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NUCLEAR REGULATORY COMMISSION

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NRC STAFF MEETING

WITH STATE OF NEVADA

AGENCY FOR NUCLEAR PROJECTS

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THURSDAY,

MAY 8, 2003

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ROCKVILLE, MARYLAND

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The meeting was held in the Commissioner's Conference Room of NRC Headquarters, One White Flint North, Rockville, Maryland, at 9:00 a.m., Mr. Wayne Hodges presiding.

PRESENT:

HAROLD ADKINS, PNNL

CHRISTOPHER S. BAJWA, SFPO

MERRITT BIRKY, State of Nevada Agency for Nuclear Projects

DARRELL DUNN, CNWRA

ANDRE GARABEDIAN, CNWRA

ROBERT J. HALSTEAD, State of Nevada Agency for Nuclear Projects

M. WAYNE HODGES, Director of Technical Review, SFPO

KEVIN McGRATTAN, NIST

RICHARD C. MOORE, State of Nevada Agency for Nuclear Projects

MARVIN RESNIKOFF

C-O-N-T-E-N-T-S

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

(9:01 a.m.)

MR. BAJWA: All right, I think it's time that we get started. Bob, do you have everyone here?

MR. HALSTEAD: Yes.

MR. BAJWA: Okay.

MR. HALSTEAD: Jamie's not going to join us, right? Yes, we are all here and all of us now in One White Flint as opposed to Two White Flint. We were convening earlier.

MR. BAJWA: All right, well, let's get started. First of all, I'd like to welcome everyone that has come to this meeting, Bob, yourself and representatives from the State of Nevada and consultants as well, members of the public. The purpose of this meeting is to attempt to clearly explain the approach and conduct of the analysis that the NRC undertook in its investigation of the Baltimore Tunnel Fire Event and the impact this event could have had on a selected spent fuel transportation cask.

Bob, obviously, you and I have had several discussions on what we want to get out of this meeting and I think we are agreed as to what we want to get out of this meeting. So we're going to try our best to make sure that you all receive what you would like in the way of getting your questions answered.

The first thing I'd like to do is to do some introductions. We'll go around the table and do those and then I'll have a few things to say about ground rules for this meeting. We'll go quickly through the agenda and then there are a few other issues that I'll need to mention before we get to the presentations. So, we'll start with Wayne.

MR. HODGES: I'm Wayne Hodges. I'm the Deputy Director for Technical Review in the Spent Fuel Project Office.

MR. BAJWA: I'm Chris Bajwa. I am a Thermal Reviewer in the Spent Fuel Project Office.

DR. McGRATTAN: My name is Kevin McGrattan. I work with the National Institute for Standards and Technology.

MR. ADKINS: My name is Harold Adkins and I work for PNNL, Thermal Analyst.

MR. GARABEDIAN: My name is Andre Garabedian. I'm a Fire Protection Engineer at Southwest Research Institute.

MR. DUNN: Darrell Dunn, Center for Nuclear Waste, Regulatory Analysis.

MR. HALL: Jim Hall. I'm a Consultant

with the State of Nevada.

MR. RESNIKOFF: Marvin Resnikoff for the State of Nevada.

MR. HALSTEAD: Bob Halstead, I'm a Transportation Advisor for the State of Nevada's Agency for Nuclear Projects.

MR. MOORE: Rick Moore, Pronghorn (ph) Engineering, Consultant for Nevada.

MR. BIRKY: Merritt Birky, Consultant for the State of Nevada.

MR. BAJWA: All right, as you know, this meeting is being transcribed, so when you do make a statement, please make sure you're speaking clearly into the microphone and that way we make sure that exactly what you say gets taken down. Just some ground rules for the meeting; each of the speakers that we have presenting today have prepared presentations on their role in our analysis effort and they've provided a great deal of detail in the slides that you have in front of you.

What I'll ask is that if you have questions during a presentation, if they're of a clarification nature, go ahead and ask them. Otherwise I would ask that you would hold more detailed questions till the end of the presentation.

Each presentation will be followed by a question and answer time, so you'll have time to ask the questions. What we'll do to make sure that we can facilitate that is one of the practices we have in our public meetings, if you have a question that you would like to ask at the end of the presentation, just take your name tent and do that. Okay?

I know it's only a few of us here but that way we can make sure that we get to everyone's question at the end of each presentation. The members of the public that have attended today will have a chance to provide comments or questions at the end of the meeting and to be sure that all the questions from the public are heard and answered, the staff who is presenting today is prepared to stay over the allotted time that we have for the meeting to answer questions, if necessary. To this end, we would ask that the questions following the presentations come only from the participants seated at the table, and then if the public has questions on individual presentations, they hold those until we're done with the meeting.

All right, what I'd like to do is just quickly run through the agenda. First of all, we'll have Wayne give some opening remarks and then I will give an overview of the NRC analysis effort, what each felt and then we'll have any questions on the general overview. Dr. Kevin McGrattan from NIST will talk about the Howard Street Tunnel Fire Simulations and we'll have questions after that. Andre Garabedian and Darrell Dunn will talk about the Analysis of Rail Car Components Exposed to a Tunnel Fire Environment and again we'll have questions.

Depending on time, if we feel we need a break and have time to take one, we will do that. I have a feeling we probably will need to take a break at some point. Then following the break, we'll have Harold Adkins from PNNL talk about the Baltimore Tunnel Evaluation. That was a cask analysis that they did for us and we'll have questions on that. And then finally, we'll have any discussion and comments or questions from the public. And then that will conclude the meeting with some closing remarks. So that is the agenda.

What we're going to also have is a parking lot and the parking lot is to serve for any issues that are not directly related to what we're trying to discuss here or that may involve a very lengthy discussion. We'll put those issues in the parking lot for further consideration, if time allows, and in order for the staff to have a record of those other issues that have been raised during this meeting.

One of the issues that has been mentioned is the Package Performance Study. And obviously there is somewhat of a link between what we did in the Baltimore Tunnel Fire Analysis and certain considerations for the package performance study but we're not here to directly discuss the package performance study.

Like I said, this meeting will be transcribed, so I would ask to that end if when you speak the first time, you just give your name and affiliation and that way we'll make sure that we get that on the record. In addition, for continuity of the transcript, it is preferred that if you can hold your questions till the end, you do that and that way you won't lose that stream of consciousness, so to speak, in the transcript when you go back to review it.

Finally, we do have, for the members of the public and for the participants in the meeting, public meeting, feedback forms. They are over there on the table. You probably got one if you -- when you came in. If you didn't, please pick one up before you leave. You can fill those out and leave them with us or you can fill those out and send them in at a later time. These forms will give us feedback on how we conducted the meeting, if you found it was useful or not useful and it helps us for the future to make these meetings a little bit better.

So what I'll do now is, I'll have Wayne give some opening remarks and then we'll get on with the presentations.

MR. HODGES: I'm Wayne Hodges with the Spent Fuel Project Office. The emphasis for the analysis that will be described was once the fire occurred, we had a number of questions, some from the Congress, saying what would happen to a spent fuel transportation package in that fire. The fire was not instrumented unfortunately. Therefore, we don't have much data. We did follow up with the NTSB and their investigation to learn as much as we could from them.

It became clear at one point that what we needed to do if we was going to understand the time, temperature, history of the fire was to try to get an analysis done that -- because NTSB was not going to be doing that. We -- in discussions with NTSB, we selected NIST to do this analysis for us, to try to give us their best estimate of what the fire conditions were. They used the calibration from the tunnel fire that had been used as a test in a West

Virginia Tunnel to benchmark our code. And during the process of doing the analysis it also dawned us that it might be helpful to get some independent corroboration for their calculations since there are no data and that's when we asked the Center, who has a number of fire experts, if they would take a look at some samples from the rail cars actually involved in the fire and see what we could learn from some metallurgical examinations, paint examinations, as far as temperatures at various points in the fire as an independent corroboration of what we were seeing.

So it was done totally independently and the reports were issued independently and we think, although there's not exact agreement, there is reasonable agreement between some of what the results show and the calculations. So even though there were no thermal couples in the fire to tell us what happened, we think what we have is a reasonable estimate of the fire conditions and we use that then as a boundary condition for the cash when we did those calculations.

So what we believe we've done is as reasonable an estimate as you can do and an independent verification as you can do given lack of specific data and I think it's a very good analysis.

And with that, I'll turn it over to the analysts.

MR. BAJWA: I'm going to go into a little bit more detail about how we structured our analysis approach and to do that, I'm going to move to the podium.

MR. BIRKY: Chris, while you're doing that, Merritt Birky with State of Nevada, can I ask a question. I see there are video cameras. Are those on or off?

MR. BAJWA: I believe they're off. This is not being video taped.

Okay, in the interest of trying to keep this meeting as working level as possible, I'm already a little bit warm, so I'm going to remove my jacket. Anyone else at the table, feel free to do that. Wayne has already given a pretty good summary of what our actions were related to the Baltimore Tunnel Fire Event. We were asked by the Commission to look at this event and conduct an investigation of it and come up with a reasonable answer as to how this event might effect a spent fuel transportation cask.

Obviously, this is a major concern. The Baltimore Tunnel Fire Event was a severe fire event and it's something that we felt we had a responsibility to look at. The first step to this approach was to gather factual information, as much as we could, as much as was available from the National Transportation Safety Board. We did meet with them several times to discuss details of the accident and their investigation, I believe, is -- has been wrapped up but they are still in the process of putting together all the factual reports and then putting out the final report on the accident.

The other -- the next step in the analysis was to model the fire that occurred in the Howard Street Tunnel. We didn't have a lot of good data, obviously, as Wayne mentioned, on the accident fires, so we decided that modeling it would be a good approach to characterizing what it might have been like. We wanted to verify that fire model with some of the physical evidence that was available from the tunnel and the final step was to analyze the spent fuel cask response to the fire that we modeled.

The fire model was done by NIST using the fire dynamic simulator, which is their fire simulation code. Dr. Kevin McGrattan will talk about in more detail what they did to put that model together. The physical evidence from the tunnel was examined and analyzed by the Center for Nuclear Waste Regulatory Analysis and Andre Garabedian and Darrell Dunn will talk about the work that was done there on looking at the materials that actually came out of the tunnel. The thermal analysis model that was put together for an actual spent fuel transportation cask was done by PNNL, Pacific Northwest National Labs, and Harold Adkins will talk about the analysis model that he put together for that investigation.

Some of the conclusions probably you already know because there have been several presentations in the past about this particular analysis and some of the work that we've done in it. We believe that the analyses that were completed included conservative and bounding assumptions and we will obviously, talk about those in the presentations today. Our conclusion on the work -- from the work that we've done to this point is that exposure of this particular transportation task to the Baltimore Tunnel Fire or a similar fire would not result in a radioactive release to the environment. That was our conclusion.

One of the things that came out of this analysis was the robust nature of these types of spent fuel casks. And now we'll have Kevin McGrattan speak and as he's coming up, I'll introduce him. Yes, I'm sorry, I'll take any questions you have now and then we'll bring Kevin up.

MR. BIRKY: Merritt Birky, I have a -- sort of a basic question that perhaps you can answer either now or as we progress during the meeting. And my question is related to the regulation that specifies the temperature and duration, the I think 850 C, 30 minutes. And the question is, what is the rationale for selecting those parameters as a regulatory performance of a cask?

MR. HODGES: I think that's an issue separate from what we're here to discuss. That's something we can put in the parking lot and if there's time at the end, we'll be happy to discuss that, but the meeting today is to discuss the analysis for the Baltimore Tunnel Fire and those results.

MR. BIRKY: Okay, I accept that. My only concern is that everything is benchmarked to that and I just want to put that on the record. And I understand that.

MR. HODGES: This fire was not benchmarked to that. The analysis -- this analysis was done independent of that. We're here today to talk about the Baltimore Tunnel Fire and the analysis and results for that. To the extent we have time at the end, I'll be happy to talk to you about the regulatory limits and how they were arrived at, but that's independent from today's presentation.

MR. BAJWA: Yes.

MR. MOORE: Rick Moore. Chris, is anyone going to talk about reconstruction of the events that led to the accident or is it best to ask you those?

MR. BAJWA: Probably. Yeah, we didn't have a specific presentation on reconstruction of events. That is strictly an NTSB function. What they did determine from the investigation that they did was that the derailment preceded the fire. The derailment that occurred in the Howard Street Tunnel happened. It was 11 out of the 60 cars that were going through the tunnel at the time that derailed and the fire started some time after the derailment. So do you have a specific question about --

MR. MOORE: Yes, is there any information on the operating speed of the train at the time of derailment?

MR. BAJWA: There is. I believe it was in the neighborhood of 30 miles per hour but I do not know that for sure. I can make sure I get the right number for you.

MR. MOORE: And is there a speed limit on the tunnel?

MR. BAJWA: That I don't know for sure but I will find that out for you.

MR. MOORE: The reason I'm asking those questions is because of the assumption that the cask would be a certain distance from the fire and depending upon the speed of the train and the nature of the derailment, you could have the accordion effect of cars stacking up against each other and ending up with the cask a lot closer to the fire even given that there was a buffer car.

MR. BAJWA: Yeah.

MR. MOORE: So that's what I'm trying to get to, whether there's answers by panel members today.

MR. BAJWA: For this particular tunnel, it's a single rail tunnel and the geometry actually will be discussed a little bit later. The actual geometry of the tunnel, for this particular tunnel, would prevent that stacking up or accordioning, you know, accordion effect of cars. You really -- you also see on one of the hand-outs the derailment sketch that shows the configuration of the cars after the derailment. So they didn't move a whole lot.

MR. MOORE: Right, I recognize that, but the analysis is tending to conclude the performance of the cask under fire conditions, and I think we have to recognize that there are double-track tunnels in other parts of the country, so it doesn't preclude the stacking up of cars.

