once again, we would be very happy if this committee would go beyond acknowledging this in the context of one-time extra regulatory tests, and recommend a rulemaking to update the routine requirements for cask certification to more realistically take into account the accident conditions through a higher impact requirement of a hotter fire, a longer fire, a more realistic submersion test.

So those are my comments for right now. Thank you.

MR. FISCHER: Do you mind if I answer?

MEMBER LEVENSON: No, go ahead.

MR. FISCHER: Okay. I think you're presenting some good arguments and some good questions. Certainly, we would want to run some tests on some -- today's cask.

The other thing is is that if a cask has a unique feature different from the one that's actually tested, I think it behooves the applicant to go out and run some tests on that, like a different impact limiter or something that is significantly different or innovative. But he doesn't have to do the whole test, the whole thing.

So if there are differences -- it's kind of like what we do -- criticality analysis. We go out and we benchmark our criticality codes against various critical experiments.

Now, if we start going into other areas that do not look like the critical experiments that we just ran, then we have to go out and run additional critical experiments. And we're starting to have to do that now, since we're looking at nuclear waste, whereas most of the stuff was done for more fresh fuel, and so forth.

So just -- I want to say that we don't just run one test, and that's it forever. But we run the test and get the general knowledge, and then, if there is some deviations from that general configuration, then more tests will have to be run and modeled.

The second thing is you had asked about testing to destruction. How about if we do that through simulation? We can show different levels of destruction by simulation. We can show different levels.

And there is at some point where it turns out there were -- that there's not going to be any catastrophic consequences. That's the study we did, a modal study. And that's because we used ductile materials. So we do not expect catastrophic failures to occur.

Things that are designed under regulation do -- let's say, fail gracefully. With the current regulation, we essentially require zero release, and that's very simple to measure. Zero, in this case, is easy to measure.

Then, you say, "Okay. Well, let's go to the next level. What are we going to allow to release?" 10? 20? 30? 40? We get, then, into a judgmental thing. And I think that it's better for us to concentrate on the fact that 99.9 percent of the accidents all fall within zero release, and the other ones that occur and go beyond maybe the regulatory thing, even those releases are quite small as shown by our risk studies that have been done.

And so to say we -- I think you'd have a very difficult time in testing the package to destruction, whatever that means. That's my comment.

MS. GUE: Well, I think, graceful or not graceful, information about the failure points of these -- of these canisters is going to be critically important for -- obviously, for public safety, not to mention public confidence.

And I think the point that I was making was that it's one thing to say, you know, you're safe if it's only a 30-minute fire. Or if you can expand that to say you're safe if it's only a 90-minute fire -- but when we have the folks in Baltimore, for instance, familiar with a fire that lasted for five days, those analyses become less useful.

And I guess when I talk about the -- well, I guess we have -- I can mention the experience of these tests in the '70s with regards to the fire test. And the information that was not portrayed in the Sandia videos was what happened after 90 minutes of a fire, what happened in terms of valve failure and, you know, the lead lining of the cask.

And those are -- I mean, a test to destruction maybe is graceful, but at what point is that zero release regulation violated? What kinds of

-- what kinds of -- what situation and how realistic is that situation would result in that kind of failure.

MEMBER LEVENSON: Bill?

MR. BRACH: Bill Brach, NRC. A couple of comments.

One, Lisa, I appreciate your coming to the microphone to make the comments after Dr. Reznikoff, but, Lisa -- and your organization has been involved in I believe just about all of our prior package performance study meetings that I described before.

And I appreciate that what we're asking for -- again, it will be in the test -- in the draft test plan asking, again, for comments. And I recognize comments come from those in the industry, come from those in government, come from those who represent public interest groups. Appreciate the input.

There are a couple of other additional comments that I did want to make. I had mentioned before in response to a question by Dr. Hornberger that the package performance study is envisioned on our part as a confirmatory test.

Based on all of our modeling and analysis and scale model testing to date, we are fairly comfortable and confident that the test standards that are currently in the NRC's regulations, 10 CFR Part 71, provide for an adequate level of safety and protection of material in transport.

The confirmatory nature of these tests we're looking for to provide us information with regard to the predictability and confirmation of the predictability of much of the modeling and simulation that we're using.

In response to an earlier question, too, I had noted that, clearly, our eyes are and must be wide open, that based on the results of the test, what information that tells us we will be reacting on. And if there are a few, if you will, surprises or information we didn't anticipate, we have to be in a position to respond to what that information might be.

A couple of other aspects, with regard to carrying out these extra regulatory tests, if you will, on all transportation packages. Our efforts in developing the test plan and the whole approach and concept -- we are trying to develop a concept so that the confirmation and the information we learn from the tests will provide results to us that will tell us if the modeling and the computer simulation techniques that we're using that are broadly used, not just used on one individual cask design but are broadly used in almost all of the cask designs, if that -- if those modeling computer techniques and simulations are, in fact, confirmed through the testing. So we're looking for that to give us a broader base of information, not just information on the one transportation package that was dropped.

And the last point I'd like to make is -- and you brought up the reference to the Baltimore Tunnel fire. Yes, that was a fire that lasted for a significant period of time.

There will be a paper this afternoon that Chris Bajwa, who is a scientist in the Spent Fuel Project Office, will be giving on our information that we've developed in working with the National Transportation Safety Board, Department of Transportation, as well as the National Institute of Standards and Technology, with regard to our review and analysis of the Baltimore Tunnel fire.

And if you were hypothesizing, had there been spent fuel -- a spent fuel package on that train, in the tunnel, in a fire, what would have been the consequences or outcome?

It was mentioned briefly this morning our preliminary information is very positive. But Chris will go into much more detail as we, too, are looking at that, because that -- not just because Baltimore is local to where we're located here, but that type of scenario and event to the concern, from the standpoint of our being able to assure that the continued safe transportation of spent fuel under different accident conditions can be assured.

I appreciate your comments.

MEMBER LEVENSON: I'd like to add one comment that might be slightly relevant, and that is the existing regulatory requirements all pretty much pre-date risk-informed or risk-based time. And so I presume that in the foreseeable future most of these will be reviewed to find out, are they still current and are still valid, and are they underestimates, are they overestimates.

So I don't think we should look forward to regulatory requirements of 20 years ago being those of the next 10 years.

Any other comments from the audience?

MR. REZNIKOFF: Just one more.

