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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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RADIATION AND NUCLEAR MATERIALS SUBCOMMITTEE

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WEDNESDAY, MARCH 2, 2016

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B1, 11545 Rockville Pike, at 8:31 a.m., Dennis C. Bley, Chairman, presiding.

COMMITTEE MEMBERS:

DENNIS C. BLEY, Chairman

RONALD G. BALLINGER, Member

CHARLES H. BROWN, JR., Member

DANA A. POWERS, Member

HAROLD B. RAY, Member

PETER RICCARDELLA, Member-at-Large

GORDON R. SKILLMAN, Member

JOHN W. STETKAR, Member

ACRS CONSULTANT:

STEPHEN SCHULTZ

DESIGNATED FEDERAL OFFICIAL:

CHRISTOPHER L. BROWN

ALSO PRESENT:

HAROLD ADKINS, PNNL

JOE BOROWSKY, NMSS

JIMMY CHANG, NMSS

JAMES FORT, PNNL

DONNA GILMORE, Public Participant*

DAVE HOFFMAN, Public Participant*

MERAJ KAHIMI, NMSS

WALT KIRCHNER, Public Participant

MARK LOMBARD, NMMS

JASON PIOTTER, NMMS

ANDREA D. VALENTIN, Executive Director, ACRS

*Present via telephone

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Adjourn

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

(8:31 a.m.)

CHAIRMAN BLEY: Good morning. The meeting will now come to order. This is a meeting of the Advisory Committee on Reactor Safeguards Subcommittee on Radiation Protection and Nuclear Materials.

I am Dennis Bley, Chairman of this meeting. Members in attendance are Harold Ray, Dana Powers, John Stetkar, Dick Skillman, Pete Riccardella, and Ron Ballinger, and our consultant is with us, Steve Schultz.

The purpose of this meeting is to receive information briefing on Staff's development of Draft NUREG/CR-7209, a Compendium of Spent Fuel Transportation Package Response Analyses to Severe Fire Accident Scenarios. The Subcommittee will hear presentations by and hold discussions with representatives of the NMSS Staff.

A little history; back almost forget, it was 15 years ago or so there was a National Academy study that looked at transportation and kind of thought everything was okay except they said the case hadn't been made for fully engulfing fires. And this work, I think -- it started before that, but it continued after that with a lot of research at NIST we'll hear about.

The rules for participation in today's meeting have been announced as part of the notice of this meeting previously published in the Federal Register on February 18th, 2016. A transcript of the meeting is being kept and will be made available as stated in the Federal Register notice.

It is requested that speakers first identify themselves and speak with sufficient clarity and volume so that they may be readily heard. We ask at this time that you silence your phones and other electronic devices. Although we have -- I don't think I did mine yet. Although we have a bridge line open, it's currently in the listen-in mode only during the meeting and no one from the public has requested time to make any oral statement or written statements.

Did I skip a -- yes, I think I did. Chris Brown is the Designated Federal Official for this meeting. Sorry, Chris.

We will open the phone line late in the meeting to allow public comment.

We'll now proceed with the meeting, and I call upon Mark Lombard, Director of the Division of Spent Fuel Management, NMSS, to begin. Mark.

MR. LOMBARD: Thank you, Dr. Bley, appreciate it.

As we've discussed with you all and with the Commission, as well, there's a lot of moving parts to the spent fuel puzzle, and the discussion today is Draft NUREG/CR-7209 that we'll be presenting is really an important part of that puzzle.

We've issued the Draft NUREG for public comment on January 25th, and encourage your comments, as well. The comment period closes on March 28th. It really contains a summary of four case studies of severe fire accident scenarios and refers to extensive analyses that we have performed over the past 14 years, as you've pointed out.

It complements work that we've done on spent fuel transportation risk assessment. We've reissued that report about a year and a half ago, and it complements, again, the information we have in the SFTRA, S-F-T-R-A, report, shows that the risk of spent fuel transportation is really less than that that's posed by background radiation, and I think we found through the fire studies the risk of engulfing fires to spent fuel transportation safety and security is low, so we'll go through some of the details today.

I'd like to introduce folks at the table. From the Division of Spent Fuel Management is Jimmy Chang and Joe Borowsky, who are our main compilers of this information that went into the Draft NUREG, and also from PNNL, the Pacific Northwest National Laboratory are Harold Adkins and James, I'm sorry, James Fort. I almost forgot your last name, James Fort. PNNL provides us really good support here in the thermal areas and other areas, as well. But primarily in the thermal areas, they really have helped us out on licensing support, but also case studies such as what you'll find in the spent fuel -- I'm sorry, the Fire Compendium. So without further ado, I'll turn it over to our folks and start the presentation.

CHAIRMAN BLEY: Just before you start, I should announce that Member Charles Brown has joined the Committee at the table. Thanks, Charlie. Go ahead.

MR. CHANG: Okay. Good morning, Committee Members. I'm Jimmy Chang.

As you see the title, Compendium of Spent Fuel Transportation Package to the Severe

Fire Response Analysis to severe fire accident scenario. I will talk about accidents in low way and my colleague, Joe Borowsky, will talk about the fire accident and the low rate.

The talk will cover the motivation of severe fire study regulation, fire scenario and consequence, and then conclusion. The first part talk about Part 71. Part 71 has three main sections. The first one, how to approve the design of a package. The second part, how to test your package.

We have five tests, drop test, crush test, puncture test, fire test, and the last one, water emersion test. In the meantime, Part 71 also provide operating control and procedure, so this amends main section in Part 71.

I want to go back the history about this research, this study. The first NRC light, the Sandia light, the fire may exceed the condition defined in the Part 71 regulation. In Part 71 define the fire temperature is 1475 Fahrenheit, that's 800 Celsius for 13 minute. However, based on a accident in railway in Baltimore in 2001, NRC did the research and later on NIST, National Academy of Science, they build a database and the research and analysis, and they commend in their 2006 report that you see in the slide from going the distance, recommend additional analysis in the fire accident. So, at that time NRC continue another three accident in the low rate; Caldecott Tunnel fire, Newhall Pass Tunnel Fire, and MacArthur Maze fire. Joe will go through more detail in those three low rate accident.

CHAIRMAN BLEY: Your reports on those three are now -- all of them are available publicly, I notice.