MR. BAJWA: In other situations.

MR. MOORE: Correct.

MR. HALSTEAD: Yes, I want to clarify one of the purposes of the meeting for us. Bob Halstead for the transcriber. In addition to discussing the analysis of what actually occurred in the tunnel, we're very concerned about what we believe are unjustifiably sweeping generalizations about the adequacy of the regulations for a range of fires, a range of casks that might be involved in rail fires. I think I'm going to save those comments for the end, but Rick's point about the assumptions about train dynamics is a good example that there are issues both of what happened in the Baltimore fire and what assumptions we can make about the way the Baltimore fire is or is not the maximum reasonably foreseeable accident that we're concerned about for risk assessment purposes. So I just wanted to clarify that in the beginning.

MR. BAJWA: Okay, I'd like to bring up Kevin.

DR. McGRATTAN: Okay, good morning.

MR. BAJWA: Before Kevin begins, Dr. Kevin McGrattan is a mathematician at the Building and Fire Research Laboratory at NIST, Standards and Technology. He is a specialist in fire modeling, computational fluid dynamics and was recently awarded an honorary membership in the Society of Fire Protection Engineers.

DR. McGRATTAN: Thanks, Chris. One of the core missions of my laboratory is to develop fire models and these fire models are used by fire protection engineers for a number of purposes. And in this first slide, you can see just a snapshot of a few of the projects that we've worked on over the years to give you a sense of what fire modeling is all about. We look at everything from the basics of fire dynamics, single fire in a plume that you see on the left, all the way up to very complicated situations where you have, for example, commodities of various types stored in a warehouse. We've looked at oil fires on large tanks, and we've looked at special things like for example, in the upper right-hand corner this project was done for the Library of Congress and they were retrofitting their sprinkler system and they wanted to know where the best location for their sprinklers should be. So this just gives you an idea of the type of work that we do with fire models.

Now, a little bit of specifics about the fire dynamics simulator in particular. This is a computational fluid dynamics model that has been under development for the last 20 years at NIST and in the last four years we have released this model into the public domain. So this model is now widely used by fire protection engineers both in the U.S. and around the world. Now, with all of the projects we work on, we like to make sure that the model works. I mean, theoretically, we're simply solving the conservation equations of mass momentum and energy but, of course, we make assumptions and approximations when we solve these equations with the computer. So we need to validate that these assumptions that we're making are appropriate for the given situation.

So we're constantly running the model against experiments in which measurements have been taken. This is just an example of a recent set of -- a recent validation exercise that we're doing for our World Trade Center investigation. What you have is just a box that's roughly 12 feet high, 20 feet long and 12 feet wide with some holes at either end and a large fire in the middle, okay, and a vast number of measurements were made not only of the temperatures, but heat fluxes to the various objects in the room, most important of which are the truss hanging from the ceiling.

You can see in the lower right-hand corner, the comparison of the numerical model with the experiment and in this case, we get very good agreement because we know exactly what the fire source is. We know exactly what the geometry of the room is. We know exactly what the fire size is. So we verify here that the model works, that our equations are valid, et cetera.

MR. RESNIKOFF: Chris, excuse me, could I just ask you one question of a --

DR. McGRATTAN: Sure.

MR. RESNIKOFF: -- I don't know, informative nature? Do they actually run a fire test before they built the World Trade Center? Did they actually run a model?

DR. McGRATTAN: Before they built the World Trade Center?

MR. RESNIKOFF: Exactly.

DR. McGRATTAN: I can't say. I don't recall.

Okay, now, when we took on the project that Chris described this morning, of predicting what temperatures were like in the Baltimore Tunnel accident, the first thing we did was we wanted to validate our model with the best set of data available involving a tunnel fire. And this data was collected in the mid-1990's in a decommissioned highway tunnel in West Virginia. This study was sponsored by the State of Massachusetts because in preparation for the Big Dig in Boston, they wanted to see what their ventilation systems in their tunnels were going to -- how they were going to perform in the event of a fire.

So we took this opportunity to use the data collected in some experiments to validate our fire model for use in the Howard Street accident. The tunnel in West Virginia known as the Memorial Tunnel, is very similar in cross section to the Howard Street Tunnel. And the two tests that we were most interested in were tests with no ventilation present. One test was a 20 megawatt fire and one test was a 50 megawatt fire. And for those of you aren't ready to think about fire energy output, a 50 megawatt fire would be roughly comparable to a house fire.

Okay, when we compared our calculations against the experimental measurements, we got very good agreement. We were within 50 degrees Celsius of the peak temperatures on both cases, both the 20 and the 50 megawatt case. In the case of the 50 megawatt case, which is a more appropriate situation in comparing with the Howard Street Tunnel, the peak temperatures that they recorded were 800 degrees C or 1500 degrees Fahrenheit.

Okay, so once we had confirmed that our model was working well for the West Virginia Tunnel experiments, we then took our model and we applied it to the Howard Street Tunnel fire and like I said, the tunnels are similar in cross-sectional area. However, the Howard Street Tunnel is longer but less sloped. The West Virginia Tunnel had a two and a half percent grade. Howard Street Tunnel had about a .8 percent grade.

I think you have a handout which shows the basic layout of the train derailment. This information was provided to us by the NTSB and we used as much as we could of the information that they provided about the accident in setting up our numerical calculations, including the position of the rail cars relative to the side walls of the tunnel. Shown here is just a snapshot of one of the calculations in which we're assuming a certain pool size, that is, we're assuming that the liquid spilled from the tripropylene car formed a pool of a given size, burned, and what you see here in orange would represent the flaming region and that's all I'm showing at the moment, just the flaming region and the red and green objects would represent the rail cars within the pool. Now, it's important in a study like this to vary as many of the parameters as you can because we simply did not know how big the pool size was. We knew how big the hole in the tank car was, okay, and we could estimate based on the hole size how quickly the fuel was spilling out. However, because the floor of the tunnel was filled with track, ballast, several drains, and the tunnel was sloped, it's hard to know precisely how big the fire bed or the fuel bed was.

So we ran dozens of calculations in which we varied the size of the fuel bed, the location of the fire, the properties of the walls, and to some extent the ventilation into the tunnel. What you see here are just a few snapshots of results and keep in mind that this is just one set of results. We ran dozens of calculations and the temperatures that we ultimately reported to the NRC represented the highest temperatures that were achieved in the various calculations.

So the top two slices, these are slices through the middle of the tunnel from the ceiling to the floor. The fire is obviously where you see the high temperatures. And in this case, what we noticed time after time in these calculations that in the beginning of the calculations, say the first five or 10 minutes, when the tunnel has enough oxygen to sustain a robust fire, we see the highest temperatures early on. So these -- the peak temperatures of 1800 degrees Fahrenheit or 1,000 degrees Centigrade, are achieved early on in these calculations and over time, what happens is the tunnel becomes oxygen limited.

So what happens is because the fresh air to feed the fire has to come from the ends of the tunnel, the tunnel becomes filled with hot gases and exhaust products from the fire, so what eventually starts happening is the fire starts to be fed by not fresh air, but air and exhaust products mixed together. Okay, that tends to weaken the fire. It doesn't put the fire out, obviously, but the highest temperatures are no longer achieved after the first five or 10 minutes.

You can also see from the lower picture if you look at the oxygen concentration, down the middle of the tunnel, okay, early on the red color in these pictures represents ambient oxygen, 21 percent oxygen concentration, and over time you can see how the oxygen concentration has been reduced to on the order of 14 or 15 percent and this is the type of concentration where fires begin to get under-ventilated.

MR. BIRKY: For clarification on your graph --

DR. McGRATTAN: Yes.

MR. BIRKY: -- a clarification on this graph you have shown here, I assume time is going down this plot?

DR. McGRATTAN: Right. For each pair of snapshots, the first image is from five minutes after ignition, the second is from 30 minutes after ignition. So, you're right, it's five minutes, 30 minutes, then five minutes, 30 minutes, five minutes.

MR. BIRKY: This is five minutes up here?

DR. McGRATTAN: Five minutes.

MR. BIRKY: And this is 30 down here?

DR. McGRATTAN: No, I'm sorry. The first two are temperature.

MR. BIRKY: Yes.

DR. McGRATTAN: Okay, so the first one is temperature after five minutes. The second one is temperature after 30 minutes. Then going down, the third one would be oxygen after five minutes and then the fourth on is oxygen after 30 minutes. And the range of values for the colors are shown by the bars on the left and the right.

So the oxygen concentrations are shown on the left and the temperatures on the right.

MR. BIRKY: I'm sorry, I'm confused. Do you have a pointer you could point to when you say this is --

DR. McGRATTAN: Okay, this is the temperature after five minutes. This is the temperature after 30 minutes. This is the oxygen concentration after five minutes. This is the oxygen concentration after 30 minutes.

MR. BIRKY: I gotcha.

DR. McGRATTAN: These two bars tell you what the temperatures are for these two plots. This bar here gives you the oxygen concentration for these two plots. Sorry, it's a little busy but I tried to pack it all onto one slide.

Keep in mind, when we run these calculations, we generate hundreds of pictures like this and this is just a representative sample.

MR. HALSTEAD: And just another clarification; this is based on -- this is benchmarked from the two 15-minutes fires that were done in 1995/1996 in Massachusetts?

DR. McGRATTAN: Right, the same code was used for these calculations as was done for the bench marking exercise.

MR. HALSTEAD: And has anybody -- have you or anyone else run any fires longer than those 15-minute fires for benchmarking purposes?

DR. McGRATTAN: Yes, for the -- I'm sorry, for benchmarking purposes?

MR. HALSTEAD: For benchmarking purposes.

DR. McGRATTAN: No, we don't have any -- we don't have any data longer than 15 minutes.

MR. HALSTEAD: Okay, well, that's an important point for us to establish here that, in fact, -- that, in fact, all of your modeling is based on a somewhat limited amount of tunnel fire testing, experimental testing.

DR. McGRATTAN: Right.

MR. BIRKY: May I pursue that just a little bit? Does that mean the 30-minute data you have in this, this particular slide, is basically an extrapolation from the 20 -- 15-minute data?

DR. McGRATTAN: No.

MR. BIRKY: No?

DR. McGRATTAN: We simply used the West Virginia experiments to insure that our model was working properly.

MR. BIRKY: For 15 minutes.

DR. McGRATTAN: Well, we could only say for 15 minutes because the data was only collected for 15 minutes.

MR. BIRKY: All right, that's what I wanted to establish, okay.

DR. McGRATTAN: But one of the things about this type of model is that we're essentially solving the conservation laws of mass momentum and energy. So we have to make an assumption when we do our modeling that we can validate for a certain period of time, but we're assuming that the equations, the laws of physics are appropriate for all time.

MR. BIRKY: But did the Howard Street Tunnel have oxygen limitations in their calculations as well, in the experiments?

DR. McGRATTAN: In the experiments, no, because they tunnel was sloped more steeply than the Howard Street Tunnel. What they found was they had adequate circulation coming in from one side. So they had uni-directional flow coming into the tunnel towards the upper end. So those fires were not oxygen limited.

MR. HODGES: Kevin, this is Wayne Hodges, just a point of clarification as follow-up to that question; have you analyzed other fires that were oxygen limited and compared an analysis with this data?

DR. McGRATTAN: The experiment that I showed in the beginning for our World Trade Center investigation, those are oxygen limited fires. That's one of the key issues with the World Trade Center investigation is the oxygen limitations in the building.

MR. HALSTEAD: While we're on these kind of issues, let me throw one more in. How does FDS input a fuel evaporation rate versus time, because that's also important to this analysis? My understanding is that you -- that the West Virginia experiments, you know, you basically got to round that by calculating the surface area of the pans that were used but how significant is that in a case like this where you're talking about liquid dripping from a tanker, not knowing what happens on the floor of the tunnel with the coarse media.

DR. McGRATTAN: In the West Virginia case we were told what the heat release rates were based on the mass loss of the fuel so we essentially dialed in those heat release rates in our calculations. In the case of the Howard Street Tunnel fires, what we did is we let the fuel evaporate based no a Clausius-Clapyron type algorithm in the code. So based on the heat flux to the floor, we would evaporate the fuel naturally.

Now, like I said, we varied the size of the pool dramatically from very small to very large and what we found in the end was that we could only achieve about a 50 or 60 megawatt fire in that tunnel which means that the fire was oxygen limited, not fuel limited, so it didn't matter how much fuel we pumped into it. It was only so much energy output we could get based on the amount of oxygen coming into the tunnel. So we -- that was the one parameter that we varied the most because that's something that we were most uncertain about, the nature of the fuel pool.

Okay, I just have one slide to finish up. So in the end, we found for the dozens of calculations that we performed for the Howard Street Tunnel fire accident, we found peak temperatures of 1,000 degrees C or 1800 degrees Fahrenheit in the flaming regions, and by the flaming regions, I'm talking about essentially where you see the reds in the pictures on the top and over the length of a few rail cars, the temperatures were on average 500 degrees C or 900 degrees Fahrenheit. Peak wall temperatures we saw were 800 degrees C or 1500 degrees Fahrenheit where the fire was directly impinging on the walls. And elsewhere, we saw temperatures of on an average 400 degrees C or 750 degrees Fahrenheit.

Now, of course, when I say we saw a certain temperature here and a certain temperature there, clearly from the hottest regions, the temperatures would decrease gradually over distance but when we averaged things out, the 500 C for the gas and the 400 C for the walls were sort of the average temperatures. And like I said, one of the things that we spent a lot of time doing was varying the parameters in these calculations to make sure that we bounded the results in an appropriate way and of course, for his work, Chris chose the large -- the highest temperatures for the cask analysis.