MEMBER LEVENSON: Very patient until you start interfering with --

MR. REZNIKOFF: I know this perhaps will come up this afternoon, but you mentioned the fire, the Baltimore Tunnel fire, and I just wanted to make a comment or two about that.

It's my understanding the National Transportation Safety Board is not going to look at the temperature of the fire. They're only going to look at the cause of the fire, and that's why the NRC took on National Institute of Standards and Technology to actually look at the temperature of that fire.

I would like the NRC to release that report that NIST has prepared. I think the committee -- the Advisory Committee should also look at that report.

It's my understanding that NIST produced a report that the NRC was critical of, and the NRC, in turn, hired another organization -- Southwest Research Institute -- to do another study on the temperature. Could you comment on that?

MR. BRACH: Well, let me -- the results of our review will all be made public. You are correct in that we have engaged the National Institute of Standards and Technology, as well as the center down in San Antonio, to assist us in the review.

Chris Bajwa this afternoon will be providing an overview of the results. The study, when it's completed, will -- when we have a response on our part to respond back to the Commission with regard to the results of our review, the study results will be made public.

Right now, I'm not in a position to discuss the preliminary information referenced. I've referenced the NTSB, and I've commented, too, before on our coordination with NTSB. We have taken the lead in working with NTSB and the other contractor mentioned to be sure that we understand the temperature profiles of the fire that occurred, as well as the duration of those profiles in the tunnel in Baltimore.

MR. REZNIKOFF: We asked for the NIST study three months ago under the Freedom of Information Act, and it still hasn't been produced.

MR. BRACH: I apologize. I'm not familiar with the FOIA, but the review is currently underway, so I -- my initial perspective is that the study report -- as well as, I know, our report -- is not final and not yet publicly available.

MEMBER LEVENSON: Any other comments? If not, we'll adjourn for the morning. And I'd like to start promptly at 1:30, so as to not cut into time for speakers this afternoon.

(Whereupon, at 12:24 p.m., the

proceedings in the foregoing matter were adjourned for a lunch break until 1:33 p.m.)

MEMBER LEVENSON: I think we are ready to start the afternoon session. We are going to hear from several vendors, and their programs. And the first one is Kris Singh.

MR. SINGH: All right, can you hear me? I hear no negatives, so I will proceed.

My name is Kris Singh, I'm Holtec's president. And I have been asked to give the first vendor presentation.

Our system is called HI-STAR. Is there a pointer? All right, okay, good.

Now I got the equipment under control here. Our system is called HI-STAR. A standard package will consist of six components. I'm going to give you an understanding of the package itself.

The analysis that we have done to qualify the package, to evaluate its characteristics, I'm going to be rather brief on that. I will use the 20 precious minutes I have, that is all that has been given to me, to give you an understanding of the package, because all analyses evolve from the design. If you don't understand the design you can't really do a good analysis.

So I'm going to give you an understanding of what we really have put together, about ten years ago. There are several dual purpose systems available in the industry, they are all very good, they are all very capable, they are all very reliable, I'm just going to focus on the system that our company designs, because I'm most familiar with it.

HI-STAR is a dual purpose cask, it is licensed for storage and transport, under two separate dockets. The item that goes inside the overpack is the multi-purpose canister.

The multi-purpose canister, as the name implies, is good for storage and transport. And in my opinion is the single most significant development in dry storage in the 20th century.

The reason I say that is because when you talk about transport, ensuring that the fuel is contained in a robust container outside, in addition to the overpack, is critical to the security of the package. And the multi-purpose canister provides that function.

The cask has two impact limiters, one at each extremity, designed to limit the maximum G load that the package will sustain, if it is dropped from a height, say, nine meters, that part 71 requires.

It requires a transport cradle, rail car, and personnel barrier, which is strictly a non-structural barrier, so people, insects, animals, can't get too close to the cask.

I'm going to talk, principally, about the first five components, personnel barrier is non-structural, so we won't talk about it. Let's go on to the next expensive piece.

We have the docket numbers for the storage and transport, if you are interested in studying the cask in detail. You see a voluminous amount of material in those dockets.

You are looking at some photographs of actual casks, HI-STARs, which are deployed at certain sites, I think this particular is in Illinois. These are actual HI-STARs you are looking at.

The design mission of the cask was to, for purposes of this particular meeting, was to provide what I call a virtually impregnable physical barrier to protect the MPC, that is the first performance mission.

The second mission is to be able to transport, on rail car, at temperatures as low as minus 40 degrees fahrenheit. Now, as you know, at low temperatures material ductility decreases, therefore the design of the cask has to be capable of dealing with brittle factor concerns at such low temperatures.

It should be capable of being stored on a pad, free standing, or anchored. This cask has, below the base plate, anchoring locations. It can be anchored to a pad, although its most common deployment is free-standing.

And then the last mission is to keep the weight under 125 tons. Now that is, the weight, as you know, is directly related to shielding capability. Weight is also directly related to how much material you have available to develop, to build the structural rigidity in this structure.

And therefore weight, although it sounds like an innocuous number, provides a great challenge to a designer. Let's go on to the next transparency.

You are looking at a view of the same cask that you saw earlier. I'm just going to give you a quick overview of what it contains.

This is the multi-purpose canister shown in a cutaway view. Inside this is the basket. And I'm going to show better views of these. This multi-purpose canister is a completely welded confinement boundary, in the lingo of the trade.

It is, essentially, a completely welded pressure vessel. Outside it is your overpack. The overpack itself consists of a large heavy forging at the bottom, heavy forging at the top, connected by a shell, inner shell, which is the -- what the NRC has christened containment boundary.

And around the containment boundary is a number of shells, five intermediate shells. And then we have a neutron absorber material that we call holtite, and that basically constitutes the cask.

Let's go on to the next transparency. This is the man who made the drawing, it shows you how large the cask is compared to a typical man. The cask, these are geometric dimensions, I'm not going to go into details, I'm just providing this in case you need to refer back to this material, you have some concise information here.

Let's go on to the next transparency. Now I'm going to show you some features that are engineered into the cask to provide rigidness, to deal with the very kind of concerns that analyst would have with respect to its performance.

First item the cask has attached in its transport mode, you can see, that the bottom is a complete base plate, the top is a bolted closure. In order to, on top it also has a gasket joint.

We want to protect that joint. To protect that joint we provide another plate that bolts onto the top of the cask. This makes a diametrical rigidity to the cask, in addition to the top bolted plate, in the transport mode.