MR. CHANG: Yes. Again, we talk about the topic. NRC has conducted the research in type and quantity of view available in actual fire, and the possible range of temperature in ideal condition and the real condition, and how long the fire could be in an accident, and the effect on the package from small sites to the large site from low decay heat to high decay heat. And it was a different design configuration. And also look into the behavior of important to several components during the fire.

When I talk about ITS important to focus on the field creating containment seal, neutron seal, and the gamma shield. In the meantime, we also look into the additional action, any action we can take, we could have to minimize or exclude the accident. Next slide.

So NRC work with PNNL, Pacific Northwest National Laboratory. We have our two friends over here, and NIST, and CNWRA, Center for the Nuclear Waste Regulatory Analysis, and we worked together, and we published a lot of report, like the first one, the railcar component to tunnel fire. And we had a database for railway accident and roadway accident. And like number four we do get a structured response to the fire. And number five, we look at the performance of containment all the material. And for the last four, Baltimore Tunnel fire, Caldecott, MacArthur Maze, and Newhall Pass we also look at the fire effect on those package. However, I need to emphasize not those four fires, Baltimore, Caldecott, MacArthur Maze, and Newhall Pass really involved radioactive material. No they are not the radioactive material spent fuel, either they still want to look at the impact for the spent fuel on the roadway or the highway, how -- what could happen, and we want to study that condition.

So now let me -- let's look at railway

accident. When we talk about a severe fire there are two criterion. The first one, the rail car must fully be engulfed in the fire. We had the finishing what would be the engulfing fire and that information in the compendium. And the second one, the principal source of fuel must come from another vehicle.

People may question is that the only source for the fuel, is that possible? We may neglect other source of the fuel. My answer is no, because based on the regulation requirement of -- we do ask for the railway -- a railway, we only allow the spent fuel radioactive material cask in the train without in the one rail car without other freight. So, therefore, the fuel source must come from another rail car because in this rail car we only have spent fuel cask without other freight. And that is the same situation for the roadway condition, one track only carrying spent fuel cask. Therefore, this will be --

CHAIRMAN BLEY: Jimmy, is that by NRC policy? Is that by law, is that by railroad agreement? What assures us that there are -- that the trains are dedicated?

MR. CHANG: Well, I think DOT regulation

has that requirement.

MR. BOROWSKY: Yes. I mean, I just want to stress that it's -- what Jimmy had said was that the package is on a single rail car, and there can't be any other combustible material on that rail car. So in order to --

CHAIRMAN BLEY: Just on that one rail car, or is the two adjacent to it, as well?

MR. BOROWSKY: Well, if there is any type of combustible material, if there were to be, they would have to be a buffer car --

CHAIRMAN BLEY: Okay.

MR. BOROWSKY: -- between them.

CHAIRMAN BLEY: And that's DOT regulations.

MR. BOROWSKY: That's a DOT regulation. Correct.

CHAIRMAN BLEY: It is regulation, though.

MR. BOROWSKY: Right.

CHAIRMAN BLEY: Okay.

MR. CHANG: Yes.

CHAIRMAN BLEY: There could be on the rest of the train, but it's just not the car the cask is on, or the two next to it.

MR. BOROWSKY: That's correct. It's possible.

CHAIRMAN BLEY: Yes, okay.

MR. CHANG: And that is DOT regulation 49173.

Again, I focused on the railway accident. Now we want to see the potential for how -- for high temperature and longer duration fire in the railway. We look at five factor, railway material, fuel formation, orbing effect, space distribution, and the oxygen supply. And we want to know which tear could be most severe in open field or in tunnel, and we compare -- first we look at the rail bed material instead of the polar substrate in the open field. Most of the tunnel we had rock, concrete, and pavement for the tunnel, and that's not easy to form for the different form of liquid to fully engulf the package.

And the second orbing effect with the fire in the tunnel, the fire will raise the temperature on the tunnel wall, ceiling, and the ground. And even the fire is extinguish the heat will continue transport from the wall, ceiling, ground into the package like a secondary heat input, so that is the condition with spent high temperature in packaging in tunnel. And then because the limited space in the tunnel it's more difficult for emergency people to cool down the tank to extinguish the fire. So if we look at the factor from one to four in favor, that means we will have the fire temperature in the tunnel.

The last one, the oxygen that it could be more favorable to the open field fire. However, we found out the hotter temperature and the long duration fire is in the tunnel, it's tunnel fire. That's why we think about that in the case we look into in this study in this presentation.

CHAIRMAN BLEY: Now before you go on, in some tunnels, I would think in longer tunnels, they probably have ventilation shafts. Is that true, so that you would get some circulation?

MR. CHANG: We do both study without ventilation and with ventilation. We do both.

CHAIRMAN BLEY: Okay.

MR. CHANG: And we pick up identical details for Baltimore fire. The fire last about three hours, three hour in an actual situation. However, in some analysis we assume seven hour based on full ventilation, and we look at that case and think about conservative, so we do the -- we did consider that situation.

CHAIRMAN BLEY: Okay.

MEMBER BALLINGER: I have another question. I have some experience with the tunnel in Boston where they did a poor job of attaching the ceiling tiles which weigh several tons each. And one of them came off and fell on a car and killed somebody because there's an epoxy ceiling thing where the studs went in. In these tunnels, is it -- has anybody looked at the fact that the ceiling tiles are not really -- they're not the kind of tiles that are in this room. They're these cement tiles that divide the air flow space from the personal space, the possibility of those things coming down on top of the package and complicating life?

MR. BOROWSKY: In one of our analyses, was the MacArthur Maze scenario. This was a roadway accident. It's kind of an analogy to what you're saying. In that situation there was a roadway and an overpass, and because of the high temperatures from the fire what happened is basically it weakened the overpass spans and they came down and impacted the package. And I'll present the results in a little bit, but basically the strain on the package was very minimal.

MEMBER BALLINGER: I'm concerned about people getting to it, if all these -- if the ceiling basically comes down in that part of the tunnel, access, like you were talking about, access for medical, for other people.

MEMBER SKILLMAN: Jimmy, I'd like to ask a question, please. What is the degree of buy-in of the codes that have been used for these analyses? There was a time when the NRC only used the scale codes, NMSS only used the scale series of codes for these analyses; although, there were other very elegant and widely used industry codes that could have been used. So for the requirements of the Part 71 they kind of back into 49 CFR which are the transportation regulations, what codes are acceptable and what is the standard by which you are using those codes for acceptability?