Okay, thank you and I'll take any further questions if you have any. Yeah.

MR. RESNIKOFF: Kevin, I have your name right this time. I notice that the Center study said that an air brake valve under the tripropylene car about 10 meters up wind from the fire reached a fused -- an aluminum alloy -- aluminum iron alloy at 2667 degrees Fahrenheit. How does your study -- is your study consistent with that temperature?

DR. McGRATTAN: We didn't see temperatures that high in our study and I'm skeptical that you could achieve those kinds of temperatures in a fire like this. Based on my fire testing over 10 years, I've never seen those high temperatures in a fire test like this one.

MR. RESNIKOFF: Well, let me ask you one other question as a follow-up. If the fire were not oxygen deprived, what would be the maximum temperature?

DR. McGRATTAN: We did some follow-up calculations after this report in which we simply opened up a large number of holes in the tunnel and there our temperatures, instead of 1,000 degrees, we bumped up the temperatures about 1100 degrees C --

MR. RESNIKOFF: But that's the max that --

DR. McGRATTAN: -- Fahrenheit and that's all we saw, yeah.

MR. BIRKY: That's without any oxygen depletion.

DR. McGRATTAN: Right, so that's typical

free burn type conditions and that is not inconsistent with many fire tests. In fact, if you'll look at the standard furnace test for structural material in buildings, you'll see 1100 degrees C used in the E119 test. So 1,000 degrees C, I think for the Baltimore Tunnel case because of the oxygen limitations, 1100 degrees if we were to simply open up that tunnel. Again, our objective in this study was to study the Baltimore Tunnel and that's what we did.

MR. RESNIKOFF: I understand. Are you talking about the flame temperature, just so we're all on the same page here? The maximum flame temperature is 1100 degrees C?

DR. McGRATTAN: This is a subtlety. Maximum flame temperatures as in an adiabatic flame temperature, could conceivably be much higher than these numbers that I'm quoting. However, these numbers are never achieved in large scale tests because the flame is not stationary. So as the flame moves back and forth, you can never achieve these ideal flame temperatures. Plus there's a tremendous amount of radiative loss when you have a very large sooty fire. So those maximum theoretical flame temperatures are reduced for two reasons. One is the large radiative loss and the other is the fact that these are turbulent fires.

So the flame is rarely anchored in one place but it moves about and as the flame moves about, you average out over a certain volume those maximum temperatures.

MR. RESNIKOFF: One final question on a slightly different subject, did you model it just for three hours or did you also look at the temperature of the tunnel as the brick and the ballast reradiated the heat?

DR. McGRATTAN: Right. We noticed in our calculations and we've noticed this for many other studies, that after about half an hour of simulation, the gas and wall temperatures come to a steady state. Now, again, subsequently after these calculations for the Howard Street Tunnel, Chris and I, along with Harold, did calculations in which we simulated 30 hours in the tunnel, seven hours burning and then the rest of the time being the -- what was the -- actually, what was the --

MR. ADKINS: It was seven hours burning.

DR. McGRATTAN: Seven hours burning and then --

MR. ADKINS: Three hours cool-down.

DR. McGRATTAN: Okay, so it was a 30-hour simulation with the seven hours burning and then --

MR. ADKINS: And then there was one that we did seven and 26.

DR. McGRATTAN: And this was to answer the question what if the water main had not broken because there's been a lot of discussion about the fact that in the Howard Street case the water main broke and after three hours, I think, the fire was dramatically weakened by the presence of the water. So we went on, subsequently, and said, well, what if the water main hadn't broken and what if there was more ventilation in the tunnel to see how much hotter we could get it.

MR. RESNIKOFF: Has that been written up anywhere and could we get a copy?

DR. McGRATTAN: It hasn't -- my part of it hasn't been written up but we could write that up.

MR. BAJWA: Eventually, the results of the initial analysis that we did will be documented and that will be available, so as soon as that becomes available, I will make sure that you all get copies of that.

MR. HALSTEAD: Kevin, I'm looking at the conclusions on page 28 of the NIST report, NIST IR6902, and I'm trying to summarize based on your conclusions what the worst case fire within a five to

10 meter region would have been and when I look at your conclusions and it seems to me that they would support an interpretation that if we were trying to translate that into an engulfing fire, which is what we look at for cask performance, that your analysis supports a conclusion, first, that the worst case fire in that five to 10 would be three hours at 1,000 degrees C. Is that a reasonable conclusion to draw from your conclusion on page 28?

DR. McGRATTAN: Where are you drawing from that?

MR. HALSTEAD: Well, it says, "The peak calculated temperatures within the tunnel during the first three hours (before the water main rupture) were approximately 1,000 degrees C (1800 degrees Fahrenheit) within the flaming regions or about half the length of a rail car and approximately 500 degrees C or 900 degrees Fahrenheit when averaged over the length of the tunnel equaled to the length of three or four rail cars". And I'm going to get to that past three hours and path regions in a minute.

DR. McGRATTAN: The term "peak" refers to both space and time.

MR. HALSTEAD: That's right.

DR. McGRATTAN: So we hit the peaks early on but that doesn't necessarily mean that those temperatures would be sustained for three hours. It would be on the conservative side.

MR. HALSTEAD: Well, are you prepared to say that that -- that a three-hour fire could not have averaged that temperature? That's what we're trying to ascertain here. What's your bottom line for helping us determine what fire we need to subject a cask to, to validate this performance?

DR. McGRATTAN: Right, right, since no ventilation studies were done on the tunnel, we can't say for certain how much air was reaching that fire because a tunnel like this has many cracks and crevices, okay. In our analysis, we assumed that the air was coming in from the portals but that doesn't necessarily mean that air couldn't be coming in from some other place to sustain the fire at the 1,000 degrees longer. So what we're saying is that peak temperatures could be 1,000 degrees during the flaming period of the fire.

MR. HALSTEAD: And that could be three hours.

DR. McGRATTAN: Yes.

MR. HALSTEAD: So what we're trying to do here is understanding that the train was not properly instrumented for our purposes, is to try and figure out what the worst case averaged over three hours would be.

DR. McGRATTAN: Well, it was stated in the beginning that this accident may not be considered the worst case.

MR. HALSTEAD: No, I understand that and in fact, as we have studied this accident more, I think that's one of the conclusions that we've come to and understand when we did our preliminary analysis of the fire in September 2001 which Dr. Resnikoff and Matt Lamb worked on, of course, we didn't have the benefit either of the NTSB findings or your modeling and actually, I think a lot of our assumptions frankly, are not that different from yours because now then I want to turn to the next three hours of the fire. It's difficult because of the water main burst to know what happened, but it certainly seems reasonable -- let me strike that.

Does it seem reasonable to you to assume that after that three-hour peak fire at 1,000 degrees C, we might have had a continual burning for up to three or four hours in the range of 500 to 800 degrees C and understand we probably can't be much more precise than that?

DR. McGRATTAN: It all depends on how much fuel is available and how much oxygen is available.

MR. HALSTEAD: Well, no --

DR. McGRATTAN: And we know in this case how much fuel was available to start with. We don't know exactly how much of that fuel ran down the hill, ran into drains, et cetera. And we don't know exactly how much oxygen was available for that fire.

MR. HALSTEAD: Let me rephrase this and ask you, if I said based on your study, that I thought a reasonable worst case characterization of what happened in the Baltimore Tunnel within the five to 10 meter flaming region closest -- region closest to the fire, that a three-hour fire at 1,000 degrees C followed by three to four hours at 500 to 800 degrees C probably represents the worst fire that could have occurred given the facts that we have in hand. Would you say that that's an accurate characterization or is it possible that something of higher temperature and higher duration should be assumed?

DR. McGRATTAN: Well, it's difficult to use the term "worst case" when there are so many uncertainties.

MR. HALSTEAD: Okay, maximum credible event given the particular scenario --the particular accident that we are talking about here. I realize worst case is a very vague phrase. But given what you know about this fire --

DR. McGRATTAN: It is conceivable right --

MR. HALSTEAD: -- what is the worst thing that could have happened in the Baltimore fire averaging time and temperature in a way that allows us to look at the regulatory standard?

DR. McGRATTAN: If I have to say it's dangerous. If there was more ventilation into that tunnel, if the fuel was confined within a container of some sort, that would lead to a longer robust fire simply because it would have more oxygen and the fuel would be contained so that it could burn down rather than just, you know, wash down the drain. So there are scenarios that would be more hazardous than what actually occurred.

But it's hard to speculate, you know, on these scenarios.

MR. BAJWA: I'm going to have to interject.

MR. RESNIKOFF: I have a quick question if I could.

MR. BAJWA: Okay, go ahead and then I have a statement and then we need to move on.

MR. RESNIKOFF: Maybe this should be directed to NTSB but do you have a theory as to why the water main broke, that is to say what thermal forces existed at the roof of the tunnel?

DR. McGRATTAN: My expertise is not in metallurgy, so I'm not going to --

MR. HODGES: I think you're right. That should probably be directed to NTSB.

MR. BAJWA: One thing I think we all need to keep in mind here, Bob, when you're saying a three-hour fire at 1,000 degrees C, do you mean an average temperature of 1,000 degrees C or do you mean a peak temperature of 1,000 degrees C?

MR. HALSTEAD: I'm trying to take the admittedly speculative analysis of a real world fire and translate it into a fire environment that those of us who have worked on cask performance are more familiar with. And while I don't want to have to parking lot this issue by mentioning a package performance study, obviously the reason that we are doing such a careful analysis of this fire at this particular point in time, is because we need to give the NRC our best advice on what type of engulfing fire might be used in a cask test to replicate the worst conditions that we think occurred in the Baltimore fire.

MR. HODGES: One thing to bear in mind, I believe, is that you still have to have a source of oxygen coming into the fire and that's generally -- whether it's this tunnel fire or another tunnel fire, you're going to have some regions that are cooler than in others. You're going to have peak temperatures near the top of the tunnel, which is what we're talking about. You're going to have areas that are cooler and so to try to say you should have a fully engulfing fire at that very peak temperature does not make sense for this kind of a fire.

MR. HALSTEAD: Well, first of all, I would dispute some of your assumptions. I think given the configuration and size of the tunnel, it's very possible that you could have a train pile-up in which the lid end of a rail cask is within the five to 10 -- I would say within five meters of the hottest zone of the fire and it could be that it's upright like this towards the ceiling. So I think we need to be careful here about how many assumptions we make about what could or couldn't have been and that's why I've carefully stated this to say if I'm trying to replicate the worst type of thermal environment that a cask could be subjected to for the purpose of designing a test that replicates the worst conditions that could have been in this fire, because it goes to the question, Kevin, maybe this isn't the worst case fire that we want to think about for cask performance and that my thinking has evolved a lot on that over the last couple of years particularly because we've studied some other real world fires that may, in fact, created more severe conditions and those were fires that were located along rail lines that are potential shipping routes either to Yucca Mountain or to Skull Valley.

So the issue here is simply trying to take you conclusions on page 28 and it seems to me that we're agreed that it's unlikely that there could have been a sustained three-hour fire averaging temperatures greater than 1,000 degrees C. Now, the question of whether that is an accurate replication of what actually happened is one thing, but if I'm looking at this for the purposes of a bounding scenario and I understand your -- and I appreciate your qualification that if there's more oxygen, in fact, the temperatures could have been higher, but that's an area of speculation that I think would be hard for us to support.

DR. McGRATTAN: But the original question was, could they get up to 24 or 2600 degrees Fahrenheit and I still don't believe that.

MR. HALSTEAD: Well, this was Marvin's question.

DR. McGRATTAN: Okay, we see temperatures -- even for open large pits of oil burning, you still don't see temperatures higher than about 1,000 degrees C or 1800 degrees to 2,000 degrees Fahrenheit. And now, it's just a question of duration and of course, if you simply have enough fuel outdoors, you can sustain a fire for as long as you want.

MR. BAJWA: Bob, the reason I asked the question is because in the five to 10 meter region surrounding the fire, I just don't want anyone to get the impression that the average temperature was 1,000 degrees C because for five to 10, you know, meters around the fire, it -- from what we analyzed and from what we generally know about pool fires, it wouldn't be that high. The average temperature would not be that high for either this fire in the tunnel or even a pool fire.

MR. HALSTEAD: Do you want to venture a speculation as to what that average temperature might be, what the range would be?

MR. BAJWA: Well, if it's a hydrocarbon

fire, the average temperature is around 800 C and that's probably part of the reason why the regulations are at 800 degrees C.

MR. BAJWA: Yes, Merritt needs to ask a question about the radiation and then we're ready to move on.

MR. BIRKY: Can I ask one quick question? You mentioned that you had done some calculations beyond this 30-minute period or beyond the three hours, I think, we're talking about. Can you give us some feel for how that temperature decays because of the radiation from the walls and that sort of thing? Does it stay high for many, many hours and how high?

DR. McGRATTAN: After the fire goes out, the temperature drops rapidly. Now, not of course back to ambient but it drops rapidly because the loss from a hot wall goes like the temperature to the fourth power. So if you've got the wall up at around 800 degrees or 900 degrees C, okay, take that to the fourth power and that's your radiative loss. You see the temperatures in the first couple of minutes drop down dramatically, but of course, they're not going to drop down to ambient but they're going to drop down into the several hundred degree range.

MR. BIRKY: So supposing we have the walls at 800 and how long will it take to get down to 400, say, the half-life, if you will?

DR. McGRATTAN: I'd have to sit down with my calculator but I'd say tens of minutes, tens of minutes or less.

MR. BAJWA: Okay, I'd like to move onto the next presentation. It will be from the Center for Nuclear Waste Regulatory Analysis, Mr. Andre Garabedian and Darrell Dunn. Mr. Garabedian is a group leader in the engineering and research section of the Southwest Research Institute's Department of Fire Technology. He holds a bachelor's degree in civil engineering, a masters degree in fire protection engineering and is a licensed fire protection engineer in the State of Texas. His primary role is a large scale fire test engineer and fire investigator.