So this plate is used strictly during transport. Let's go on to the next transparency. Here it shows you, we have dual gasket closure, we have the man bolts, and here is the buttress plate bolted on to the extension of the over back forging.

Notice here, one of the speakers in the morning pointed out that designers now make casks so the joints are protected. You see how this joint is protected. There is a bolt, there is a series of bolts, and these bolts basically provide the compression load on the gasket, to create the seal worthiness of the joint.

Then you see, outside, there is a forging extension here that protects this bolt, in case of a tip-over in an impact blow. This lip will have to bend, and impact the bolt, before this bolt will see any direct impact force.

This buttress plate is also secured to this lip to give it strength so it will not, under an actual impact load, deflect. Of course it is very rigid by virtue of the geometry, to begin with. But it is further buttressed by the buttress plate.

Let's go on to the next. Now, here, you will see something that we were, it is a small innovation, but it is important when you deal with large loads, impulsive impactive type of loads.

The bolted closure has a recess in it. Do you see this recess here? And the MPC is down here. If the MPC lid were to impact, attempts to hit the top cover, the force will be located in the peripheral region of the cover, as opposed to loading the central region of the cover, which is not that strong.

The idea being to make the joint more rugged, it has the impulsive effect in the type of loads. This here is the part for lifting the cask.

Let's go on to the next transparency. Here we are looking at a section at mid-height. At mid-height you have the inner shell, this inner shell which is two and a half inches thick. All materials in this cask are made out of either nickel steel which, as you know, other than asthenic stainless steel, has the best brittle factor properties of all materials used in the pressure vessel industry.

The enclosing shells are made up of 10

carbon steel. Which, again, would give you 10, so it has good impact fracture property. We chose nickel steel because nickel steel is stronger, it has a higher yield strength, and still has excellent fracture resistance at low temperatures. That is why we chose nickel steel instead of asthenitic stainless steel.

We have a number of layers around the inner shell. And the idea here is we make the steel shell thin, and at the same time we have multiple layers to get the total thickness for gamma attenuation that we need.

You can see, quickly, if you do factor type of analysis, that a crack from the outside cannot propagate to the inside. So if there is, if there were a large impact force, and a crack were to develop, the crack will not propagate.

Outside is holtite, which is a material that is a rigid type material, and therefore it has very high damping properties, but it is not a structural member, per se.

The general idea is to make the cask extremely resistant to impact impulsive bolts. Let's go on to the next.

I mentioned that materials are nickel

steel, or 10 carbon steel. They are all qualified to remain fracture resistant at minus 40 degrees. Let's keep going.

You are looking at, here, the MPC in a cutaway view. The key piece of information here, for those of you who don't load casks, is that this entire structure is manufactured in the shop, the top lid is welded after the fuel is inserted.

So this top lid joins to the shell, is a cause for concern, because it is a field weld. And we have done a great deal of investigation to ensure that that weld will perform, will not fail, actually, under very, very high g-loads.

We have, on the computer, dropped the canister from 25, 30 feet, and seen that the weld will not, we will not have a fracture, without an impact limiter cushioning the fall.

Let's go on to the next one. You are looking at the basket. I think one of the speakers in the morning said the basket is your biggest concern. Indeed it is, because it does contain the fuel. And we have taken the steps to ensure that this basket, which is made of, basically, plate type members, in an octagonal grid, every single seam is continuously welded at every junction, wherever the plate meet, all junctions are continuously welded along the entire length.

Which makes it an extremely rigid structure. As a matter of fact, it is so rigid that under loads that you will apply, say in the central span, you don't see much deflection. It is a multi-flanged rigid beam.

Also, having the welds along the entire length provides for good heat transfer under storage conditions, storage and transport conditions.

The cask has two impact limiters at both ends, as I said earlier. Now, if you look at this structure, the impact limiters themselves protect the cask at the end.

If you are looking at a missile kind of a load, that load, of course, the most vulnerable region is the central region of the cask. And that is where we have layered shells to keep any fracture from propagating.

So the cask, essentially, is protected from the wide variety of loads that now we envision, after 9-11. It will not only take a direct fall, but it will also take localized impact loads.

Let's go on to the next. This show you the impact limiter. The impact limiter is made of aluminum, so it will be resistant to fire, and it will not change its property depending on humidity and temperature. If it were made of wood, you would have a concern about humidity dependence for properties.

The impact limiter is the external body is made of stainless steel, inside is aluminum compressible material. It is a honeycomb material that is made to deform easily at low loads, and actually provide a plastic kind of response under a contact load.

Let's go on to the next one. This shows the rail car that we have. We took the private fuel storage car that they had designed some years, and we designed a cradle to go with it.

The idea with the cradle is to keep the center of gravity of the cask as low as possible. And to also provide for very high axial load bearing capability. I'm not going to go into the details of the cradle design, there is not time for it. But the design mission is to, essentially, make this structure, again, extremely energy absorbent.

Let's go on to the next. Now, this is an artist rendering of our HI-STAR cask headed to the repository. The cask, as you can see, the central region of the cask is where you can have a direct impact from a foreign object.

The ends of the impact limiter, there is a good deal of technical detail that characterizes this impact limiter, but the -- it suffices to say that under loads that the rail car is designed for, nothing happens to the package at all. The stresses will be minimal.

This is the last one, or is there another one? All right, let's go to it. The availability of the cask. Four HI-STARs are currently in use at Exelon's station. I think we showed you, the first photograph was that one.

There are three HI-STARs are used at Southern Nuclear's Plant Hatch. We had built one HI-STAR in 1998, using all the regulations of 10CFR70.1, but at the time we did not have the license, we did not have the certificate. And, therefore, the task theoretically was not certifiable, even though it met all the requirements.

Exelon purchased that cask from us. This presumably is available from Exelon for testing purposes, if you folks do make a full scale testing program.

Let's go on to the next one. Now, I'm going to talk to you, very briefly show you, how many half minutes do I have left? Five, okay.

We made a simplistic model. I would not brag about the model, but it is a good model, because it characterizes the behavior of the package under an impacted load.

We, incidentally, we ran a number of benchmark tests, actual tests, on the impact limiter, as prototype, many years ago. And all the data is in the literature, so I'm not going to talk about them here.

I'm going to show you how this cask is predicted to perform if one were to subject it to a missile load, such as from a jet engine. We took a GE engine that is used in Boeing 767, it weighs 13,000 pounds, and we decided to apply, have it impact the cask, in the center, away from the impact limiter, in the most vulnerable region, with a force of 500 miles an hour.