MR. CHANG: We used the computer code, COBRA-SFS. That computer code -- we used two code. I will give more detail in the slide, next one, but basically we use two type of computer code. The first one we call FDS, Fire Dynamics Simulator. That was developed by the NIST. We use that one to predict the fire condition in the tunnel. And then we use those output as input for the summer structure code, either COBRA-SFS. That was developed by the PNNL and the ANSYS to see the summer response in the package. However, let me give you more detail.

MEMBER SKILLMAN: Let me pull the thread a little further and you'll see the direction of my question. Are the cask manufacturers using those same codes, and are they aligned with you in use of those codes?

MR. CHANG: The kind used, I mean the packaging manufacturer used the -- many type of computer code ANSYS in COBRA-SFS. We have the NUREG as the guidance to tell the user or the manufacturer what type of code we approve. We did the tunnel review and the provocation, so the cask user or manufacturer need to use the computer code we approve.

MR. ADKINS: Another thing I'd like to add. This is Harold Adkins from PNNL. Dr. Skillman, very good question. So either indirectly or directly those codes that the applicants apply are evaluated based on the results that they produce and the analytical methodology that they employ by virtue of the fact that either our lab or other labs that support the NRC will apply those codes that are more often validated heavily. In fact, to speak to COBRA-SFS, DOE -- that was a code that was developed by DOE. It was used to perform 78 -- more than 78 blind pretest predictions on standard NCT, as well as NCS storage evaluations, and also some fire benchmarks that were performed, actual fires for the calorimeter study at Sandia.

As far as the structural codes that were employed on some of these particular applications like the MacArthur Maze that Joe Borowsky spoke of, there's been a lot of validation studies and some validation history associated with that code, as well, so I would think in the same light they would have the same pedigrees like a scale code. In fact, COBRA-SFS was reviewed by NRC for DOE, so they were hired to review the outcome of that code and the particular details associated with that, and how it benchmarked to perform its validation against those blind pretest predictions in Idaho, and it was found to yield very good results. And that's exactly why the NRC cut a contract for independent evaluation to PNNL.

MEMBER SKILLMAN: Harold, thank you.

MR. ADKINS: You bet.

MR. CHANG: So now I'm talking about -- I will talk about the Baltimore Tunnel fire scenario. It was called Howard Street Tunnel fire, like the tunnel located in the City of Baltimore. In 2001 a train carrying flammable tripropylene derailed and then the tenth car was punctured by the braking vehicle containing them, so the flammable liquid leaked and caused the fire.

The flammable liquid tripropylene has a combustion heat almost identical to gasoline. In Compendium we compared with different studies about different type of flammable liquid, the combustible and we found out that combustion heat of tripropylene is at the higher end of the combustion energy. So what we did in this case, we pick out a high combustion flammable material and as you see in the second bullet, the ignition was around three hours estimated by the NTSB, National Transportation Safety Board. However, we assume if the tunnel was fully oxygenated the fire could last seven hours with gas temperature about 2,000 Fahrenheit in the flame region. And at 66 feet downstream the temperature was near 2,000 Fahrenheit. That's greater than 1475 Fahrenheit defined in regulation, and seven hour, it was longer than the thirteen minutes again defined in regulation, Part 71.

So now let me talk about --

MR. SCHULTZ: Jimmy, can you provide a qualitative discussion of what has determined the fully oxygenated case? As you describe that, it could have lasted seven hours if it were fully oxygenated. What factors went into that evaluation versus the actual three-hour case?

MR. ADKINS: Yes, absolutely. This is Harold Adkins from PNNL again. So backing up that slide, there were a couple of factors that were taken into account, one of which was when this accident occurred the only thing that NIST could surmise -- and again, you know, based on one of the questions that was asked previously. This is a code that's heavily validated, the FDS code where they've validated its fire consumption rates and heat output based on a number of different fires, Runehamar fire and a couple of others that I'm not recalling at this current moment. So anyway, they took this validated code and they couldn't figure out why the fire didn't burn more than three hours.

And then the other thing, too, is based on the data that was collected that didn't corroborate, it indicated that the temperatures were lower than what they would initially find during the fires, so we set that as a high point and said okay, you know, clearly there was fuel that got absorbed into the rail bed and things of that nature.

One of the other telling factors was the ventilation fans were shut off on the Baltimore Tunnel when the accident happened. So then what we did is go back and evaluate if the whole fuel inventory was available with full ventilation, which is your fully oxygenated fire, evaluated that temperature point and then did a best estimate of what could actually occur based on how much fuel loss could be assumed in the soil.

And one other key factor is when you have tunnel fires, unless they have an insulated construction with ceramic interface, like the tiles are ceramic in nature, which is not a common practice for construction in the United States, more so overseas, you could end up with substantially higher temperatures. So what we did is, we maximized the temperature that was the seven-hour peak temperature fire with the fuel inventory that was available and then did a best estimate. And you see both of those numbers reported in that particular report. Hopefully, that answers your question.

MR. SCHULTZ: It does, and the ventilation system just happened to be --

MR. ADKINS: Off.

MR. SCHULTZ: -- off?

MR. ADKINS: Yes. I think -- I can't remember exactly the details, but I think it's based on air stagnation because some of these tunnels are slightly canted and they do ventilate, passively ventilate very effectively. However, versus something that's being buoyantly driven or force fed, force feeding, you know, something with oxygen is going to be the limiting case.

MR. SCHULTZ: Thank you.

MR. ADKINS: You bet.

MR. CHANG: Now we come to the computer model. The first step we used our NIST perform -- we used the NIST code, FDA, Fire Dynamic Simulator. We predict a fire condition in the tunnel and then we used that as the bounding condition to the summer code, COBRA-SFS that was developed by the PNNL, and the ANSYS code. We do use the summer code to verify the result to provide more confidence. And we had many conservative in the FDS code when we use for analysis. The first we assume fire fully oxygenated, and burns up to seven hour to fully consume the fuel. The second one in the model we have many -- we define the entire computational domain as many subregion. Instead of the local temperature distribution we pick out the maximum temperature in each subregion and we use the maximum temperature as the boundary condition to the summer code. That's conservative.

MEMBER POWERS: Conservative with respect to what?

MR. CHANG: Excuse me?

MEMBER POWERS: Conservative with respect to what?