Mr. Darrell Dunn is a senior research engineer at the Center for Nuclear Waste Regulatory Analysis. He has a BS in metallurgical engineering and an MS in material science and engineering. He is involved in the analysis of materials degradation and metal corrosion at Southwest Research Institute. And they're going to be talking about analysis of rail car components exposed to a tunnel fire environment.

MR. GARABEDIAN: Thanks, Chris. Good

morning, all. My name is Andre Garabedian. I represent Southwest Research Institute Center for Nuclear Waste Regulatory Analysis and I'll introduce Darrell Dunn a little bit later on.

Our tasks in this project were to review the antidotal information on the Howard Street Tunnel fire. That included photographic documentation and initial reports. We visited the site to collect some data, inspect the damaged rail cars, and then we analyzed the recovered train components using metallurgical techniques. The last step was to verify those analyses with a simple convection radiation model backed up with a "reality-check" small scale test that we conducted later on.

Our ultimate goal was to use the physical evidence backed by numerical modeling to estimate the fire duration and temperature witnessed by components during the post-derailment and fire. I think we all know why we're here and the idea behind getting those data were to submit to the NRC to give them an idea of the exposure in an effort to aid in policy. The analyses performed, two type of analyses will be covered in the presentation. One, a materials analysis, those type of analyses include studies of paint degradation, blistering, peeling of paint.

Materials analyses, including oxidation of steel, how the steel reacted to the fire. That was backed up by some empirical computational analyses using transient heat transfer models onto various components in the tunnel and specifically the aluminum air brake valve components. We noticed them melting, so the transient heat transfer model was focused around those elements.

Data collection, as I mentioned before, we visited the tunnel, spent a day on site and a day at NTSB, collecting antidotal data, photographing the rail cars, taking measurements of what we saw and here's just an idea of what some of the rail cars looked like. You saw the picture on the right earlier. The picture on the left is a -- I believe that's they hydrochloric acid rail car, that's car number 53, the one right after the trypropylene car, similar in size 28,700 gallons.

Some of the samples that we collected included some steel scale that was pulled from car number 51. If you refer to your hand-out, that's one car uphill from the spill source, approximately 30 feet away. We collected a section of the roof plate from car number 50. This was the source of substantial exposure due to a long-burning paper fire. This is a boxcar containing paper, so for a duration the contents of that paper car and their impact on the steel were -- we were interested in. We also collected some sand, small sand samples from the base of one of the rails near the derailment point and the reason that was interesting was the sand appeared to be clumped to the rail, so we wanted to take a quick look at that sand to see if any changes in the material structure of the sand due to heating.

Here's a quick overview of the rail car components that we were very interested in. This image to the right is the air brake, ABDX air brake and you get an idea from the scale of the unit, it's mainly a cast iron body with a lot of aluminum covers that cover components on either end of the unit. These are very interesting witnesses to temperatures.

So talking about the ABDX air brake valve, we collected the remainder of the valve on car number 52, which was the car of origin, the spill source car. This air brake valve, obviously, exhibited the most notable damage, so we were very interested in how the steel in the bolts and the remaining components of that air brake valve looked. And this was very comparable to other air brake valves throughout the train. Every car has an air brake and the location and spacing of these units is fairly uniform throughout the train. So it was a very good tool to use to compare car to car.

Again, as I mentioned, on that air brake there were some exposed bolts that were analyzed and these bolts were the bolts that were holding one of the aluminum air brake covers onto the cast iron body. That aluminum air brake cover completely melted only leaving the bolts, so it was a very good indicator of what the temperatures were in that area. And then we analyzed or evaluated a new air brake valve cover, just to get an idea how these things perform. We wanted to see one melt. That was supplied directly from the manufacturer.

So to start with the material analyses, the paint analysis, I'll introduce Darrell Dunn.

MR. DUNN: Thank you, Andre. The rail cars on the train were painted with a Dupont alkyd-enamel paint. And we know that the blistering temperature of this paint is about 700 degrees centigrade or just under 1300 degrees Fahrenheit. We studied the burn patterns on the rail cars and looked for signs of paint damage on both the tripropylene car and also some of the other cars, including some of the box cars that were hauling paper.

What we observed was that there was no

blistering on rail car number 53. This was adjacent to the tripropylene car and about 50 feet away from the tripropylene car and this suggests that the temperature observed by this car was less than 700 degrees Centigrade. We did observe blistering on some of the box cars that were hauling paper even though these were further away than the rail car number 53. These particular cars, however, had secondary paper fires so the temperature was likely caused -- would blister the paint, the temperature that would blister the paint was likely caused by the internal materials in the car burning, rather than the fire caused by the tripropylene spill.

Now, I'm going to move to that materials analysis. The graph here shows the way that we analyzed our steel components. One of the things we did was to look at the formation of oxide films on the steel components because this is a known function of time and temperature. I show a couple of different rate constants here. One of them is for the formation of an oxide layer thickness and the other one is for the reduction in metal thickness due to oxidation of the steel. These rate constants are available over a wide range of temperatures and for different alloys. I've shown a couple of different alloys here. We used the rate constants for iron, since our components were basically low carbon steels.

Okay, the photographs here show sections of the roof of car number 50 and I'm going to point here, we're looking at the cross-section going this way across this particular sample and for here we're looking at the cross section going in this direction. The thickest portion of this roof is shown here on the graph, about 1700 microns and the thinnest portion, which was exposed to the fire was substantially less than that. Based on the loss in metal thickness, we observed some spalling of the outside layer for this particular component, so getting an estimation from oxide layer thicknesses is probably not a good method. So we looked at the reduction in metal thickness and from that, we can estimate that if we have a four-hour fire, this particular component saw temperatures in the range of 750 to 850 degrees Centigrade.

It's important to note that this particular item or this particular component was on a car that had a secondary paper fire, so the actual exposure to elevated temperature was quite likely longer than four hours. This is a -- this slide here shows a cross-section of a bolt. This bolt was recovered from the air brake valve of rail car 52 and again, I'm going to use the pointer here. What you're seeing this kind of dark gray area is actually the epoxy that we mounted our sample in. Over here on the right side of this picture, you'll see the bright area. This is the steel base metal and then you see a thin layer in between that is actually the oxide layer and the second picture here that's kind of inset is actually an x-ray image map so and we'll looking at iron, so we see lots of iron here on the bolt, as you would expect and less iron in the oxide layer, again, as you would expect.

This particular iron bolt has a very nicely uniform oxide layer. We don't see any evidence of spalling here and so we use the oxide layer thickness to determine what type of temperature this particular component would have seen and again, based on an assumed four-hour exposure, this particular component would have seen a temperature of a little over 620 degrees Centigrade.

This is another portion of the same bolt and this is actually the head of the bolt and the phase that's been mentioned before in previous discussions, actually is right here. This is a very small phase. It's about 50 microns deep, I believe, and the micron scale here in the larger picture is two millimeters for your reference. This particular area has this phase that's shown here in atomic percent, 66 atomic percent aluminum and 30 atomic percent iron. And this particular phase would have a melting temperature that's inconsistent with what we observed for either the oxide layer of thickness or the condition of the aluminum cover on this particular air brake valve.

It's important to note that this is a fairly small area and in fact, the melting temperature of this particular phase is actually slightly greater than the melting temperature of the cast iron component. We didn't observe any melting of the cast iron component so we don't believe that this particular phase was formed by a melting process. And now I'm going to --

MR. BIRKY: Just one question if I might on that analysis or on the previous one, too, on the oxide; on this particular one, what assumptions did you make when you did the calculations -- get the equations for the calculation for the oxide determination, the thinning of the metal?

MR. DUNN: We took rate constants that are well-established from the literature and that's -- I provided a reference to our source there.

MR. BIRKY: But previous stuff done by NIST suggested there was serious oxygen depletion limiting of the fire. Was that taken into account to calculate the temperature and thinning of the metal for the oxide build-up?

MR. DUNN: No, we did not assume or take into account any oxygen depletion. It's -- I believe this data shows about 14 or 15 percent oxygen in the tunnel. That's --

MR. BIRKY: So what would be the effect of that? Would that increase the temperature or the time duration to get the same oxide build-up?

MR. DUNN: Well, most metal oxides form quite spontaneously and it's doubtful that the slight decrease in oxygen concentration would not have effected the oxide kinetics significantly.

MR. BIRKY: It would have? Would not have effected?

MR. DUNN: It would not have.

MR. BIRKY: What about -- how long were these cars -- after the fire did you do these oxide determinations?

MR. DUNN: The analysis was done, I believe, approximately a year after the accident.

MR. BIRKY: Was that taken into account?

MR. DUNN: Yes, we did take that into account. We, in fact, in our report, show that some of the phases that are formed are a corrosion product rather than a thermal oxide.

MR. BIRKY: Then on this measurement, your initial report, could you tell me what assumptions you made in terms of calculating those temperatures, the temperature of the diffusion process here that you had?

MR. DUNN: On this particular bolt?

MR. BIRKY: Yeah.

MR. DUNN: This is a -- again, I think we've pretty well detailed this in the report. This is assuming a simple diffusion in a voluminum in gamma phase iron which would expect temperatures over about 720 degrees centigrade.

MR. GARABEDIAN: We could focus on that but I think it's important to understand the --

MR. BIRKY: Well, I guess I was -- you're not suggesting it was 1400, 1500 degrees C at all.

MR. DUNN: No, no.

MR. BIRKY: Are you correcting that?

MR. DUNN: No, I think what's written in the report is to show that this particular phase could not have been formed by diffusion because the temperature is too high. At that temperature you would easily see melting of the cast iron valve components.

MR. BIRKY: I was misinformed by that.

MR. DUNN: Yeah, in fact, even the melting temperature of the steel bolt here is around 1490 Centigrade.

MR. BIRKY: Right. Now, I have one other question on what you presented on the blistering of the paint. You're suggesting that was done by the smoldering inside the rail car itself rather than on the outside fire, from the outside fire?

MR. DUNN: Yes.

MR. BIRKY: How do you determine that?

MR. GARABEDIAN: It is difficult to say where the blistering -- what the blistering was occurred from, whether it was an external fire or internal fire. Picture painting a frying pan and putting it on a stove, it could easily blister the paint on the top side of the frying pan because of the heat underneath it. So it is difficult to say where the exposure came from but we do know that it occurs at about 700 degrees C and it occurred in a very small region of that, just a couple of rail cars in that train.

MR. HODGES: Something to keep in mind on those box cars with the paper in them also was they smoldered in the tunnel for some long period of time, several days. When they were pulled out of the tunnel and they got plenty of oxygen, then the fire flamed up and it would have been a much hotter fire.

MR. DUNN: Okay, we're done. I'm going to give it back to Andre.

MR. GARABEDIAN: Thanks. Yeah, I'm going to step into the empirical and computational analyses that serve to be a reality-check to what we saw in our inspections. And what I want to focus on is the analysis of the air brake valves. Here we see an isometric view of the ABDX air brake valve and you can see -- let me get this pointer, here we go -- these are the aluminum covers, a photograph of it earlier on, if you want to flip back to it you can get an idea of what those covers look like.

Air brake valves are used on all the cars. Cast iron valve body, which is the main portion of this unit with these aluminum covers. The aluminum cover that we were most interested in was located about 10 meters from the fire source and this the guy that melted completely. And we know that the aluminum melting temperature is somewhere in the vicinity of

600 degree C. So we can kind of put those two together. To verify or to get us some computational verification, we used a transient heat transfer model, a very simple convective and radiative heat transfer. Assuming that the aluminum acts as a single body, the heat that's absorbed by the unit raises its temperature and the unit melts, so that's what these equations serve to demonstrate.

Going into the assumptions, as I mentioned, we assumed a lumped mass, so we're assuming that this aluminum is one clump of aluminum whether it be a sphere or a square. It's not a thin or unusually shaped unit. It's a full volume of aluminum. We also assumed that the radiative exposure from luminous flames, we didn't take that into account and that's usually about 30 percent of the total heat release of a fire. It's a good assumption for those targets that are underneath rail cars. They don't get the benefit of the radiation, heat radiation from the fire onto it.

So these assumptions on this slide actually delay the estimated melting time assuming this being a lumped mass and no external rate of exposure. So this would predict longer melting times. On the flip side, we did not take into consideration conduction into the adjacent steel or other materials. You know, these covers are bolted to cast iron but we did not assume that the cast iron was capable of drawing heat away from the aluminum, no conduction out of the aluminum. So what that would do if there were conduction out of the aluminum, that would -- without assuming conduction away from the unit, that would accelerate or speed up the melting because we're assuming that all the heat that enters that aluminum cover stays there, doesn't go into anything nearby.

Some assumptions on the heat transfer coefficients, conducted heat transfer, 50 kilowatts per meter to kelvin. These are applicable convective heat fluxes when you're calculating exposure of structural steel elements, hydrocarbon fires. There's a lot of performance based design that revolves around the fire modeling and its interaction with the structures. And this is a published heat transfer coefficient for that purpose.

We also assumed varying fire exposure profiles. Again, not knowing what the fire profile looked like, we assumed some fairly typical profiles. Immediate growth and a plateau, that's common for hydrocarbon fires. They grow very quickly and assuming perfect conditions, they will plateau at a certain temperature.

The second one is the rap-to-plateau. Ramp over a certain amount of time, assuming fairly slower growth but that it does achieve its maximum temperature then stays at that temperature for some duration. And then the ramp-plateau-decay, this is the case where the fire grows over a growth period, plateaus at its maximum temperature and due to some external suppression or oxygen limitation, it begins to plateau or fuel consumption, it begins to plateau.