And the object here is to study what happens to -- whether the cask would separate from the cradle, or is the cradle well enough designed that the cask and cradle remain together.

That was the object of this test, this particular numerical simulation. We have also performed a much more detailed simulation where the entire cask is modeled as an elastic plastic body in a large finite element program.

That I will not present to you in main presentation, if questions are asked we will show you that visual in the discussion period.

We are going to see two movies now, so I'm going to -- this is the last one, right? Another one. Well, here is the actual visual of the engine impacting the cask.

And this, as I said, these are modeled as rigid bodies. Now, you are looking at what happens to the package. Now, realize, this model is limited in the sense that the cask can separate from the rail car, but you will not see actual deformation of the cask, you will only see the -- you will see, if they were to separate, you would see the separation develop.

The next one is with a different coefficient of restitution, meaning that the amount of energy, the first one we assumed that there is no energy absorption. The entire kinetic energy, the coefficient of restitution is one.

Here we assume the coefficient of restitution is .25, which means there is some dissipation of energy.

Now, these solutions in the post-impact response, it is already written for me, the package remains with the vehicle during rollover for a specified impact angle, which in this case is 30 degrees from the horizontal.

One can, this model is capable of studying additional level of refinement, in the sense that we can study the separation between the rail car and the package, we could separate other main components, and determine whether they make them separable in the model, and determine actually whether they separate under an impact load.

This will be more of a solution for a day to day study. We have made a complete model, done a 3-D model of the package, with the impact limiter, the cask, represented by thousands of finite elements, so is the impact limiter, and the MPC inside it, is to characterize the deflection response of the cask, the actual deformation of the cask under the impact load.

We have the visuals for it, we will show you later. But let me just tell you, what we find is that at 500 miles an hour, the same engine impacting the package, the multi-purpose canister is not affected at all, the cask withstands the entire impact.

We will continue our own study, funded by our own company, to characterize the behavior of the cask over the coming months and years. And we will, of course, work with the laboratories to -- we will do our piece.

I think it is important that we do interact with the laboratories because they have much larger computing capabilities, as you heard, and they are able, they will be providing information on the physical design details, so they can do their work more effectively. Thank you.

MEMBER LEVENSON: We are going to keep most of the discussion on these three papers for the end. But at this point, do any of the committee members have a question of clarification?

(No response.)

MEMBER LEVENSON: The next paper is by Peter Shih of Transnuclear.

MR. SHIH: Good afternoon, my name is Peter Shih. In the next 20 minutes I'm going to present Transnuclear's response in regard to design analysis and testing of the transport cask.

By doing this, today, I'm going to -- the topic I'm going to discuss this afternoon, first I'm going to give a very brief discussion about

Transnuclear. And now I'm going to show how the cask as designed by Transnuclear complies with rules and regulations, by using analysis and testing.

By doing this, first, I will go through the U.S. design criteria, based on Part 71, NUREG, and ASME code. Then I'm going to touch a little bit about the European design criteria based on IAEA and the ASME code.

The reason I'm doing that is because some of the casks designed by Transnuclear licensed in the U.S. we also design to meet the IAEA requirement. And in the analysis I'm going to describe the methodology used by our company, and also what kind of computer code we use in our company.

In the testing, first I'm going to describe a symptom test during the fabrication stage, then I'm going to describe the impact test, and how we do the test, the purpose of the test, and the result of the test.

Then I'm going to list the cask designed by Transnuclear licensed in the U.S. and Europe, by using analysis and testing.

In conclusion I'm going to summarize based on the past experiments, and what we can do from here. Next slide, please.

Transnuclear we have over 30 years experience in design, license, and fabrication, and operation of a package, for both storage and shipping of spent fuel, radioactive waste and other radioactive material. Our experience include design, analysis, testing, fabrication, certification, and operation.

Next slide, please. The U.S. design basis of the transport cask that is based on 10 CFR Part 71. In the Part 71 specify all the design requirement, including the normal condition, and the action condition load.

And the NUREG 7.6 describe the structure design criteria of the transport cask containment boundary. And the NUREG 7.8 summarize the load combination required.

ASME code, Section III, Subsection NB and Subsection WB, we use this to code for design, fabrication, inspection, and testing of the transport cask containment boundary. And we use Subsection NG for design, fabrication, testing, again inspection of the basket. And we use NUREG 607 for the lip analysis.

Next slide, please. In the Europe, most of the country use the guideline specified in the IAEA for the design. And they also use ASME code as applicable for inspection, fabrication, whatever.

And if you have designed a transport cask for use in Europe you would pay special attention to this transportation constraint, especially the outside diameter cask is longer compared with the cask in use in the United States.

Next slide, please. The acceptance criteria basically you divide into normal condition, and an accident condition. The normal condition basically we base on ASME code, delivery allowable. And, of course, we need to maintain the containment.

And in the accident condition we base on a level allowable, again, you know, we also need to maintain containment. Next slide, please.

In the Transnuclear basically we use ANSI's finite model for both structural and a thermal analysis. And, of course, we also use some calculation, you know, we use NUREG 607 for LIPO analysis, and we use the COCASE N-284 for the bucket analysis extra.

And the rest of this, you know, we use, in the criticality, we use scale -- we are KENO-5A with a scale of 4.4, and a containment we use ANSI 14.5, and use MCMP code for gamma and neutron dose rate calculation. Next slide please, thank you.

And this is a sift and testing during the fabrication stage, and it is pretty self-explanatory. I'm not going to address this too much.

Thank you, next. Scale model testing -- by the way, you know, because I put a lot -- try to put as much material in the preceding slides. So if I go a little fast, you know, please excuse me.

And since everybody have a handout -- the scale model test, this test is for a cask dropped to a surface from the 30 feet with impact limiter. And the purpose of this test is to validate the G value predicted by the computer analysis.

And in the same time we also use this testing to validate the cross distance predicted by the computer. And we also demonstrate adequacy of the impact limiter attachment design, and in the same time one of the impact limiter during the test, we put it to the freezer, and it is chilled for a minus 20 degree temperature for 24 hours. Then we take out, attached to the test model, on a truck, in 30 foot to an unyeilding surface.

And last, you know, we do a 40 inch punch to a puncture bar. Next slide, please. And this scale relation we generate from the scale alone. Next slide, please. And this overhead, you know, describe the justification and advantage of a scale model test.