MR. ADKINS: I think the question you're asking is, you know, based on a rudimentary comparison how does that maximize your temperatures that are the boundary condition inputs? So what Jimmy is indicating is, when you have a whole periphery around this, and you have pretty much a steep gradient of temperatures around the periphery of this tunnel that would influence the package, what we did is broke that up in zones of what it would see from a radiation interaction standpoint, and maximize that based on the output from the FDS code, and took the highest temperatures --

MEMBER POWERS: Somehow that didn't strike me as pertinent to the issue of conservative. Conservative is something like heat load on my radioactive material or something like that.

MR. ADKINS: In essence it is, because you're taking the peak temperature of the whole zone instead of the distribution of the whole zone.

MEMBER POWERS: It is not obvious to me that this maximizes the enthalpic input into my package. I mean, suppose it's not fully oxygenated, so it's -- the burning of the fire is dictated by the oxygen supply so you have a longer time period in which things burn, but it's not as hot. I get more enthalpy -- I still get more enthalpy into my package than I do with an intense but short fire.

MR. ADKINS: That's correct.

MEMBER POWERS: So I don't understand what it's conservative with respect to.

MR. ADKINS: And I think one of the things that we're trying to do is just hit topically. I think in this particular case, we had 21 different boundary condition sets that we did to seek out -- and you raise a perfect point. When you look at a -- especially a large-scale spent fuel cask, it's got a huge thermal inertia, it's got an internal decay heat load, so it can only absorb or take on heat at a particular rate. So what we did is perform 21 different studies to establish which one elevated the peak temperatures imparted to the fuel, the highest out of all of those cases with the associated boundary conditions on how they could exist realistically. Does that better answer your question?

MEMBER POWERS: It still doesn't tell me why you would write conservative assumptions up there. Those are --

MR. ADKINS: Well, if you start from the very reporting of the details of the accident and the data that was gathered, there were only so many materials that were compromised by the temperatures that were incurred in the tunnel. We're going far beyond that. We're taking all the fuel and figuring out instead of allowing any of it to soak into the substrate, or the soil, or the rail bed, we're --

MEMBER POWERS: Well, those might be arguably conservative assumptions, none of them are listed here.

MR. ADKINS: Oh, that's an excellent point. I think for brevity we didn't go into that because the reports speak for themselves.

MEMBER POWERS: You're trying to snow me.

MR. ADKINS: No. Am I -- maybe, Jim, am I missing a point there?

MR. FORT: This is Jim Fort from PNNL. And I think the basis of the conservative assumptions were stated on this slide, is that we're maximizing the heat input, the heat flux into the cask. You bring up a good point that you could look at a different scenario where you have --

MEMBER POWERS: I can put --

MR. FORT: -- a lot longer fire.

MEMBER POWERS: -- a billion watts onto that cask for 39 nanoseconds and the cask won't even think --

MR. ADKINS: You won't see it.

MEMBER POWERS: You won't see it.

MR. ADKINS: That's correct.

MEMBER POWERS: And that would look very impressive. I'd put a billion watt source onto this thing, but would not be a conservative assumption.

MR. ADKINS: Understood.

MR. FORT: I think what we've done, and you'll see over the course of the scenarios we look at is, the one thing that's common in all of them is that they're based on actual fires. So where we could up with different conditions or imagine different kinds of accidents that would --

MEMBER POWERS: Well, I think that's the problem with the study. The study is that you looked at fires that will never occur again.

MR. FORT: So these are very unlikely to occur, but actually have occurred. And then we look at conservative assumptions that maximize the damage, potential damage to the cask.

MEMBER POWERS: Well, it would be nice to see what those conservative assumptions are. These aren't they.

MR. ADKINS: Yes. I think on the next slide there's some more detail that's given, as we get to it. So that was the basis in this case. You'll see in some other cases where we looked at the effects were more evident of a longer term, a longer fire, and a longer cool down. This was conservative for this test case, is the way we judged it, by maximizing the heat input. The actual accident that was observed was much shorter because it was oxygen-starved and they judged the fuel content was lost to the subgrade, so we made the selection of different conditions that would --

(Coughing.)

MR. ADKINS: I think the case we ran would make it a more conservative or worst case.

MEMBER BALLINGER: I have some other comments. Apart from being able to calibrate -- to calculate a temperature to the nearest degree in these analyses, I think somebody needs to correct the numbers. But when you say conservatism, in these cases there are some boundaries which you cross, for example, the melting point of lead, aluminum, steel, things like that, which if you make a conservative assumption, you may cross one of those boundaries. Where if you did a best estimate, you wouldn't cross that boundary. Have you considered that kind of calculation?

MR. ADKINS: Yes. Yes, we have.

MEMBER BALLINGER: Okay.

MR. ADKINS: And, actually, more of that will become apparent as we go through some of the latter slides. In fact, one of the packages that was looked into -- and an excellent question, an excellent point, is the NAC-LWT, which is a leadlined cask. Right? Or the neutron shield is lead and it's sandwiched by two stainless boundaries. And one of the things that we had to do is look at slump or reduction in shielding, as well as, you know, how its conductivity would change over the course of going through that process.

And then also, you know, one thing that you can count on is latent heat effusion and how that's going to change. It sucks up energy until it finally melts. That was something that we didn't have originally in the model. And the temperature differences were marked, but they're, like you say, you know, when you take apart and make that as a conservative assumption that you don't have melting, you're doing it with slightly higher temperatures. That's correct.

MEMBER BALLINGER: Thank you.

MR. CHANG: Thank you.

CHAIRMAN BLEY: Yes. I want to follow-up Dana's questions on the previous slide.

MR. ADKINS: Sure.

CHAIRMAN BLEY: Certainly, they were all right. And you explained that you ran 20 some cases.

MR. ADKINS: Yes.

CHAIRMAN BLEY: Did it turn out when you looked at all of those cases that the case that led to maximum heat into the cask were the cases where these three things were true, or did you just pick these because these looked --

MR. ADKINS: No. There were quite a sequence and this was some time ago, so I'm going to try to recall all of those and then rely on Jim maybe kicking me on a couple that I forgot. So again, going back to the NIST code FDS, one of the things that we noticed when it had a limited ventilation is that you have the potential of, you know, partially volatilizing the fuel, but mainly making it evaporate and be even part of the cooling of the fire where it doesn't get consumed because there's a lack of oxygen. So one of the things, obviously, is the ingredient to pump up the fire. And then, you know, depending on pool size was another factor. Depending on the pool size you only get so much of a burn rate. And going back to Dr. Powers' question, you know, so how is that conservative? Well, considering the fact that these packages, at least the larger packages have huge thermal inertias, the point that was made is if the fire is instantaneous and you consume all the fuel instantaneously, you will do very little to that cask. So we played with -- played with, that's a poor term, altered the -- and performed a sensitivity study on the full fire square area and burn rate to see what would be the worst effect. And one of the things that comes out of this, and it's easier to kind of establish, what the most damning influence would be, it kind of heads towards Dr. Powers' question, is when you cut off the decay heat load's view to the outside world or to a cooler ambient, that's really the most damaging situation when you're looking at the containment or the confinement characteristics of the cladding of the fuel itself. It's not that the fire insult is passing so much energy into the package, so as soon as its view to the ambient reaches cessation at least temporarily you end up with temperatures and temperature excursions that take place seven or eight hours after the fire.