Here are a couple of graphs the simple model output. Here's an example of a ramp-to-plateau, so this simulation had an 800 degree Celsius fire ramping at about two minutes and then sitting there at 800 degree C for some duration and what we wanted to look at was the bulk temperature of that aluminum cover. We were most interested when that entire aluminum cover hit 600 degrees C. That was one of our assumptions. And that occurred, you can see, in about less than 10 minutes in that case. Another case here is a model run that assumes a ramp-plateau-decay a little bit more typical of what other investigators have found, Kevin as well.

We have a growth to 800 degrees C, some plateau at that temperature and then a rapid decay.

And even with the rapid decay, we can see that melting can occur in about 800 seconds, you know, 15 or so minutes. So these are just simple heat transfer rates that indicate that aluminum when exposed to these types of temperatures can melt fairly readily. So how do we validate that, do a reality check on it? We used ASTM E1354. It's a cone calorimeter test. Irradiation method, I know there's some confusion in that term. This is all heat radiation, heat radiation to a sample. And the way it's done, it's a conical heater that basically looks like a Nichrome wire, a toaster, and that's dialed into a certain heat flux and that irradiates a sample. The irradiation flux that we used was 150 kilowatts for meters squared. That's a souped up toaster and that's consistent with ASTM E1529. That's the heat flux that's expected to impinge structural steel exposed in these hydrocarbon pool fire situations.

And the picture on the left is the ABDX valve recovered from car 52. Again this is the rail -- the tripropylene rail car. You can look on your diagrams. This is the spill source, fire source and we see some very interesting things. Most interesting is that we can still almost read some letters up here. A, B, D is what I see and a cylindrical section right here. This is the factory provided valve cover that we irradiated with the cone calorimeter. This was new to begin with and it melted in about six minutes. Even with that high degree of melting, you can still make out some of the reliefs of the profile of the cover but no lettering.

This was interesting, as I mentioned before, because these air brake valve covers were fairly evenly spaced throughout the tunnel. The picture on the left is, again, the air brake -- the remainder of the air brake valve from car number 52, again, about 10 meters from the fire source, and this air brake valve cover was located on car number 51. You can look on your diagram. That's the next car down, located approximately 20 meters or 66 feet away from the fire source.

This is in very good shape when you consider how easily these components melt. So a summary of the analyses, temperature estimation from the aluminum air brake components, well, we know it's greater than 600 degrees C, 10 meters from the fire source, we got complete melting of that valve cover. The estimation is approximately equal to 600 degrees C 20 meters from the fire source. Why approximately equal to, because the valve cover that I showed you on the previous slide was partially melted. We're going to give it the credit that it saw 600 degrees C. And less than 600 degrees C, 40 meters from the fire source, we did look at some other air brake valve covers later on in the train in both directions and saw no damage to those.

Incidentally, the hydrochloric acid rail car, one rail car away from the tripropylene spill source, was not effected by the fire. In fact, the pictures that I showed you to demonstrate what one of those valves looked like was actually from the hydrochloric car. Temperature estimation from the steel components, as Darrell had mentioned, 750 to 850 for four hours at the roof or rail car number 50, again, this also had the secondary paper fire, we have to discern what the difference between an exposure fire and the fire from the internal contents, what effect those had, so it's a bit difficult there.

And then a temperature estimation from the rail car pain, this was the toughest one to nail down. The best we can say is it was greater than 700 degrees C within 15 meters from the fuel spill, but again, it is important to note that there was not widespread blistering of the paint. It was very concentrated into a fairly small area. Interestingly enough, it was actually concentrated on a rail car that was quite aways uphill from the spill source, again, indicating that it might have been caused by the interior paper fire.

So again, a summary, model calculations indicate that the assumed hot fire environment in the tunnel would have melted solid cores of aluminum in about five minutes. And the ease of melting was verified during an empirical test, the cone calorimeter test, where melting was observed in about six minutes. Does that tell us that aluminum melts very readily and the summary is that the fact that the aluminum covers remained intact elsewhere in the tunnel indicated lower temperatures were observed only a short distance from the spill.

Are there any questions?

MR. RESNIKOFF: I just have one question. I notice in your report that this ramp-to-plateau temperature that's recommended by ASTM is 1180 degrees C, in other words, the plateau, but I notice in your calculations you assumed 800 degrees C. Is there any reason?

MR. GARABEDIAN: No, 800 degrees C was chosen to be more representative what a pool fire would be. ASTM E1529 is very severe. They chose, I believe it's 2000 degrees Fahrenheit as how it's specified in the standard. No specific reason why we chose a slightly lower temperature but obviously, choosing a higher temperature would have only accelerated the melting time, so --

MR. RESNIKOFF: I had one other question. These oxidation measurements that you've taken, this depends both on the temperature and the duration of the fire, right? You have two variables and you only have one known.

MR. GARABEDIAN: Yeah, I'll have Darrell answer that one for you.

MR. DUNN: That's correct. That's correct, so you have to either assume a temperature and get a time or assume a time and get a temperature. For our particular case, we looked at a relatively short time, what we thought would be the exposure prior to the water main breaking, and got a temperature from that.

MR. GARABEDIAN: And, again, the site visits and the photographs of these valve covers was to serve as a functional check of those analyses, so that was the idea. We were very lucky to find those aluminum covers very systematically spread out among the rail cars. They were very good indicators. Yes.

MR. MOORE: Speaking of aluminum covers, can you tell me where they're physically located on a rail car?

MR. GARABEDIAN: Yeah, they were located in different places and excuse me while I flip back through these. This one was located on the brake end, which is the end furthest away from the tripropylene car. This is on the hydrochloric car, the next tanker car down. This is actually on a -- a plateau at the back of the rail car, I'd say a little bit more than waist high. Let's give it three and a half to four feet. This one is exposed in all directions to the walls of the tunnel. There are covers on the top that are exposed to the roof of the tunnel.

This is a fairly typical location. Other locations, as you saw in the slide later on in the presentation, had one or two of these units underneath the rail cars at certain locations underneath the car. A convenient place to attach it is probably where they ended up. So they were in different locations to kind of give us an idea of exposures.

MR. MOORE: Once you move away from the immediate fuel source for the fire, does the vertical location and also the cover provided by the car itself if it's located underneath the car, effect what temperatures you might see in the heat profile?

MR. GARABEDIAN: Yes, yes, it would, yeah.

MR. MOORE: So, I guess my question is, are you -- looking at the location of the covers as you looked at the covers on different cars to try to determine whether there was enough temperature to melt, their physical location on the car itself and any sheltering that might be provided by the car in addition to looking at the physical distance, up rail or down rail?

MR. GARABEDIAN: Yes. There was not much to see after car number 51. They were all intact, so there wasn't much to discern from, well, this one was intact when it was at waist level, this one was intact when it was under that car. They were all intact up stream or up tunnel. So tough to tell whether the ones underneath the cars received additional exposures or additional exposures because they were closer to the ground and that's where the spill fire was or additional exposures because they were closer to the roof and that's where the hot gases were, difficult to tell but we know that they didn't melt so I don't -- I can't take any data from it.

MR. BAJWA: All right, thanks, Andre. I'm going to recommend a short break and I think we all need that, and we'll come back in five minutes and then have the last presentation and questions on the last presentation. Restrooms are through the door, take a left.

(A brief recess was taken.)

MR. BAJWA: Can we get back to the table so we can get started again, please? Thank you. All right, let's get started. Our next presentation will be on the Baltimore Tunnel Fire Evaluation of a Spent Fuel Transportation Cask. Mr. Harold Adkins from PNNL will present. Mr. Adkins has an MS in mechanical engineering. He is a member of the Fluid and Computational Engineering Group at Pacific Northwest National Labs. That particular group has been involved in spent fuel storage and transportation thermal analysis for over 20 years. Harold.

MR. ADKINS: Good morning. As Chris said, I'm Harold Adkins from PNNL and what I'm going to discuss are the thermal results that we came up with when we subjected a HOLTEC Hi-Star 100 transport system to the particular conditions that were given to us by NIST.

The first thing I want to start out with is just kind of a general description and give you an idea of how big and what they're shaped like. This is an artist's rendition that HOLTEC provided and basically what you see is the cask sitting on a rail car on a cradle that's a boxed in cradle and it's strapped down and pretty much almost the entire cylindrical surface of the cask, the structural portion of the cask is covered with a neutron shield and outer casing, if you will, and then the ends are covered with impact limiters. They're made up of -- they're hybrid multiple panel honeycombs with a stainless steel shell.

This particular cask is a similar description information. Also you have a handout, by the way, that you can probably read. It's a little more legible. Basically, what you have is a cask that's loaded with a sealed, weld sealed canister, stayed flanges and a fuel compartment for multiple fuel assemblies that slips into the cask and then a bolted closure. Now, of course, the impact limiters go on the ends of this and it's loaded on the transport trailer you saw on the previous image. Some, I guess, general characteristics; more description here is, it's roughly 306 inches long, 128 inches in diameter. That's with the limiters themselves.

Again, two forged end flanges, the cask's structural portion is primarily made up of a number of concentric shells that are welded to the end and stayed flanges. This cask is comprised of 2.5 inches thick stainless steel containment shell, five inches of carbon steel for gamma shielding, two forgings, of course, bottom and top closure, two hybrid honeycomb impact limiters, again that are made of different pound honeycombs and then a stainless steel skin.

The cavity of this particular cask is 191 inches long, 68.75 inches in diameter. This particular design has a five-inch thick composite, neutron shield construction on the outside of the structural portion of the cask that is comprised of channel plate, steel channel, steel plate and epoxy resin that the channel and plate are filled with. Of course, this system passively dissipates the heat from the spent nuclear fuel. Some more details of the canister that fits inside of the cask is it's 191 inches long, 68.4 inches in diameter. It's a thin-walled steel vessel that's made out of stainless steel and it's got two stayed end flanges. They're both welded into place.

The internal is a basket. It's roughly and egg crate construction that allows for 24 spent nuclear fuel assemblies to fit inside with appropriate envelopes. It also is comprised of flux traps, helium gaps, boral sheet with their associated storage pockets. This particular canister is backfilled with five atmospheres of helium, five atmospheres of pressure helium, and this, you know, unit also dissipates the heat passively to the cask to be passively dissipated to the atmosphere.

This particular system is licensed for 20 kilowatts decay heat load. Going to the objective here, the main objective that we set out to do is to perform a detailed analysis of the HOLTEC transport system when subjected to, of course, the BTF conditions and the data that NIST provided. And you know, obviously, all conductive, convective and radiative heat transfer regimes need to be incorporated to accomplish this. Some of the assumptions associated with this particular analysis; first of all, one of the things that we immediately looked at is, you know, you've got this entire body sitting in the tunnel fire environment. However, the impact limiters themselves are comprised of aluminum honeycomb which is mainly pressed ribbon that's bound by epoxy that's covered with stainless steel skins and essentially what happens to the aluminum honeycomb is it will melt back from the skin a little bit and provide an insulated barrier to the top and bottom ends of the cask and is actually a fairly poor heat transfer path out of the particular system. Use of nominal dimensions were acceptable. That was another assumption. The fuel assemblies were centered within the basket cells themselves, where there was no readily available conduction path out of the basket.

The canister was radially centered within the cask. Spent nuclear fuel, decay heat profile for this particular model, we chose to go with an absolute hottest possible cross-section of the cask. Again, it's a 2D model, so what we did is we imposed a 1.1 peaking factor on the decay heat within the basket. Another thing that we did is we assumed that this particular cask before even going into, I think, the ambient inside of the tunnel is 70 degrees of the ignition of the fire. We assumed that this cask reached normal hot steady state which was 100 ambient and was sitting and baking out in the sun in reached steady state before it went into the tunnel. And then we ignored the transport trailer and we considered this to be conservative considering the fact that it's in the vicinity of the colder air temperatures that are sweeping through the tunnel to feed the fire.

The method of solution was to apply a

general finite element solution code. ANSYS was the particular code we used to solve this and we used well-ventilated or well-validated convection correlations, buoyant and forced convection for the two different regimes. Obviously, buoyant convection for the normal conditions of transport, when it's sitting and reaching steady state and then forced convection during the fire situation.

Let's see, accurate thermal physical properties were imposed. These were properties that were taken from the HOLTEC TSAR that had been verified and those were even cross compared before we performed the analysis. We used ANSYS Parametric Design Language to go through and evaluate the convection coefficients on the fly throughout this transient so everything was being continuously updated as far as the heat transfer coefficients on the surface of the cask as we went through the calculations, so it wasn't just a matter of assigning a particular value.

We incorporated all the conductive, convective and radiative components that we could possibly justify and also rolled in explicit representations of all the sub-componentry including Boral plate. The pocket itself contains the Boral sheets inside of the basket. The basket structure, the basket stays, the canister shell and then of course, we used in this tunnel fire, the air temperatures, tunnel wall temperatures and the velocities to form out boundary conditions for this particular problem.

Model construction, I guess the first thing I can speak to here is the canister body. We incorporated roughly 18,500 elements to represent the conduction through the basket and canister itself and through the fuel assemblies. Convection was incorporated inside of the basket and the magnitudes were -- I guess, the magnitude of available convection were values that were taken directly from information that was used in the development of COBRA SFS and then, of course, all the radiation interaction within the basket was counted for by 72 -- a small -- the modeling of 72 small enclosures inside of the canister.

The cask body, the model construction details on that, we went ahead and rolled in over 8,000 elements to represent the cask body. Convection, of course, was accounted for on the outside of the cask, not the inside. The gap between the canister and the cask is so narrow that you do not have a -- you don't establish a convection regime.