And basically there is three report I show from Lawrence Livermore, Sandia, and Ecole Polytechnique, you know, it describe in very detail, so I'm not going to elaborate too much about this, you know?

Next slide, please. This is one of the test program performed by Transnuclear in January 2001. And this is one third scale NUMOS-MP197 transfer cask. We perform this test.

This is a test body, and the top and the bottom impact limiter. And we also have twelve accelerometers mounted to the cask body. And this accelerometers are used to measure the accelerations during the drop.

And this is a three orientation we drop, side drop, 20 degrees slap-down, and a 90 degree end drop. And a median up to 90 degree end drop. We raised the damage the impact limiter 40 each above the ground, and an impact to a one-third scale punch bar.

Next slide, please. And in the next few slides I'm going to show you the drop orientation, and a before and after. This is zero degree set-up. The distance from the bottom of the impact limiter to the test target is 30 foot plus one inch, minus zero inch.

Next slide, please. This is after the drop. And each time after the drop we not only record the G-load, plus go through thorough inspection, measure the deformation on impact limiter, attachment bolt, and also measure the torque of the bolt.

Next slide, please. This is acceleration versus time history, record by one of the accelerometers. And this is a field by 1000 hertz. And you can see, based on this, the maximum G-load is about 180-G, this one-third scale. And the transfer to a full size scale about 60-G.

Next slide, please. This is the test setup for 20 degree model. And it is about a 20 degree, in this line, to the perpendicular, to the horizontal impact cervix.

Next slide, please. And this after the drop, and our engineer inspect, you know, after the drop condition.

Next slide, please. This 90 degree end drop, next slide, and it is of a 90 degree end-drop. Next slide please. And immediately after a 90 degree end-drop we go to the punch, to the bottom of the impact limiter.

Next slide, please. And this is the measured G-load during the zero degree, twenty degree, and a ninety degree. Again, you know, during the structure analysis we add additional safety factor at least like a 15 to 20 percent more than the measured G-load used for structure analysis.

You can see 61, we have 75, and at 65 we also have 75. And this one normal 32, 53, we have a 60, 196.

Next slide, please. We are talking about a scale model test. In the next few slides I'm going to describe two full size train crash tests. One of these performed by the Sandia this morning, he already described, so I'm not going to elaborate that particular one, because we already go through that pretty much, pretty detailed.

And this particular two-thirds, basically, is for public acceptance purpose. I'm going to be talking about a CEGB test, you know? This is talking about central electricity generating bolt at UK.

Next slide, please. This test basically actually is two kind of test. The first kind of test is the full size model is dropped to, from 30 foot to an unyeilding surface, with string gauge, okay?

So you measure all the force of deceleration, and the whatever, you know. Then after the drop the damage to the package was refocused, then placed this package on the railroad truck. Then the train, 240 ton train, drive 100 mile per hour impact, smash into this particular package.

And we find out, you know, the cask had survived for the train crash without any leakage. And at the impact force, from the train crash, was less than the 30 foot impact test.

So basically our conclusion is the full scale testing give public confidence, and conform to regulatory test are realistic when compared to the real accidents.

It is very important to find out, you know, accident 30 foot drop to an unyeilding surface give you a much, much higher impact force compared with this train crash.

Next slide, please. This, the package, next slide, and a train crash, you know, diagonal to the package. Next slide. And this see from a distance, you know, so you can see the whole picture.

Next slide, please. In addition to a 30 foot drop to an unyeilding surface, Transnuclear also had some experiments on the high speed impact testing. And we performed this by simulator, the F-16 and F-18 fighter jet.

And what we do in this, you know, the test was performed on missile, or model with missile representing the real hardness of a jet engine, and the impact condition.

And at the impact velocities, 336 to -- between 336 and 481 miles per hour. And we test, it was performed using one-third scale of TN24D and TN24G cask, okay?

And following component was modeled in the cask, steel shell, neutron shared in the containment vessel including forged steel shell, weld at the bottom, and the bolt lipped with metallic seal.

And the next slide will show you the picture, please. Okay, this is the high speed missile representing the jet flight just before impact to our TN24D cask. And these three slides, you know, that show you how the missile impact to the cask.

Next slide, please. The test result, the only deformation is local deformation at the outer shell, and a not deformation of the force containment vessel, or the closure lid.

The lid tightness was unchanged, because we measure lid tightness before and after the impact test. And virtually is identical. And this, by the way, we have 24D and 24G, we perform a lot of tests, you know, and because of time, I don't have time to show you the picture.

But based on all the tests our conclusion is that the dual purpose metal cask can survive very, very severe impacts.

Next slide, please. And this slide show the cask designed by Transnuclear, and licensed in the United States, based on analysis and testing. And from here you can see most our testing is about, oh, one-third scale, and one of this half-scale.

And one thing I wanted to mention, the TN-68, this particular cask is dual purpose cask. We are not only licensed for transport, but also licensed for storage.

And a new NP197 cask, this particular cask is not only designed to meet the Part 71 requirement, but we also design to meet IAEA requirement, and also meet European transport constraint.

Next slide, please. These are the casks that we license in Europe. And also you can see the testing scale. Most of them are from one-third scale to half-scale, and this one is one scale.

One thing I ought to mention, you know, TN24D, TN24G, these two casks not only do we perform a 30 foot drop test, but also perform a missile impact test to simulate the jet flights.

Next slide, please. In conclusion this, Transnuclear's past experiments in design the cask, and analysis, and testing, and it combine ways of today's advance technology, especially computer, high speed computer. And we conclude that, you know, analytical thought can actually predict the test behavior.

Scale model test result provide valuable benchmarking data. Reduced scale tests is just, is fully justified. Scale one test on large package is not required.

Then, basically from the four side, the public demonstration test, to prove that the current regulation give adequate safety margin to real accident conditions. That is what I tried to show, that four side package test.

Based on the G-load, based on the force measured from the 30 foot drop, compared with the train crash, you know, we find that the force from the 30 foot drop is much higher near the train crash. Thank you.

MEMBER LEVENSON: Any committee members have a question?

VICE-CHAIRMAN WYMER: What is the shielding, the gamma shielding material?

MR. SHIH: Well, we have a neutron, we have a reason that we also have a stainless steel shell.

VICE-CHAIRMAN WYMER: So what is the gamma shielding material, again?

MR. SHIH: Rayzor.

MR. SINGH: Gamma shielding.