So to get back to some of the conclusions, or some of the assumptions that we felt necessary to evaluate this as a worst case, we performed all these sensitivity studies and tracked the peak fuel cladding temperature as the determining factor. So how can we cut off that particular entity's view to the ambient, and its influence of being able to reduce or draw the decay heat out, essentially? Hopefully, that answers your question.

CHAIRMAN BLEY: It does a lot better job. Yes, thanks.

MEMBER POWERS: Yes, it would suggest don't put foam on these fires. That's what you said, don't put foam on them.

MR. ADKINS: Don't put foam?

MEMBER POWERS: Don't use foam firefighting equipment on these kinds of fires.

MR. ADKINS: I don't remember --

MR. FORT: Jim Fort, again. As an insulating effect you were saying.

MEMBER POWERS: Yes. That's what you're saying. I mean ---

(Simultaneous speaking.)

MEMBER POWERS: -- a fairly powerful conclusion there to come out of it that didn't --- somehow doesn't emerge.

MR. ADKINS: Well, one of the things that we're going to discuss, too, here, when we had to take a look at -- and this is one of the things that Joe will discuss, when we had to take a look at the MacArthur Maze. Initially we thought, well, you know, it is fully oxygenated because it's open, but there's really only so many surfaces that are going to heat up and have the radiation interaction and elevated temperature to the package until you, you know, go further having the rail structure fall on the package and it's already elevated in temperature, and it does exactly that, is insulate it. Good point.

MR. CHANG: So the next one is the fire boundary condition predict by the NIST FDS code. We transfer data to the COBRA, the PNNL code, COBRA, and the ANSYS, and then we predict the summer response in the package getting the fire and post-fire cool down. We did assumption the rail car and package's supposed structure are neglected to maximize the heat input into the package during the fire. And then we use the first combustion in the fire and natural combustion in the post-fire cool down.

In fact, during the post-fire cool down the temperatures could be still very high, and the first combustion still exists. However, we assume natural combustion to minimize the heat going out on the packaging. And then we put an intent limiter and the neutron shield we retain a nominal property field in the fire to maximize heat input the package. And then back to the normal, and then grade in the post-fire cool down to minimize the heat out of the packaging.

All we want to is maximize the component -- raise up the temperature of the package component. We want to see how hot the component could be. Are they going to abut the temperature limit or still below the limit? So we are able to justify what could be the worst condition to those packaging component. And we used a benchmark decay heat load in the package.

MEMBER SKILLMAN: Before changing, why didn't you consider ignition of the impact limiter? The impact limiters that I've been experienced with are either redwood, cross-redwood, or they are high density polyurethane. Both are combustible. Why aren't those considered part of the heat load? These are big. I mean, these --

MR. ADKINS: This is an excellent question, so like all studies, kind of the system of compromises, what we did is look at the industry workhorses or ones that were going to become the industry workhorses, and of those particular configurations, to make an example, in the Baltimore Tunnel fire study, if the impact limiter is exclusively made of seven different types of oriented honeycombs, whether it be flex core, cross-core, what have you. So, essentially, the only thing it has to contribute to the fire other than aluminum oxides and things of that nature is literally the epoxy that joins the honeycomb before it's constructed and actually put into service on the HOLTEC HI-STAR 100. So what we did on that to again provide conservatism is, we assumed that it was in complete tact all the way through until it hit its melting point, and then after it reached its melting point, and this was, you know, over the course of pinpointing very small volumes, we made those radiation interfaces to draw more heat in from the fire. And then after cessation of the fire basically just capping that off as a thermal insulator that was occupied by molten aluminum at the bottom that had no access to the interface on how it secures to the cask, and the rest of it was merely a void that was occupied by gas with decently low emissivities, so all you had was this radiation gap that was an air thermal insulator on the end.

On the TN-68, it was wood, so that is a consumable. And one of the things that we evaluated is literally how much oxygen you would have to have to stoke, if you will, and get that material to burn. So we had a lot of problems with trying to figure out how to capture that successfully without breaching the impact limiter to provide an interface where it would be -- what is it, realistically or oxygenated enough to accommodate the consumption of that wood. We ended up taking the impact limiters completely off and just exposing the ends of that cask to the fire itself to maximize its insult because the thermal output from the wood, you know, would be a lot less than the actual fire to the impact limiter itself. Does that --

MEMBER SKILLMAN: You're saying that the heat input by the combustion of the wood is, in fact, less than the heat input that would occur if the impact limiter is not present.

MR. ADKINS: That's correct.

MEMBER SKILLMAN: Copy that. You sure?

MR. ADKINS: Yes.

MEMBER SKILLMAN: Thank you.

MEMBER POWERS: I understand that you -- in the cases of aluminum honeycomb, you melt the honeycomb?

MR. ADKINS: That's correct.

MEMBER POWERS: You take into account the inner metallic reaction between molten aluminum and the cask itself?

MR. ADKINS: The -- okay, the honeycomb itself is sandwiched with very little capacity to come out because of the fact that it's encapsulated by stainless steel.

MEMBER POWERS: So you have a worse inner metallic reaction.

MR. ADKINS: From the -- we didn't take that into account, no. I guess I have to answer that. But the one thing I will go on to comment, is so you have an impact limiter that encapsulates these seven types of honeycombs with septums that are anywhere from a quarter-inch to a half-inch in stainless that are then stood off of the cask and bolt to the cask I think with Nitronic-60 bolts. So you have an insulation gap that's anywhere from a quarter to a half inch all the way around the periphery from the impact limiter except for where it engages and pulls into the bolts.

MEMBER POWERS: Melt aluminum and drop it on that stainless steel, it looks like somebody went through with a cookie cutter, punch of bolts in there, the stainless.

MR. ADKINS: Yes, I don't have experience with that. I guess that's something that we need to evaluate.