Radiation was accounted for on the inside and the outside of the cask and this is in two phases. Obviously before we do into the tunnel, the cask is radiating to the environment, you know, like the standard ambient it would be if it was to sit in a rail yard or what have you. And then, of course, during the fire, there was a radiation interaction accounted for between the tunnel and the cask and then in the case where we actually -- we ran two cases. I need to mention this early on so some of this will make sense.

We ran two cases where the cask was situated at five meters center from the fire source and then the cask was also evaluated 20 meters down from the fire source. In the case where we evaluated the five meter fire source, the radiation from the actual fire face or sheet of the fire was accounted for and its associated view was calculated.

The cask cradle, also, there was some considerations that went into it. It had roughly 1100 conduction elements that were used to represent it. We modeled convection within the inside of the cradle and the outside and how it interacted with its environment and radiation was also accounted for between the cradle, the cask and the tunnel.

MR. RESNIKOFF: For the neutron-absorbing part of the cask, you know, how did you model that? Did that stay intact throughout the fire or did that melt?

MR. ADKINS: I'm going to go into more detail on that further on here, but I can tell you what I did. That's not a problem. Mainly what we did is we said the conduction path would be enhanced if the material was to stay intact during the fire and then for some other details that I'll give you on some other evaluations that we performed that Kevin had briefly mentioned, we actually right at cessation of the fire said that that material magically turned to air and became an extremely insulative material.

Let's see, we're done with that. Basically, to give you an idea of the modeling venture here, here's the cask with the canister inside, a cross-section of it, sitting on the cradle and this mainly just outlines that materials and the fact that each sub-component and everything else was accounted for. Basically, you'll see different colors for each particular material in this but as you can see, the fins, through the neutron shield, the capping, the plating, the gamma shield, everything is explicitly accounted for. Here's a close-up basically of right at the top of the cannister and what you're seeing is where the fuel -- you're seeing one fuel compartment with the Boral sheet. Maybe the next slide is a little clearer, yeah, here we go. The difference between these two slides is merely the helium environment inside of the canister, but basically, what you'll see is, you'll see narrow sheets on the outside of the fuel compartment that represent the Boral sheet and also its pockets. You'll see the fuel inside of there where there's a radiative enclosure between the fuel and the compartment and then, of course, you can see the stand-offs of the canister that you can also see are put in direct contact. That was another assumption.

MR. BAJWA: Harold, can you use a pointer to point those out?

MR. ADKINS: Yeah, that would be great. In fact, what I'll do --

PARTICIPANT: Go back over that.

MR. ADKINS: You mean, you guys don't know this stuff? I will actually. Basically right in the center here, this big blue chunk is the fuel. Right between the purple and the blue is the gap between the fuel radiative enclosure. Right over here, this black portion, this is a flux trap and you can see the Boral sheets with their wrappers on the outside and the pockets. The red is the basket stand-off. The green is the canister shell and this kind of, I guess, lime green -- this lime green is the gamma shield. Okay, the next slide here is basically a backed up version of -- or backing up from the particular section that we were looking at and what you can see is the neutron shield plates, the capping, the channeling and this is on the outside of the cask here. Where is my pointer? Right here on the periphery of the cask.

You can see these fins. The purple is the neutron shield material which is a Holtite-A specified by the manufacturer of the cask and then this wants to rush me, I guess. The next slide here is basically the boundary conditions associated with the analysis and how we used NIST's temperature data, temperature and velocity data to establish the effected zones per the temperature regimes and the flow regimes that Kevin calculated. We'll go into more detail here, I've got some bullets, but basically what you can see is right where these red stand-offs are, the little tick marks on the sides of the tunnel, those are basically panels.

If you look at the top of the tunnel, Kevin's data where he specified the absolute hottest tunnel temperature, we went ahead and conservatively lined that whole cylindrical portion with his peak tunnel temperature reporting and then the side portion where it's over to the sides of the tunnel here, just down from the cylindrical portion, that was his wall temperature we assigned the lower portion of the wall, obviously, the wall temperature. The bottom was the bottom of the tunnel, of course. And then the air -- or I guess the air environment as the air was sweeping through, we assumed the roughly around from the very top of the cask to about halfway around to the cradle, which is a huge effected zone considering the fact that like you saw in Kevin's slide, a lot of the hot air was basically entrained and stuck to the tunnel surface very effectively. But what we assumed is that this huge portion of the top of the cask was exposed to the convective environment.

Now, the one thing that is critical to mention here is this whole thing was modeled as a huge radiation enclosure in the interacting radiation enclosure, thermal radiation. Okay, the loading and boundary conditions associated with this analysis are as follows. A 20-kilowatt heat load was just as what it's certified for and what we did is we applied a 1.1 peaking factor on top of that to represent the absolute hottest possible cross-section. Now, one thing that needs to be realized here is that in the whole cask body, the steel shelves are so thick that typically, you know, even if you're modeling your hottest cross-section of the cask, it's not going to be as substantial and as conservative as applying this 1.1 heating factor and then you know, isolating it where it has no way of migrating heat down the axis of the cask.

Some of the pre-fire conditions associated with this, as I referred to before, one of the things that we did is we assumed it came to steady state with its normal hot conditions which was 100 Fahrenheit ambient. We applied 12-hour solar over this 24-hour period which is, you know, per the regulations, 10 CFR 71.71. Emmisivity on the outside surface of the cask pre-fire was .85. The ambient was one. Buoyant convection correlations were used for this and basically the same APDL logic that was incorporated to determine the convection coefficients through the transient were applied to determine the heat transfer coefficients for this particular case as well and then, as I said, we allowed it to come to steady state prior to going into the fire.

MR. MOORE: Harold, before you leave that slide, real quickly, what age fuel correlates with your 20 kilowatt decay heat load?

MR. ADKINS: I'm not a fuel guy, but I don't believe that matters, especially from a thermal standpoint. I can't comment on that. Mainly what we did is we took the geometric configuration of a W 17 by 17 fuel and put the specified heat load that they're certified for that does envelope that fuel. That's all I can comment on.

MR. MOORE: Thank you.

MR. ADKINS: Okay, fire conditions were such. The boundary conditions, of course, came from the NIST data. We ran two cases, a five-meter and a 20-meter case from the fire source, the ignition, the fire ignition. The cask outer surface was assumed to be -- the emmisivity went from .85 to .9 and the tunnel surface was .9, the external environment to the cask. These are per 10 CFR 71 again.

Forced convection correlations were used with the APDL logic. We used laminar convection correlations, well-validated correlations, I might add, and the reason laminar ones were considered is there are some other cases that I'll discuss here where we did some post-fire considerations and, of course, as this thing sits and the tunnel cools down, you're obviously, going to be walking away from the turbulent regimes.

Convection interaction was obviously modeled, a radiative interaction inside the tunnel and to the tunnel itself was modeled. The gamma shield gaps, this cask is built by welding a number of concentric shelves that have air gaps in them, and what we did is, when it goes into the fire, we automatically assume all these gaps disappear. So there's a stronger heat path into the cask the minute the fire initiates. Let's see here.

Okay, one thing that's critical about the results that I'm going to present here shortly, are the fact that, you know, as Kevin was saying, after 30 minutes we have our peak temperatures on the fire and then basically you know, the temperatures start to witness down trending, but what we did at that point is we said, okay, 30 minutes is where we establish our peak temperatures and for the analyses results that I'm going to discuss shortly here, we assumed that right after 30 minutes, basically the temperatures were held constant. They reached steady state and held that continuously further on into time. Go ahead, Bob.

MR. HALSTEAD: You got ahead of me,

Harold. If you'd go back to your last slide or this is still the one you've got where you have the NIST data, BC's assumed. What actually are you -- for the -- if you actually overlay this with the illustration of the cask, in terms of the heat input that's coming into the top half of the cask, where your two little ears indicate correlation with the --

MR. ADKINS: Sure.

MR. HALSTEAD: -- what's the external -- what's the external temperature on the surface of the cask that you're assuming there?

MR. ADKINS: When?

MR. HALSTEAD: Well, I mean, once you reach this steady state for three hours, the first three hours of the fire that we -- what's the hottest temperature during the three hours where we know the water main hasn't effected the fire?

MR. ADKINS: Okay. Boy, Chris.

MR. BAJWA: I think you're asking -- you want to know what the heat input to the cask is?

MR. HALSTEAD: Right. I want to directly relate this to the NIST characterization.

MR. BAJWA: Okay, Harold if you go back to the --

MR. HALSTEAD: The temperature in the

upper half of the tunnel.

MR. ADKINS: I think what's important here is the NIST characterization didn't involve accounting for the water line bursting or anything like that. I mean, none of that was weighed in. So basically what we did is, NIST provided time, temperature curves to us for the upper region of the tunnel, the mid region of the tunnel and the lower region of the tunnel, the air. Then they provided surface temperatures for the top of the tunnel, the side of the tunnel and the bottom of the tunnel and then they also provided velocities, I guess, gas velocities, if you will, because it's not pure air, gas velocities traveling through the upper portion of the tunnel, the side portion and the bottom portion and the velocities were selected in regions where they would give us conservative values over the course of the fire.

MR. HALSTEAD: Well, I understand that. What I'm trying to ascertain is -- okay.

MR. MOORE: While Bob's looking for that, is that data that you just mentioned, the time/temperature curves for the various regions available?

MR. BAJWA: It's not specifically in the NIST report. However, I believe we could provide you whatever data you'd be interested in. So if you'd just let me know what you want, we'll provide that for you.

MR. HALSTEAD: Okay, looking at this region of the cask --

MR. ADKINS: I'm sorry, yes.

MR. HALSTEAD: All right, I'll do it on this one. Looking at this region of the cask, the top, the top half, what's the -- what assumption are you making about the average surface temperature due to all of the -- all of the heat processes in the tunnel over the 30 minutes, 3 hours and 150 hours? Is that constant and what is that temperature that you assumed -- that you ran, not necessarily what happened in the tunnel? What did you run?

MR. ADKINS: Yeah, I think the important thing here is first of all, I didn't assume a cask surface temperature because that is calculated. When you come out of the NCT, I believe we're up at, if I recall -- I mean, one of the things we did is we have a macro that goes out and pulls the absolute peak temperature of a particular component and reports it as a function of time.

MR. HALSTEAD: No, I understand that. I want to relate this to the NIST characterization of the fire. So is the top half of the cask in an 800-degree C fire, 450 hours in your analysis, 1,000-degree C fire for 100 -- I want to know what it is that you're modeling for 150 hours, okay?

MR. BAJWA: I can speak to that. Basically, we took the NIST data, okay, so for the first half hour we are polling the NIST data. We are following that time/temperature curve that the NIST data provided. Then in half an hour, taking the maximum temperatures that existed at the end of that simulation, at 30 minutes and we're holding that constant for the remainder of the time, so for the next 120 hours.

MR. HALSTEAD: Okay, that's what --

MR. ADKINS: And that top portion interacts with the peak temperature and velocity of the fluid that was reported out of Kevin's model for the location of the tunnel, because realize we did a five-meter and a 20-meter case.

MR. BIRKY: Clarification; you're not holding that at a temperature, are you? You're holding it at some heat flux, right, from the fire? Isn't that what the input is in your model?

MR. ADKINS: No, no, no, it is not. The heat fluxes are calculated, okay, and the heat transfer coefficients are calculated. The temperatures are not held but inputted the way Kevin reported out of his model directly. What's that?

PARTICIPANT: (Inaudible)

MR. ADKINS: Yes.

MR. BIRKY: And that gas temperature is what the cask is seeing up there between those red ears; is that the thing?

MR. ADKINS: That's right, that's right.

MR. BIRKY: Oh, okay.

MR. ADKINS: And I guess the one thing to remember here, too, is, you know, you look at how high this cask sits in reference to the geometry of the tunnel and it doesn't stick up very high. And, you know, you look at Kevin's plots, here's another measure of conservatism, you look at Kevin's plots and the majority of the hot air volume is sticking to the top of the tunnel.

MR. HALSTEAD: Well, I would just add, that involves an assumption on your part that that cask sits on the rail car in the cradle and that's a very questionable assumption.

MR. BAJWA: What he's saying is that the maximum temperature at the ceiling of the tunnel is applied to the top of the cask for this analysis.

That's what he's saying.

MR. HALSTEAD: I understand that, but what I'm talking about in terms of subjecting portions of the cask to that, it would be interesting to see the lid end of the cask tilted up into that temperature and that's, of course, the issue that we're looking at here, taking the data from the Baltimore Fire and trying to see what would be the maximum type of test we would subject the cask to based on the worst thing that could have happened in this type of fire. I understand that's different from the assumption that you made here.

MR. RESNIKOFF: I'm still unclear. Just maybe you could clarify it. You have this cask sitting in a tunnel at 800 degrees Fahrenheit for 150 hours, yes, no?

MR. BAJWA: No, 800 degrees C.

MR. RESNIKOFF: C. Is that wrong?

MR. BAJWA: That's not correct.

MR. RESNIKOFF: What's right?

MR. BAJWA: What's right is we are taking a time/temperature curve. The temperature varies with time in the NIST data. We're taking that and applying it to the cask. Okay, so for the fire that -- for the fire simulation that lasted 30 minutes, we took the time and the temperature data and applied it to the --

MR. HODGES: And also if I'm remembering right, you didn't take the peak temperature and apply it to the full circumference of the cask. You used a temperature gradient from the top of the tunnel to the bottom of the tunnel and applied those gas temperatures to the cask.

MR. BAJWA: That is correct.

MR. RESNIKOFF: So that temperature gradient that you found at 30 minutes, you then applied that for 150 hours.

MR. BAJWA: Exactly.