MR. SHIH: Oh, gamma shield, okay. The stainless steel shell, stainless steel.

VICE-CHAIRMAN WYMER: All stainless steel?

MR. SHIH: Yes.

VICE-CHAIRMAN WYMER: Okay, thank you.

MR. SHIH: Thank you.

MEMBER LEVENSON: For clarification, is it still true that casks built to the IAEA standards are usable for shipments into the United States, not from one place in the United States to another, but from anywhere in the world into the United States, the IAEA cask can be used, is that right?

MR. SHIH: I think I will refer to NRC to answer this question.

MR. BRACH: This is Bill Brach, NRC. That is actually a role and responsibility of the Department of Transportation has for countries, or companies, that are importing into the U.S., they must apply for approval through the DOT, the Department of Transportation, for authorization to a non-NRC certified package.

MEMBER LEVENSON: Okay, thank you. Now we will go on. Our third speaker is Michael Yaksh, from NAC.

MR. YAKSH: My name is Michael Yaksh, NAC International. I appreciate the opportunity this afternoon to describe some of our experiences, and analysis, and testing.

Next slide. These are associated, of course, with COC, this is a list of our COCs that we currently hold. The NLI1/2, and the NAC-1, And NAC-LWT, these are legal weight truck casks.

The unique feature about the NLI-1/2, it is an older cask that we purchased back in the late '70s, and it, as a shielding, uses uranium. The other cask we use is basically lead.

The difference with the NAC-STC and the MPC, and the UMS, these are what we call our high capacity casks, 24 or more PWR fuel assemblies, 56 or more PWR fuel assemblies.

If you look over the column of the number of applications, and NLI, and NAC-LWT, you see that those numbers are rather high. It just shows you just a variety of types of fuel that is used, and radioactive materials that are transported in these casks.

Next slide, please. This is a slide showing our overall usage of these casks. There is 8 LWTs being used throughout the world, 5 NLI-1/2s, use over 3,300 shipments, over six and a half million miles, so it is quite extensive.

When we do campaigns, that are usually -- when we ship fuel out of Taiwan, there was quite a number of shipments. Some of these other locations, like Colombia, and European, Scandinavia, those are just maybe one or two shipments.

As far as modes of transportation, we ship over trucks, boats, and when we ship the weapons grade fuel out of Iraq, after Desert Storm, that was done in Soviet aircraft. So these casks have been used world-wide, and the only accidents I'm aware of is when an empty NLI-1/2 cask, the truck jackknifed, the cask fell off the truck, damaged the bolts and impact limiter, falls on impact, and it was repaired and put back into service.

So far as major accidents to these casks, over the six and a half million miles, there has been none, none that we would tally.

Next slide. Each one of these casks has a license, and this license is supported by a combination of testing and analysis. The testing is used to confirm the analysis.

Because ultimately you want to demonstrate what the intent of 71 is. The integrity of the cask, and so we use both testing and analysis to do this. Testing confirms the structural response of some things that, early on especially in the '90s, it was demonstrated best through tests, as the impact numbers, what happens to the impact limiter bolt, does the wood, and the other type of crushable material, does its maintain its orientation.

So those sorts of tests demonstrated and validated our assumptions. Now, the view of analysis, though, once we've benchmarked the methodology is, if we need to do what-if type study, it is much easier done with the analysis, as opposed to going out and performing a test, temperature variations, variations of density, variations of manufacturing, those sorts of things.

So the bottom line is we use the test to confirm our analysis and technically our manufacturing methodology as well.

Next slide. When we speak about

containment, there is really a number of systems that are involved here. There is an impact limiter that limits the acceleration to which the fuel clad will be exposed, the basket structure will be exposed, the cask body shells will be exposed, the lid, the bolts, those sorts of things.

And there is the cask shells. Our gamma shielding is lead, it is in between two thick stainless steel shells, and then there is this very robust bolts that maintain the containment at the top.

The main thing, criticality control of the fuel within the basket, the basket is a very robust basket made out of stainless steel. And each one of these, COCs, that we developed in our design licensing, we feel like the testing experience has been rather extensive.

Next slide please. This is a slide showing some of our high capacity casks, as well as our truck casks. That is 24 spent fuel assemblies, PWR 56, for BWR, total design weight is 260,000 pounds, fuel weighs about 40,000, so you can see that this is canister fuel, we are dealing with about 220,000 pounds worth of packaging to protect, 40,000 pounds, roughly, worth of fuel.

Impact limiter is attached to both ends, contained within the stainless steel shell. We use redwood and balsa. We find those are very economical materials, and very stable materials, as we will point out in just a little bit.

As far as testing type, in order to do your analysis you have to have certain input, material data to do that analysis, and that is what we call material testing.

We just received the COC, that testing involved dynamic testing of the redwood and the balsa, that was performed at the Naval Surface Warfare Center. The actual quarter scale model testing of the impact limiter is down to the anti-limiter bolts, the net area is modeled to a quarter scale, the shells, the impact limiter are modeled to the quarter scale.

The way we would manufacture the impact limiter and the full scale is the exact same way we did it in the quarter scale model. We started the test at Oakridge, and then we completed the test at Sandia National Laboratories.

The CY-STC has 26 fuel assemblies for canister fuel for Connecticut Yankee type fuel. We did both material testing here, same material testing we did for the GMS, we just applied that to the CY-STC design.

The reason why we went back and did a quarter scale model is that we realized that we could cut 30 or 40 percent of the weight of the impact limiter, convert that to fuel weight, and make it a much more efficient design.

We learned quite a number of things from the EMS, and from the STC down in the early '90s, and we wanted to employ that in the CY-STC design. So for that reason we returned back to Sandia, confirmed, do some more confirmatory drop test.

The NSC-STC is primarily for loaded fuel, and two of those are being fabricated in Spain, for use in China, to transport fuel for Diambay to a processing plant and back to Diambay for reuse.

And that was one of our earlier designs, that was done back in the early '90s, and at that time we used primarily static crush test, and we used some dynamic data from one of the national laboratories to extrapolate for the dynamic data.

Now, the unusual thing about the NSC-STC, not only was the impact quarter scale modeled, down to net area on the impact limiter attachment bolt, but it had a quarter scale basket, as well, all the shells were quarter scale, the inner shell called for XM-19 pedigree, that is what went into the quarter scale model.