MR. SCHULTZ: With regard to that bullet, this degradation of properties that are seen in the post-fire cool down, could you describe that in more detail, why that assumption, and what is it, in particular, that's --

MR. ADKINS: So one of the things --

MR. SCHULTZ: -- degradation?

MR. ADKINS: So one of the things that you can end up with depending on the amount of oxygen available is on the outside if we're just talking about emissivities, and you're talking about the whole gamut. Right? Conductivities, emissivities, everything. More often than not what you'll end up with it sooting which raises the emissivity of the package above .8, .9 to where it's going to radiate and have a more effective radiation interaction with the surrounding bodies than it would normally if it didn't have that sooting. Okay? Because typical stainless steels can range anywhere from .3 to .6, 16 if they have a lot of surface roughness and are seasoned, if you will. So those are raised to .9 during the fire, or greater depending on the analysis and the ease of using that tool, if you will, and then they're reduced to a reasonable or conservative magnitude, the emissivities would then be reduced or either be representative. So that was one of the sensitivities that we performed, as well, to look at what a bounding calculation would be, and how long that delays your peak fuel temperature hike during the excursion after the fire is out.

MR. SCHULTZ: So it's a sensitivity study --

MR. ADKINS: Exactly.

MR. SCHULTZ: -- in a conservative direction.

MR. ADKINS: Exactly. With a lot of the steels that are used in construction of spent fuel casks, none of those hit melting points with the exception of lead, so those are very easy. Then it's just a matter of looking up reliable material properties that come from Talupian and Sorg, and making those track one for one with the local temperature and predictions associated with that, you know, from a standpoint of being fully resolved as an analytical model.

And then, you know, of course we talked about the lead when you do go through a melting temperature transition and what have you, whether you take into account your latent heat effusion or not, and how that influences the package and the contents.

MR. SCHULTZ: Thank you.

MR. ADKINS: You bet.

MR. CHANG: Yes, in that case we have seen many case work based on the regulation, the package itself must be .8, that means more heat would be into the package. However, that's still maybe just .4 and we use .8. And then during the post-fire it will be change the heat direction from package to the ambient making this .8, too. However, you go back and you check .4 to have less heat going out so that it would be the case like this.

MR. ADKINS: That's correct. Sensitivity, again.

MR. CHANG: As I mentioned earlier, we have four important to seventy component, fuel cladding, containment seal, gamma shield, and the neutron shield. Now we had three different type of packages, TN-68, that's a large with high decay heat. HI-STAR 100, large package with decay heat around 20 kilowatt. And then we have a small packaging, NAC-LWT that's decay heat around 2.5 kilowatt. And based on the COBRA prediction we found the peak cladding temperature, PCT, less than 1058 Fahrenheit, and that is the limit of fuel cladding by NRC guidance. So all the fuel cladding will be maintained integrity, will be in good shape. And then we look at the peak temperature yields used in the gamma shield because both TN-68 and the HI-STAR 100 use the steel as the neutron shield material. As you know, the melting point of steel is very high, so right now the condition we are concerned. However, NAC-LWT used the lead as the neutron -- use as the gamma shield material and had the temperature greater than 622 Fahrenheit, the melting point. That mean that lead as the gamma shield material in NAC-LWT will be melted. However, it still contain inside of steel cavity, so that mean the lead could be melted, have expansion, and then cool down, solidify again. And then we may have the specs inside the cavity. They made a deal because we had the specs stay on top, it may reduce the shielding effect. We did such investigation and we found the maximum specs could be up to 5 percent, and that will cause the release going up. However, still much, much below the limit in the regulation.

And then for the neutron shield, in fact, in regulation loss of neutron shield is a design base assumption in the instant. In our instant case for transportation packaging we assume neutron shield will be lost and still below the dose limit. So limiting the neutron shield is required to me and no molten issue of transport. Anyway, so even with loss of neutron shield in a fire it still meet the dose limit requirement. Any question?

MEMBER SKILLMAN: I think what you are communicating is, you presume that the impact limiter has reduced --

MR. CHANG: Oh, no.

MEMBER SKILLMAN: Let me finish, has reduced the deceleration rate so that the lead has not flowed in the cavity, so you do not have a preexisting cavity void. And then when you proceed to melt that lead the void that then exists, if there had been a void prior to then, still enables the lead to perform its shielding function, and the dose rates remain below the allowable transportation dose rates. Is that what you're saying?

MR. CHANG: Yes.

MR. ADKINS: Yes, for the most part. The one thing that in the particular instance of the NAC-LWT, we did not subject for the Baltimore Tunnel fire the one that he's speaking to, to any structural insult prior to lighting it on fire. It was sitting on the conveyance. Otherwise, if it were loaded -- adversely loaded to the extent that it wouldn't be on the conveyance, it wouldn't be subjected to such an extreme fire because then it would be on the bottom of the rail bed or, you know, elsewhere. Right? So we relied, like one of the assumptions that Jimmy had, and then I'll answer your question more perfectly, or more completely.

What we did is basically assume that this rail conveyance was not drawing any heat out of the fire. It wasn't shrouding the cask from receiving the full insult of the fire, and then even more after it's exposed to that, you go through your lead melt. That expansion that would take place, volumetric expansion due to the melting would actually cause -- structurally load the inner and outer shell such that it would slump and produce the greatest gap on the top for shine in the tunnel, and that was still evaluated to meet the specific requirements in 10 CFR 71.73.

MEMBER SKILLMAN: Okay, thank you.

MR. ADKINS: You bet.

MEMBER SKILLMAN: Oh, one more question.

MR. ADKINS: Yes?

MEMBER SKILLMAN: You've identified three casks here. What about the other casks? Are these the only three casks carrying fuel?

MR. ADKINS: Yes.

MR. CHANG: Yes, but we think about these three casks as representative.

MR. ADKINS: That's correct.

MR. CHANG: With different configuration, different dimensional means, and different heat load.

MR. ADKINS: Construction practices keep capacity, so we go from large to small, as well, different materials that are incorporated. You know, you look at the big three vendors, cask vendors, and there's quite a bit of similarity between the designs with the exception of wood impact limiters, honeycomb impact limiters, web, EU shielding which we evaluate on the MacArthur Maze, I'm getting them confused. So we actually look at DU cask in that particular case, and primarily due to the fact that when we did the Baltimore Tunnel fire studies, it only involved a small-scale cask that has a lot less thermal inertia with one single assembly. Well, GA-4, even though it hasn't -- they haven't constructed one yet, I believe the CFC is still current, and the intent was for it to eventually see the light of day as being one of the industry workhorses until we could start transporting larger packages by rail and a repository was identified. So what we did is we tried to evaluate as many casks that were either representative or were currently workhorse, industry workhorses.