MR. ADKINS: I'll continue here, I guess on the fire boundary conditions. Well, I'll finish up actually. The model -- I need to provide some clarification to you. I see where the confusion starts. The 150 hours is just how long the model was run. You know, the times at which we say that peak temperatures exceed a particular limit that we have chosen, that is shorter than that duration, so -- additional fire radiation again, one of the things that I told you, at five meters, the five meter case -- is there a question, Bob?

MR. RESNIKOFF: Yeah, I'm lost. I thought we had established that at 30 minutes whatever that temperature gradient was, you're going to apply that for 150 hours.

MR. ADKINS: That's correct. And the model was run for 150 hours, but I'm saying temperatures where we say that this is the maximum that we can take, are not just automatically reported at 150 hours. It's shorter than that. Yes, peak clad temperatures is what we ran this particular evaluation to and made that the judgment point. So the one thing, too, here is for the 5 meter case is we went ahead and established how much heat would be coming from the fire itself via radiation to the surface of the cask because it did have a minor view when it's that close. So that was also captures for the 5 meter case.

The 20 meter, it attenuates so much that it really wasn't necessary to roll it in and it was neglected. One thing that I'd like to mention here is some of the conservatisms associated with the modeling that we just discussed. One is, we allowed the system to reach steady state. It wasn't moving down the tracks and convecting and cooling down more than -- you know, it would have cooled as it was being transported. The 100 ambient where it's just sitting out in the sun baking and not moving is somewhat conservative.

The 2D modeling with 1.5 peaking factor, that could actually take the -- this spent nuclear fuel decay heat load up to an order of magnitude of like 22 to 24 kilowatts depending on, you know, the rest of the geometric configuration. So that is another conservative approach. Full conduction of the Holtite-A was considered throughout the fire. Now, if we did any evaluations where we didn't have -- where we had a post-fire cool-down, what we did is we turned that into air and made it extremely resistive to any kind of heat transfer so the only mechanism was through the fins.

The fire BC's were considered steady state after the 30 minutes NIST data, so once they reached peak temperature, they were just assumed to continue on to infinity. Max tunnel ceiling temperatures were applied over the whole portion of the cylindrical surface of the tunnel. And I guess now it's time to discuss some of the results here.

The model was run until -- basically, it was run 150 hours but the judgment criteria that we used to say that there was a problem was the primary containment boundary and that was a fuel cladding and we assessed the temperature at which we said the response time should be limited to, to the short-term regulatory limit of the cladding reaching 1058 Fahrenheit. For the 20-meter source case, it reached that in 116 hours. To give you an idea of how long that is, it's five days. And that's after the ignition of the fire. For the five-meter source, it was obviously shorter. It was 37 hours, 1.5 days, approximately and just to give you an idea of the trends, the particular figures.

Here's the 20-meter case, and as you can see the surface temperatures of the casks comes up rather quickly. Now, one of the things that needs to be mentioned here, too, is, some of this lags with the tunnel surface temperature and things of that nature, because obviously, when you're in the 20-meter case, you're down from the fire so it's going to lag a little bit. The tunnel temperatures come up in that portion or region, let's see here, but that was only for the 30 minutes. I'm getting confused with some other cases I'm going to present to you here.

But one of the things, I guess, the key feature is this; the surface comes up relatively quickly. The thermal inertia of this cask is substantial, including just to give you an idea of how much the fuel weighs, we're talking about 1100 pounds, times 24 of those and then all of the structural bodies around this are all steel, you know, with comparable rates. And then basically what you can see is that the fuel has a very long response time after the surface of the cask has come up appreciably and roughly, again, 116 hours. And then for the five-meter case, obviously, we have some things happen quite a bit faster. The surface of the cask comes up relatively quickly in comparison to even the 20-meter case, but, again, we still have some lagging but as you can see, the approach to 1058 happens obviously, rather quickly in comparison to the previous case and that was at 37 hours.

Now, one of the things that I was going to mention before we go to questions is, you know, Kevin was discussing a case where he had run a fire that basically lasted seven hours and he can give you the details of that, but my understanding was, that was roughly how long it took to fully consume the contents of that tanker car under ideal conditions and then what he did is ran the model out for 23 additional hours to capture the trends of the whole tunnel cooling, the wall surfaces, basically you know, the fluid velocities coming through the tunnel and the air temperatures and we went ahead and modeled that as well.

Now, one of the things that I need to mention is that some of the assumptions are a little bit different. This -- we'll call it the 30 hours, so it was a 7-hour fire, 24-hour -- or 23-hour post-fire. The pre-conditions were the same as all the modeling. Fire conditions, the gamma shield immediately went away at ignition of the fire. The neutron shield material, again, was held to represent conductivity of pristine material until the end of the 7-hour fire and then on the post-fire condition basically, that material to lock some of the heat in to the cask, that material went away and was automatically assumed to have the conductivity of air.

The tunnel BC's, since we ran out of temperature data, roughly at the 30-hour mark, we assumed that even though the tunnel was going to cool down further, after 30 hours, and that's, of course, including the 7-hour fire, that things were held constant from that point. It didn't continue to cool, because that's all the data we had. The temperatures for that particular case maximum reported. For the fuel, it came up to 764 which is obviously, below the 1050A. The canister shell is 809. Cask inner shell was 859. Gamma shield, you're getting out to the outer periphery of the cask, was 934. Now, the outer surface of the skin came up to 1873 and the peak on that, I think, was after the fuel really started to -- or the fire, and Kevin can comment on this, but the fire was obviously well-established, but also that the surroundings, the tunnel and everything else was pretty much up to temperature and so the surface of the cask, you know, obviously responds accordingly, but it peaked out at about 4.8 hours and carried to 7 hours.

Now, another case that we ran was a ventilated tunnel where Kevin actually opened up the ventilation to the fire so it burned hotter. However, one of the things that was mentioned and this was per Chris' recommendations, we went through and did a search of the peal temperatures within the tunnel environment and the average, where the highest average temperatures were and it ended up coming out with this ventilated tunnel since it had kind of a cant to it and ventilated out, you know, in the direction of the tunnel tipping up. Basically, the peak temperatures were reported out around 30 meters from the fire ignition source.

Some of the assumptions associated with that are the conditions, the same as the previous for the pre-fire fire conditions were the same as the previous actually, but it was 30 meters up from the fire source. And then post-fire conditions, the neutron shield material again, was pristine until after the fire was out and tunnel BC's were held 19 hours past the fire, but basically, we ran out of data again at 26 hours, so we just held those temperatures and velocities at that point.

The temperatures are somewhat similar here. For this particular case, maximum reported, 776 for the fuel, but you know, out to the surface of the cask it was at 1821 or further away from the fire. 6.3 hours is where it peaked out and carried to seven. It took a little longer to heat up the portion, obviously, of the tunnel, I think, is where we're seeing response from the 4.8 to 7 versus the 6.3 to 7.

I guess at this point, I'd like to open the floor to questions. Sure.

MR. RESNIKOFF: I realize that you've taken a cross-section with -- the hottest cross-section of the cask --

MR. ADKINS: Sure.

MR. RESNIKOFF: -- to magnify some of the results that you might see. But I have a few questions about that. Since it's a 2D analysis, there are parts of the cask that you have not been able to model.

MR. ADKINS: Yes.

MR. RESNIKOFF: Like the drain port, the bolts that head into the cask.

MR. ADKINS: Sure.

MR. RESNIKOFF: Do you intend to do that?

MR. ADKINS: Yes. I will comment on this particular model, though. You know, one of the things that we're seeing and we have one that we're coming to completion on which is another cask that we're evaluating and one of the things that we're seeing currently is again, you know, one of the things that I told you about, the impact limiters, is you're going to have the material melt back from the skins and you're going to have a huge insulated barrier and then basically you look at the surface of this cask and it's covered with neutron shield except for the impact limiters for the most part and maybe the top pivot trunnions (ph), but all your drain ports and everything else are covered by an impact limiter.

Now, another thing that --

MR. RESNIKOFF: That may or may not be true. If there's an impact then the whole impact limiter could smash down.

MR. ADKINS: That's true, that's true, but one thing to keep in mind, too, and I agree and, obviously, that will need to be further discussed. One thing to keep in mind, though is these casks are drop tested to 30 feet and, you know, they're designed to maintain their impact limiters because they are the protective devices of the upper and lower portion of the cask. They're also a thermal shield. One of the things that also needs to be considered is you have these drain ports that are underneath the impact limiter and we're -- typically -- I won't say typically. This particular cask design has metallic seals that have a service temperature up to 1200. Okay, the peak temperatures that we saw in the gamma shield of this particular cask at the hottest cross-section is 980.

MR. RESNIKOFF: That's degrees Fahrenheit.

MR. ADKINS: Yes, good point.

MR. RESNIKOFF: Now, I notice that you've done the simulation that you showed us is for a 20-meter distance and I assumed you have another one for a 10-meter distance or not?

MR. ADKINS: A five-meter and a 20-meter distance.

MR. RESNIKOFF: A five-meter distance

then. Is there another one here for five meters?

MR. ADKINS: It should be in your hand-out, I hope.

MR. BIRKY: Yeah, it is, right here.

MR. ADKINS: The one after it.

MR. RESNIKOFF: I'm sorry.

MR. ADKINS: The 20-meter first and then the five-meter.

MR. RESNIKOFF: Okay, well, let me just say that there's an accident limit for the canister shell in the HOLTEC TSAR of 775 degrees Centigrade and that seems -- is that reached within how many time -- what time, 775 degrees Fahrenheit, excuse me. And that's reached within what, five hours, three hours?

MR. ADKINS: Is that correct, Chris?

MR. BAJWA: I'd have to check the TSAR, I don't know that.

MR. ADKINS: 775 is low to me.

MR. BAJWA: That sounds low for stainless steel.

MR. RESNIKOFF: I have that. I'm glad you asked that. I brought the handout, I brought the page. I copied it out of the TSAR. Let's see, it's page 3.5-11.

MR. BAJWA: That's -- it does say here 775 degrees Fahrenheit. I'd have to look at the TSAR to see why they picked that number.

MR. ADKINS: Yeah, because my understanding is that particular design, they don't even count on the canister being the containment boundary.

MR. BAJWA: Right, so in HOLTEC's opinion, whether the MPC shell failed or not, it wouldn't matter. That's how they designed the test.

MR. RESNIKOFF: This is the TSAR that you approved?

MR. BAJWA: Yeah, right.

MR. RESNIKOFF: Yeah, okay.

MR. ADKINS: The canister isn't the primary containment boundary on this system.

MR. RESNIKOFF: Well, but if you're counting on the fuel assemblies, you're counting on the cladding being the primary containment, you're looking at the 778 degrees Fahrenheit, but if you also looked at the bolts for the cask, you would probably find that they would fail, too. This is my conjecture. That is, and if the canister itself failed, and if some of the fuel elements were damaged, and there are a small percentage that are damaged, you know, that had degraded cladding even before you, you know, start this simulation, then some of the material will get out of the cask. I mean, all those ifs.

MR. HODGES: That's a lot of ifs. And I believe what we actually considered here when we did the analysis, if you looked at the canister, looked at the temperature as it was observed and we used the limit from, I think it was an ASME code as far as when you start getting creep failure of the materials, and considering the internal pressure of this canister and looking at potential for creep failure and so what we concluded is it would not fail. We didn't just use the HOLTEC temperature limit. We looked at the material and creep failure.

MR. RESNIKOFF: You're looking at whether the wall of the canister actually fails? Is that what you think is going to fail or do you think the bolt -- do you think the bolts are going to elongate, the seals on the --

MR. HODGES: Well, first off, the canister --

MR. RESNIKOFF: -- imports might fail?

MR. HODGES: The inner canister is a welded inner canister. It does not have bolts. We looked at that inner canister and whether or not under the conditions it would fail and based upon creep limits from the ASME code, the answer is no.

MR. RESNIKOFF: Well, there's an inconsistency between what you say and what the TSAR says.

MR. BAJWA: You'd have to look and see what --

MR. HODGES: What you have in the TSAR is probably a conservative limit for other reasons. What we're saying is, in the fire, would this fail and based upon creep limits and ASME code.

MR. HALSTEAD: Well, I have three general comments to make on this and I won't make these long ones because I'm hoping at some future date, Wayne and Chris, that we'll have another meeting. As I've said, for the next three weeks, our primary concern is analyzing this information relative to a rather small issue, that is how to specify a fire test for PPS. And we're not satisfied that the larger issue of the sufficiency of the cask performance requirements in Part 71, but frankly, we're going to spend time between June and December of this year working on that.

But first of all, it seems to me that there are some specific differences of opinion here about the performance of the specific cask that you evaluated. Secondly, I have a general concern that I can't explain as to why your findings are so different than some of the other analyses that we rely upon. In particular, I'm looking at the performance envelope analysis that Professor Miles Greiner prepared under contract from DOE. So it's certainly not that I'm throwing research at you that was necessarily funded by the State of Nevada.

And thirdly, we think the most important issue regarding the adequacy of the regulations is given the uncertainties about what happened in the Baltimore fire, making a conservative assessment of what the worst fire could have occurred there based on the NIST findings, what happens if the most vulnerable cask currently certified by the NRC that could be used in rail shipments, and remember that includes the truck casks, because they have been used in rail shipments and there are proposals to use them large scale.

And we also have the issue of currently licensed rail casks the IF300 and the NLI1024, in which there are major differences both in terms of the thermal mass, we're talking about 24 to 27 ton packages compared to 130 to 140 ton packages. We're talking about major materials differences, steel, lead steel for example, as opposed to the composite steel construction. So my third concern here and the biggest concern I have with the way that this whole body of research has been put forward publicly by the NRC is to say we took this analysis of what happened in the Baltimore fire and we took a cask that in my opinion has extremely good inherent thermal performance characteristics, and includes an extra regulatory barrier which the State of Nevada has advocated for many years, i.e., a welded canister which, in my opinion, provides most of the protection both in terms of creation of direct pathways for escape of cesium 137, but also has thermal significance as well. So that's the issue that I'm hoping we will come back to after we've had time, first of all, to deal with our immediate burden of dealing with the PPS implications of all this.