As far as stainless steel, the pedigree that was used, and the full scale design, we also used in the quarter scale model. So it was a very detailed test, not only of the impact limiter, but also of the cask body. And that -- those particular tests were done in the UK, at Winthrop.

Earlier casks, legal weight truck casks is NFC-LWT, for that cask we use honeycomb. Why didn't we use honeycomb for the larger one? Just from an economic standpoint we converted from honeycomb to wood, because legal weight truck cask is a much smaller cask, the internal diameter is about 13 and 3/8ths, the internal diameter of the larger casks are 67-plus inches.

For LWT we used dynamic data from the manufacturer of the material. We also had an impact limiter that was down to a quarter scale. The impact limiter skin was fabricated out of aluminum. The impact for the quarter scale, those skins were also made out of aluminum.

So we were very meticulous in using quarter scale just exactly what it would be in the full scale materials, and from the manufacturing standpoint.

The cask body also was at quarter scale. We had poured lead, just like we did for the NSE-STC quarter scale model, we poured lead for the shells, for the gamma shielding, so it was an exact replica.

In fact, at one time, we thought about selling the NSE-STC as an actual cask, because we had all the pedigree to it.

The NLI-1/2 is a cask that we purchased. The reason I mention it is that it uses a balsa impact limiter. Those casks are still in service. We didn't do any of the testing for those.

I mentioned the Californium, that was a specialty cask developed for Californium. In the micro gram the level of Californium is a very fissionable, very highly radioactive material. Most of the cask volume is comprised of NS-4, that is our neutron shielding material.

During the review process one of the reviewers said, what can you tell us about the integrity of your NS-4? So we immediately said, well, that means go out and do some drop tests.

So we went out and did material testing of the NS-4. A cask is not shown here, but we have done analysis for recertification, was the Paducah overpack for transporting UF-6 to and from Paducah.

We had the data, this data is rather old, but we went back and modeled it, and we got excellent agreement.

Next slide. With material testing, material testing is the basis of your analysis. And it obviously uses samples and would determine stress-strain curve. Now, we realize that some of the data, perhaps, that was out in the literature for stress-strain data for the wood, maybe there was some gaps in it.

So we contracted with Naval Surface Warfare Center to perform a whole array of tests. And more importantly about these tests is they include the strain weights of, rather low strain weights quasi-static, we did static as well, strain weights all the way up to 375 strains per second.

Now, that is a bizarre high strain, but we wanted to see what happened to the stress-strain data as we really approached astronomical strain rates to kind of review the fact that what if somebody wants to do an 80 mile an hour, a 100 mile an hour test, or do something other that was not quite in the regulations at that time.

We also had testing that covered all the way from minus 40, based on the regulations, to 200 degrees. That is our normal operational condition. Because wood is orthotopic, just like honeycomb, we performed a whole array of tests, in both directions, to ascertain the weak direction, as well as the strong direction.

Then, of course, with any natural material you want to observe the variability of the properties. Whatever criteria that we used in performing these specimen tests, it is the same criteria that we used to build the quarter scale limiter, it is the same criteria that we are using to build the full-scale limiters for the redwood impact limiters over in France at this time.

So the materials we've tested, that we have been involved with, is redwood, balsa, honeycomb, and NS-4 and some foam.

Next slide, please. The importance of this testing, it helps us define the extent of variabilities associated with the materials, such as the moisture, such as density.

But once we've ascertained what the variability, and we've clamped down on, we will only accept this type of material, then we get rid of the effect, basically, we fact out the effect of the variability of material we see in the natural materials.

And here, again, as I point out, the reason for the importance of this, if you want to produce accurate results, in your tests, as far as predictions are concerned, then you need to start with your material testing.

This is not only with the maximum acceleration, it would also, how well does your acceleration time history compare to that of the acceleration time history of the actual test itself.

Next slide, please. So in analysis, what kind of things are we looking for? Well, obviously we are going to qualify against a code. But we specify, in the beginning of the design an acceleration basis based upon our experience, 15 year plus worth of designing transportation casks.

And we do that to allow the analysis to be decoupled so that we can proceed in parallel paths. One group will go off and perform stress analysis of the basket and the cask body, the other group will go off and design the actual impact limiter to be tested.

When we do these analyses we make sure that we implode the temperature conditions, both hot and cold, and then in addition to that, to take into account any kind of manufacturing variation, we push the cold properties ten percent higher crush strength, and we take the hot properties, and lower them by 10 percent, to make sure that whatever is covered, as far as manufacturing is concerned, that those, indeed, are covered.

The other thing we do in the analysis, we obviously look at the different drop orientations, the end drop, the corner drop, the side drop. And then, in some cases, we will even look at the slap-down.

Slap-down is a pretty interesting topic, a lot of -- a great deal of studies have been poured into the slap-down shallow angle. When it comes to large casks, which have very small type ratios, length versus radius of gyration, you don't really have a slap-down effect.

And we did a series of analyses to come to that conclusion, as well as we used some drop tests to reach that conclusion. Now, with respect to the scale model, the full scale design, we obviously do it to envelope, the worse case conditions, in terms of crush depths of the impact limiter, as well as the accelerations to the cask body, and the basket will see.

When it comes to the scale model we are in a different track. At this point we are interested in how close can we come to the prediction for the actual drop test. In that case we want to use the best properties we have.

When we specify a temperature, for these we specify approximately 70 degrees for the temperature of these analyses. When we go do the drop test, and just as Doug pointed out, we showed up in the winter to do a 70 degree drop, you obviously have to heat the limiter up.

We showed up again, in the summer, to do a 70 degree drop, and out at Sandia it gets rather warm in the canyon, there, so we had to cool the limiter. So we are very careful of making sure that what we analyze is what we are going to drop test.

Next slide, please. We use the commercially available LS-DYNA code, it is a five element code, but that is where the similarities between that and other codes like NSSS and COSMOS, that is where the similarities end.

It is an explicit code, it accommodates large strain, it accommodates finite rotations, finite displacements. Not all codes can do that very well. And it is a code that was born out of the DYNA code out of Lawrence Livermore, that was described this morning.

This is a rather detailed model, starting here, the impact limiters are modeled explicitly, the shells in the impact limiter are modeled explicitly. Different portions of the wood, which is balsa, those strain rate sensitive properties, we use strain rate sensitive properties, we used a modified foam.

It is called modified because the standard foam model in DYNA does not accommodate strain rate sensitive properties. We accommodate strain rate sensitive properties in the analysis.