And to go on a little further is, when you look at the big three who are the primary manufacturers right now, HOLTEC I think dominates 55 percent of the industry within the United States, and 78 outside. TN is the next runner up to 45 percent with their transport casks, so we picked the TN-68 which is a dual purpose cask. The HI-STAR 100 actually has a canister. We didn't know what the net long-term effects were going to be with the canisterized fuel, so we evaluated those two, and then went for a small-scale cask, as well. That was the intent behind the selection.

MEMBER SKILLMAN: Thank you.

MR. ADKINS: You bet.

MR. CHANG: And now we look at the last components, containment seal. And we found out for package TN-68 and NEC-1170 temperature are over the limit. That mean there is a potential for radioactive release from this to package. However, because in all packages the temperature of the fuel cladding is below the limit of 1058, so we don't expect the limit for spent fuel particulate fission gas and a particulate like a fine. The only release could be cloud bullet number three, chuck liver are known deposit. However, the activity is very low, less than 82, less than 82. The 82 is a quantity allow -- is the activity on the radioactive material allowed in the Type A package. The 82 mean it will not cause significant headache to the first responder when they're near the packaging, so that is very small amount of radiologic release.

In the meantime, no loss in the gamma shielding, and loss of the neutron shield would not cause any dose consequence for all three packaging, so we conclude the spent fuel packaging supplied by the rail fire fuel integrity maintained and radiation dose below limit. Any question?

MR. SCHULTZ: Is there a particular quantification that is -- assumption that is used with regard to the CRUD release?

MR. ADKINS: Yes. So one of the things that we had to look at here is, when we evaluated the cladding peak temperatures they weren't in excess of what is currently accepted by the NRC as kind of a vulnerability temperature where you would actually get cladding breach. So the next thing that we had to take a look at is what might be available for dispersible inventory on the outside of the cladding. Right?

MR. SCHULTZ: Understood.

MR. ADKINS: Yes. And then in this particular calc, one of the conservatisms we weighed in or incorporated was taking the inventory of CRUD and assuming that it was available, the full inventory instead of having like particulate scale off and spall and then, you know, drop to the inside of the interior and not be available for further dispersal, which would typically happen. So we assumed that the CRUD inventory itself was available to the public and dispersible, readily dispersible, and that's what the AT number is based on.

MR. SCHULTZ: Full inventory.

MR. ADKINS: Yes.

MR. SCHULTZ: Thank you.

MR. FORT: Let me just add. This is Jim Fort, again. I think we used cobalt-60 as the basis for --

MR. ADKINS: That's correct.

MR. FORT: That was the only additional.

MR. ADKINS: I forgot to mention that.

CHAIRMAN BLEY: I kind of missed that, didn't look closely. Did you look at CRUD buildup as we used to have because we're going to ship a lot of old fuel first?

MR. ADKINS: Yes, that's right. And that was exactly what was weighed into it, per the NRC's recommendations over what should be anticipated for the types of fuels. The other thing I forgot to mention, we skipped over because there's a lot of details associated with these analyses, but as you read the documents, we look at -- and you just brought up a very important point.

We looked at a number of different spent nuclear fuels. You know, despite the fact that I think 85 or more percent of the fuel is now 17 by 17, or some variance, whether it be VEN-5, VEN-5OFA, what have you. What we did is we looked at -- and we did the same for BWRs, but just to make an example of PWRs, we've done analyses with 14 by 14, 15 by 15, 17 by 17, and the main purpose is, when you look at the bounding cladding temperatures of a 14 by 14 fuel, if you had the capacity of loading it at its design basis decay heat load, you've got a lot more heat per rod, and then when you break the communication of that rod's view to the ambient it goes up pretty substantially. You've got a lot more thermal inertia combined with that decay heat load per rod, so you end up with higher PCTs, peak cladding temperatures. So we also did those sensitivity studies.

CHAIRMAN BLEY: When you looked at the state of the spent fuel, I'm assuming you -- that already cooled to the limits for handling and shipping.

MR. ADKINS: What we did, here's another conservatism. We actually -- when you look at the bulk inventory of spent nuclear fuel in the states that's in SFSIs, and available for transport right now, a lot of these systems are being loaded at about half their design basis decay heat load. We assumed that they were at their peak, that they were at 100 percent of what they had the capacity of hauling. So that's --

CHAIRMAN BLEY: Okay. Well, whether that's conservative or not, some of the -- I know that some of the owners wanted to ship the hottest fuel first rather than the coolest fuel.

MR. ADKINS: Right.

CHAIRMAN BLEY: They would have been right at the limit when they ship, or they would be, I should --

MR. ADKINS: If the casks were loaded with the higher decay heat loads because of the four different in-service inspections that were done by DOE UFDC program, whether it be Calvert Cliffs, Oak Creek, Diablo, and there's one other, and all of the current sites that are loading -- doing out loads to the ISFSIs, the unfortunate thing is these systems are not being exercised.

They're being loaded at half their design basis decay heat load, meaning that the fuel has sat so long in the pool that it's relatively cold by the time it goes out to the pad. And then the thing is, those numbers are still -- you still have that exchange as to whether -- when it goes out of the ISFSI and it goes to a transport system, if you look at some of these internally ventilated storage casks, they have about double the capacity, double the decay heat load removal capacity as a transport cask. Okay? But the thing right now, so they're currently outloading even on some of the ventilating casks below the capacity of what a transport, a typical transport system would be able to accommodate, so they are cooler.

CHAIRMAN BLEY: They are cool, okay.

MR. ADKINS: And we're maximizing those.

CHAIRMAN BLEY: One last question, kind of a tutorial for me on cask design. The neutron shield, is that even -- if it's not there, you still meet the limits for these ones being shipped. I assume we need the neutron shield for the case of when we first load the casks --

MR. ADKINS: Normal conditions it's --

MR. CHANG: Normal condition --

MR. ADKINS: -- required to dose based on contact and dose at a distance. Now one of the things that the Nuclear Regulatory Commission requires, though, is that under any kind of off-normal or accident condition there is -- the parameters for dose are slightly elevated. So as part of that process, the NRC requires that the applicant review their system under an accident condition that they can still meet the dose requirements with the absence of the neutron shield. The gamma shield is a different matter but, you know, in every one of these case studies there's no compelling reason to think that the gamma shields would be compromised. Good question.