And I know we're going to get into, you know, some -- you've done all the presentation work, right, you're going to put forward?

MR. BAJWA: That's correct.

MR. HALSTEAD: I want to just take a couple of minutes to say how much we appreciate having this meeting. Those of you who are close to this particular issue know that there has been -- there have been some extremely hard feelings between Nevada and NRC, on Nevada's part for feeling that we were excluded from meetings and I'm sure on the Commission staff's part, a feeling that someone who's not even a licensee has asserted the right to interfere in management prerogatives. I really try to see both sides of this. And having been a project manager, I know how difficult it is to have meetings with contractors when preliminary reports and data have to be evaluated.

All that said, I'm sorry that we didn't have a meeting like this back in July of last year, before you started your work. I'm sorry that you didn't invite us to the table to explain our initial analysis of the fire and our plans, which have always been pending the completion of the NTSB studies to come back and take a look at the Baltimore fire with that information in hand. And my goodness, that may be years from now as the NTSB schedule goes. I think it would be useful if we could work out a better protocol for the way that you provide information.

We feel that we were unwisely, if not unethically and possibly illegally excluded from early meetings that you had with your contractors, but we're still researching whether you have a legal right to exclude us and realistically in a post-9/11 world, getting in and out of these buildings, you know, makes it very difficult for people to show up at a meeting and say, "Gee, we'd like to speak". So that's an area.

There's the area of the availability of written documents. You know, we had to file a Freedom of Information Act request in order -- and we burned a lot of resources and frankly, it wasn't very helpful to us and I understand, Chris, that you had some concerns from NTSB as to why you felt you had to withhold an essentially completed document, the NIST report, from August to February but I would argue in return that you could have eliminated the figure that the NTSB was concerned about and then we could have had that data earlier on.

So the long and the short of it is, I would hope in the aftermath of this meeting that we can work out at least as far as the State of Nevada and the NRC are concerned, a better protocol for interaction between your staff and contractors and our staff and contractors on these issues so that we don't have to continually rip each other to shreds in public.

Now, we're going to have an adversarial

relationship because that's how licensing dockets work, but I think that this could have been conducted better. I wish from my initial contacts with Wayne Hodges that I had thought this through and decided what do we really want, what do we really need, how can I clearly state that to the NRC in a way that would make it easier for them to comply with that and I think you have to look at the model of stakeholder interaction that has been established in the package performance study. Now, we're not going to parking lot it here, because for many things that I think haven't been done in a mutually advantageous way, I think that there's a good model for the NRC to consider patterning its future stakeholder interactions on, and Chris, you've been part of that. And so you've seen that it can be messy at times when it gets to the issues.

So before anything else, I guess I want to just reiterate again how appreciative we are that you scheduled this meeting and brought your people in. I find that while there are a lot of unresolved issues, the issues that we needed to deal with most for the May 30th deadline, I think this meeting has been extremely helpful. I think on the larger issue of looking at what happened in the Baltimore Tunnel as a potential insult to an NRC certified cask, I believe that's still largely open and we would hope to interact with you again on that. Thank you.

MR. RESNIKOFF: I know you had some more specific --

MR. BAJWA: What I'd like to do, Marvin, if you could hold you question just we want to try to get to it but we have run over time and I did promise that we would give anyone in the public who would want to comment or question. I'd like to do that. Before I do that, I'd just like to make a comment on your third point about looking at other cask designs. We are currently doing that for the Baltimore Tunnel Fire exposure and when we get to a point when we have some results on that, we will put those out and share those with you.

We are also concerned about other cask designs. We will not deny that the HOLTEC Hi-Star is a robust design and has performed very well, obviously, in the analysis that we've done. So we are looking at other cask designs. So I'd like to go to anyone in the public if you have a comment or a question to step to the podium and state your name and affiliation if you would, and we'll go from there, unless we've scared the public away. Okay, Marvin, why don't you go ahead?

MR. RESNIKOFF: Has this been written up yet? Do you have a report or is just all in overheads?

MR. ADKINS: You've got some information in the FOIA, basically on the approach for the five-meter and 30-meter primary evaluations.

MR. RESNIKOFF: I just got a few overheads is what I got from the FOIA. Is something else in the mail?

MR. ADKINS: Something else is being worked on. At this point I don't know what the status of it is. There will eventually be a more formal document that explains the approach for this. We just haven't had time to gin it up basically.

MR. RESNIKOFF: Is there any -- do you have any estimate as to when that's going to be done?

MR. ADKINS: I'd only be speculating. I really can't tell you at this point.

MR. RESNIKOFF: Because it's fairly hard to digest all of this without also looking at the nitty-gritty of it all.

MR. ADKINS: The one thing I should have mentioned right at the beginning of my presentation, but there's only so much you can pack into -- keep in your head, but there's a lot of detail in the slides that typically isn't mentioned in a situation like this, just because slides are meant to be brief. There's a lot of information in those slides that you pare it down and that was included for your benefit in case you had questions associated with that particular analysis.

And you know, Chris is obviously more than equipped to answer a lot of the questions, too, because he was in on the ground floor as well.

MR. RESNIKOFF: Well, let me just ask one more specific question. Just looking at the neutron absorber on the outside, it's your judgment that if the neutron absorber melts away, that that actually provides less conduction, well, definitely less conduction, but there's less heat removal or heat going into the cask when you have no neutron absorber than when you do. I mean, the design of the HOLTEC cask with these half-inch radial connectors, it's designed because the neutron absorber is an insulator.

MR. ADKINS: Yeah.

MR. RESNIKOFF: And you need to get rid of that heat some way and so they've -- those elements, those radial elements also serve as a heat conduction pathway.

MR. ADKINS: Sure.

MR. RESNIKOFF: So, I'm sort of -- I'd like to see more detail about it, but it doesn't look like the presence or absence of the neutron absorber makes much difference in the scheme of things.

MR. ADKINS: I wouldn't necessarily go to that because I can tell you hands down the difference between the neutron absorber and pure air. There's a substantial difference on conductivity and I don't recall those values offhand. It's been awhile since I've looked at those. But, you know, another thing to consider, too, is you know, as far as the heat path in, typically what this -- it's a polymeric material. It's like an epoxy and what it does is, it's -- if I remember right, it's a thermoset. It may not be a thermoset but the stuff chars so bad that it leaves no gap for radiation interaction. I mean, it just basically degrades the conduction path.

So the fins really are the key to the design of those casks. And -- well, I guess that's all I should say.

MR. BAJWA: Merritt?

MR. BIRKY: Well, I sort of have a question on follow-up on that in terms of the fins. When you do the calculations, does that take into account when that happens, what happens in terms of the temperature rise and that sort of thing and once you lose that path?

MR. HODGES: Where you get the pyroboric reaction and all of a sudden there's no path through that. Well, we have assumed it's there through the course of the fire to maintain conservatism. Do you see what I'm saying? I mean, within the seven-hour period as you can see, we're up, I think the service temperature of the stuff is up in the -- if it's anything like the Bisco, it's like 300 Fahrenheit, 400 max, maybe 250.

And then if we take a situation where we're saying that it's fully intact at, you know, 900 to 1400 through the course of the fire, you're saying that, you know, it's drawing in more heat than if you were to let it degrade. And then, you know, when it chars --

MR. BIRKY: But then you have more heat load to get it to dissipate, though, too, do you not, from the fuel? I mean, how does that get out then?

MR. ADKINS: Well, that's the point, it can only get out through the fins after we degrade it to the level of oxygen and say that there's no radiation interaction in there. So basically, if you were to look at -- and I understand what you're saying there. If you were to look at pre-fire, fire, post-fire, and if you were to expose the cask well into the post-fire and let it come to steady state, after the stuff was charred, the inner components of the cask would be above temperature, but by the same token, to find out that evaluation where that would reside is those values are in the TSAR. The reason is, is because they have to evaluate that cask after the neutron shield material gets charred and they do a similar approach.

They say that it's in full tact through the fire. After the fire it's gone, so they have nothing to air in that void and obviously, the inner components are going to come up to temperature, but by the same token, typically after the cask comes out of the fire, another reverse weighing component is the fact that being sooty, you're typically higher on the outside just because of the sooting and --

MR. BIRKY: Now, you refer to air, but the thing is charged with helium, is it not, part of it?

MR. ADKINS: No, not in the neutron shield.

MR. BIRKY: No, further in.

MR. ADKINS: Yeah, but I wasn't talking

about anything to do with that. I mean, mainly what you're doing is taking the conductivity through that thin layer on the outside and reducing its conductivity slightly because the neutron shields material is gone.

MR. RESNIKOFF: The concern I have is the cask outer surface, I mean, your 30-hour NIST fire has a cask outer surface of 1873 degrees Fahrenheit. These conductors -- the outer surface is at 1875 and that's directly connected then to the shell. But the shell then is down at 934, about half the temperature of the outer shell even though they're connected.

MR. ADKINS: Yes. And part of it is, is because if you look at the way those are attached, it's a tiny little weld that's attaching it. I think it's roughly a quarter inch and there was some weighing that we did at that particular juncture and I need to go back and revisit that but one of the things is, too, is the cask has a huge thermal inertia. It's only on fire for seven hours. You called it a 30-hour fire. It's not a 30-hour fire. It's a 7-hour fire. Over the beginning portion of the fire, when it starts up, especially at the 20-meter -- I'm going to get all these numbers mixed up -- the 20-meter portion, basically what's happening is you know, it's coming up to temperature a little slower because all the environment around it is coming up to temperature slower and then another thing that you have to keep in mind, too, is, is at the same time, when it's coming through this hot portion of the top cask, there's huge conduction paths all the way around the cask, so it's redistributing the heat readily.

MR. RESNIKOFF: So you don't assume then that this half-inch radial connector is connected to the cask body at a half inch. You assume a much smaller connection so there's not a big connection path?

MR. ADKINS: I'd have to go back and check but if I remember right, full credit is given to that till after fire.

MR. RESNIKOFF: Okay, well, I guess that will come out in your paper.

MR. ADKINS: Yes. The main driver though, is the conduction path that's circumventially around, you know, because you're talking seven inches thickness steel, seven inches thick.

MR. RESNIKOFF: Right.

MR. ADKINS: And it's only the top portion that's exposed to this hot gas, whereas, the side -- and you know, this is relative, obviously relative, because these are extremely high temperatures, but the side portion, the air is substantially cooler than the top portion and the bottom is substantially cooler than, you know, the top portion and also the side portion.

MR. RESNIKOFF: Well, as I remember, the slides that were shown at the ACNW you had it actually a time -- you showed over time what was happening to the various temperatures and you showed the under-carriage heating up slowly, much more slowly than the top. I remember that, but then in your model I assume this was taken into account, you assume that the under-carriage was then reradiating the heat as the fire declines.

MR. ADKINS: Yes. I'm not familiar with the term "reradiation". I think what you're saying is radiation interaction within the tunnel, so you have the cask, the tunnel and the cradle all interacting with each other. Yes.

MR. GARABEDIAN: I have a quick comment to add to the fin --

MR. RESNIKOFF: Just as long as it's not a question. We're asking all the questions here.

MR. GARABEDIAN: No. My experience in actual fire testing would demonstrate that the temperature on the inside of a steel plate, let's take a bulkhead of a ship that's connected to another bulkhead with a fin stiffener, you have to take into consideration the percent area that you're talking about. It took the cumulative area of steel and contact with steel and took it over the entire circumference of all of the other area that's not in contact with steel. That's a better indicator of how that temperature is going to get distributed. If you have a certain percentage of steel in contact, it will be governed by the rest of it that's not in contact by a function of the area. It's an easier way to look at it.

MR. BAJWA: All right, I'd like to give another opportunity to any members of the public who would like to make a comment and then we need to start wrapping things up. So last chance.

(No response)

MR. BAJWA: Okay, seeing no interest, Wayne, I'd like to give you a chance to make some closing comments and then I have a few more kind of paperwork stuff to clean up before we close out for today.

MR. HODGES: I don't have a lot to say in closing other than we've tried to present in as much detail as we thought you'd be interested in what we did in analyzing the fire. We still think given the limited data, it was the best analysis we could do. We've tried to make things bounding and we think it shows the robustness of that cask. We agree that other work on other casks is needed. We're going to look at them. We'll look at the other conditions and all these analyses take time.

MR. BAJWA: Okay, I've been told that there are additional copies of the handouts and so if you didn't get a copy of the handouts when you came in, please come to the front here.

The slide that's up now is just some additional information. There was a recently released Commission paper which summarizes, basically, what you've heard today. And it is available on the web and the address is there in case you want to look it up.

The transcripts for this meeting will be available. We will make them available via the web as soon as we can. That usually takes, in my experience, two to three weeks to get back but we'll try to do that as quickly as we can.

Finally, there are the public meeting evaluation forms. Some of you picked them up, some of you may not have. If you have not, please pick those up and fill them out, if you can. And basically, I'd like to thank everyone for coming. I think this has been a very useful meeting. I think there's been a lot of good information exchanged. Obviously, this issue is ongoing and will continue. There is work to be done on both ends from what I gather and we appreciate any input that you have in what we've done. As you take these slides back and digest them and maybe think about it more, you may have some suggestions or additional comments. Please feel free to send those directly to me.

And Bob, you mentioned that we might want to have a meeting in the future. If we feel that we need to do that, we're open to doing that. So, thank you for coming.

(Whereupon, at 11:51 a.m. the above entitled matter concluded.)