When you get down to the details of trunnion, we model the trunnion just as it actually occurs in the design. If you notice the elements don't match up here, the elements don't match up here.

When it comes down to attaching the trunnion to the actual cask body, there is some really -- material code features allow you to more or less weld these two pieces together. Because this region is a fairly rigid region.

And so far as the impact limiter what we do is we specify an interface with it, compression only. So it is allowed to slide. We actually model the bolts themselves, so that we can see if the bolt is going to maintain their integrity during the impact.

And as far as the cask body is concerned, while our full scale design, or quarter scale design too, as far as that goes, would have a steel lead, steel design, what you see are just two elements.

Now, we are very careful to match the frequency content of the full scale steel edged steel, with this here, and we confirm that, but then extract the modes. Now, when you do the perfectional modes it is obvious went into your model, and we go to an ANSIS code like that, which does a very good job of extracting the modes.

Some important issues about the scale modeling I would like to bring up. Whatever material requirements we have for full scale, we employ that for the quarter scale, as well.

However the material is oriented in the full scale design, the same criteria, the same orientation material is used in the quarter scale design. As far as simulated components, the impact limiter, the bolts, whatever we use in the full scale, we make sure that the net threat area is either equal to, or less than, so it is conservative.

Whatever materials are specified for the impact limiter attachment bolts, that are made of highly ductile stainless steel, we make sure the same material is used in those bolts.

Whatever acceptance criteria, in terms of moisture, and density, crush strength, pressure strength, whatever is used in the full scale, we make sure that is used in the quarter scale as well.

So at this point scale model, then, can give us data that allows us to compare to our predictions how much the impact limiter crush, what were the maximum accelerations experienced by the cask body.

Now, the code we are using, this is a confirmatory test, it is important not only to get the numbers, it is also important to understand what is happening in physical phenomena.

And what we found was that no matter how rigid is, the cask body is basically still an elastic body, and you can -- how much weight you can put into your body, next slide please, you are going to get some oscillatory behavior.

Now, we have a great deal of test data, so I just brought a typical curve. The little curve here is the drop test data, and this is the LS-DYNA curve. You notice those are rather smooth curve.

Now, that will give you a clue, real quick, that we are filtering this data. And you say, what is your criteria? Because there was some discussion about that this morning. And that is a very important criteria.

One of the features that you can do in post-processing, with electronic data, is you can perform an FFT. BaSically what you are doing there is looking at acceleration versus the frequency content.

And for every test that we do we examine that FFT to make sure that it is a good test. Accelerometers, there is a great deal of technology in accelerometers. If you notice we shopped around at the different national labs. That is only half the story. We didn't tell you which ones we did look at, and didn't go to.

And so accelerometer technology is not a trivial matter. And even when you get the data you still must carefully examine it. And the FFT is a good way of saying what should the filter frequency should I use?

And one of the questions that the reviewer is always going to ask you, please justify your cutoff frequency. Because I know when you make it lower, it goes away. And there is a reason for that. When you make that filter frequency too low, you are actually cutting out exciting modes in your cask, when you do that, you are actually going to reduce your acceleration.

So we approach it both ways. Before we go out and do the test, we've actually submitted these results to the NRC, because they were curious how, they didn't want us to change the results after we did the test, so we presented to them the results, before we actually went out and did the test.

And so we did a careful examination of our mode extraction to make sure that what we are going to see in the FFT, are we going to see our mode of extraction, we got excellent agreement.

So not only is the -- did we look at the maximum acceleration, we also look at the overall frequency content, as well as the time duration. The thing to keep in mind is, we are looking at, approximately, 180 Gs here, which is 45 in the full scale design.

Actual acceleration used, and the stress evaluation is for 60 Gs. So there is another 30 percent of conservatism before we do anything else.

Next slide, please. So one of the reasons why we conclude that the design is safe is that we feel that there is inherent conservatisms and margin in our design.

One thing to keep in mind is, drop testing uses a rigid surface. Now, you could technically say nothing is rigid in this world, but the amount of elastic energy stored in that pad, there is not enough significant digits to compare to the amount of energy being absorbed in the impact limiter.

We've done a whole series of analyses. When WTC happened last year one of the first things our engineering department did was, let's go analyze a fully loaded 747 crashing into one of the vertical concrete casks.

And we presented those results to the NRC staff last year, and concluded that we would not have a breach of containment.

Some other kind of conservatisms when we do our analyses, we try to concentrate the load in our simplified stress analysis. Now, I say simplified stress analysis, but in reality these are very complex models, with a number of interfaces. So they are not as simple as you would think.

One thing that we noticed, in our force deflection curves, which are easy to compute, you take the mass times the gravity, acceleration of force, you double integrate the acceleration, you get the displacement, you plot, and you get a force deflection curve.

We noticed that we got extra capacity in our displacement. So if we would just take the curve lower, the force over, and you look at the end of the curve, we have 20 to 30 percent more, as a minimum margin, in much of our designs on impact limiter.

So we could take quite a bit more surface from energy reporting if we run into a problem. As far as the stress analyses of the system, if I could point out, the accelerations that we were seeing in the drop test are significantly lower than what we used in the actual design in stress calculations.

The other thing to keep in mind is the analysis used the ASME code, and we elected to use the elastic evaluation in the ASME Code. They do have an appendix that allows you to use elastic behavior. But you just get less questions if you just go with the elastic analysis.

The important thing that you have to realize, when you do an elastic analysis with stainless steel, you completely neglect the ductility of the stainless steel. This is a massive, massive conservatism.

So the acceptance criteria was very conservative. The other thing, too, is that if you notice on that previous curve, there were some oscillations in that acceleration. Now, we didn't filter those out.

And yet when we do our analysis, we take into account another DYNA factor, so in some ways we actually double count in the acceleration. Slide, please.

Continuing on with the inherent conservatisms. In the early '90s we were developing our NAC-STC cask. And that was, as pointed out, that was a quarter scale model. The basket was quarter scale, the shells were quarter scale, the bolts were quarter scale, the pedigree of the materials used everywhere.

We ran into a little problem with our impact limiter because we had done static tests, we were using aluminum shells in order to try to conserve some weight. And when we did the side drop, the aluminum didn't quite keep the correct orientation, so the impact limiters didn't quite work.

As a result the cask body impacted upon this massive steel block in two locations, producing, on the quarter scale model, 1,200 Gs, which is 300 Gs full scale, which is over five and a half times what our design G load.