CHAIRMAN BLEY: Thank you.

MR. CHANG: Thermal shield is needed for both NCT and HAC. Now this is Slide 15. Because this slide, we already talk about robustness of the package design. So the next one, for this slide we talk about the transportation element associated with DOT regulation, Part 73. And some action or control we could apply over the years to minimize the accident, the railway accident.

The first one, we talk about DOT-49 regulation 17485, requirement of buffer car. We had this one to increase the distance, the space between the spent fuel cask and the other rail car, and we had AAR OT-55, Association of American Railroad OT-55. No pass through that mean a train carrying the spent fuel cask or radioactive material and another train carrying a combustible or flammable material should not pass over each other within the tunnel. And then we had the AAR standard 2043, it's a design standard to have the risk car and the cask car, and the escort car at the end. And then we could even in some specific condition, we need a different and coordinated shipment to minimize all possible, and that's with the package design and the regulation.

Department of Energy recommend the railway shipment may be the best idea to ship spent fuel package. I mean, using the railway to ship spent fuel package, that's a DOE recommendation.

MEMBER SKILLMAN: Jimmy, let me ask this question. With regard to AAR OT-55, is there a no pass rule for only two tracks in the tunnel, or could that same, or does that same guidance apply also to a three-track tunnel?

MR. ADKINS: Right now, as I turn on my microphone, as you probably know, the OT-55 has been pretty dynamic and is changing very rapidly. And one of the fundamental drivers is the AAR S-2043 spec conveyance, they're articulating conveyances under development. I think right now they're really close to getting the M290 rail car for Navy fuel certified. And, unfortunately, OT-55 is trailing fairly substantially, so right now the only no pass envelope that is identified in OT-55 is that it's within tunnels because of the potential risk that is added by the tunnel enclosure itself.

MEMBER SKILLMAN: But my question is, now that's aimed at a two-track tunnel. Are there three-track tunnels where the AAR OT-55 does not apply?

MR. ADKINS: But the no pass rule means that when that consist, the nuclear fuel consist goes through that tunnel it is the exclusive user of that tunnel at that time.

MEMBER SKILLMAN: Oh, okay.

MR. CHANG: And two.

MR. ADKINS: Yes, yes. But the one thing I think that we'll see in OT-55, you know, because OT-55 just incorporated this rule even though it's been on the books for about 10 years now. So what

I'm saying is that we'll probably see even more stringent criteria become -- that revolve around the nuclear consist itself, that it will probably be completely exclusive use. I think that's what DOE NFST is now considering, and some of the reasons are is just from the standpoint of going from region to region. It's a lot easier to certify that consist and its path, and do some of the preplanning and coordination itself. And the primary reason is they don't want to hold up revenue track, and revenue generation for the train.

MEMBER SKILLMAN: What's really on my mind is what we're seeing in the east are the bulk oil coming in on these almost mile-long tanker trains.

MR. ADKINS: Right.

MEMBER SKILLMAN: And these trains can occupy each part of the yard, or each part of a mainline, and if there's a consist that's waiting for the tunnel, I would think the consist -- the nuclear fuel waiting consist -- that consist should wait until that huge mass of combustible cargo is clear.

MR. ADKINS: I'm highly confident that's

what we'll see for the outcome.

MEMBER SKILLMAN: Because we are seeing it on the east coast, and these are huge, massive consists of brand new identical tankers, and they're carrying bulk into the east coast is what they're doing.

MR. ADKINS: And like you say, a mile long.

MEMBER SKILLMAN: Thank you.

MEMBER BALLINGER: The Navy has been shipping fuel in this configuration for years. The 290 cask, they actually had a rail crossing accident with one of those casks. There was no fire or anything, but then they had -- they've also had an earlier design cask, I forget what the number is, where one of them tipped over in the rail yard, and just fell over and they just righted it back up and kept on going. So there's a lot of history with this configuration.

MR. ADKINS: Yes.

MEMBER SKILLMAN: Well, this is a configuration for all of the TMI-2 fuel. If all of those consists were just like that time and after time, and the problem was getting the permissions from Pennsylvania, from Ohio, and from Chicago to get to Idaho, north of Idaho.

MR. ADKINS: Yes.

MR. SCHULTZ: Jimmy, the last bullet, preplan and coordinate shipments, it's kind of a summary that this also would be done. Is there any particular approach or regulation that you see coming down the road that will cause that to be more than an expectation?

MR. BOROWSKY: Yes, this is Joe Borowsky. The preplan and coordinate shipments actually is the wording that you'll see in 10 CFR Part 73.37, so that's basically a requirement that such activities are performed prior to the shipment of spent fuel.

MR. ADKINS: And requiring NRC engagement.

MR. BOROWSKY: Yes.

MR. SCHULTZ: Okay. So that's a summary of what will be done associated with that expectation to document.

MR. BOROWSKY: That's correct, Part 72.37.

MR. CHANG: So to come to conclusion, on the railway fire accident, so the package evaluated are shown to be training to bust in response to a real life railway fire that is beyond the regulation fire. With a temperature than 1475 Fahrenheit, and the time period is much longer than 30 minute. And the current NRC regulations and the package standard provide a high degree of protection, again this radioactive material during real life railway transportation accident. However, we understand any accident could happen again so we continue to watch and see what we need to do to minimize, what we need to do in the regulation to minimize the accident, and we want to provide health and public health and safety. And that's the concern we work on with this research. And that's my conclusion on the railway fire accident.

CHAIRMAN BLEY: Okay. Jimmy, thank you. Anything more for Jimmy? We're going to take a break now for 15 minutes. We'll come back at 10 after 10 on that clock. Joe, you've got a few more slides than Jimmy had. We may have to speed up through some of them, especially the descriptive things. I'm sorry?

MR. ADKINS: It might go a little faster because we've discussed quite a few things that actually go into those analyses, too.

CHAIRMAN BLEY: Yes, that's what I would

hope, so we'll see how it goes, but after an hour we might have to speed up a little bit. We have to be finished before noon. Okay, we will recess at this time for 15 minutes.

(Whereupon, the above-entitled matter went off the record at 9:53 a.m. and resumed at 10:10 a.m.)

CHAIRMAN BLEY: We'll turn it over to Joe.

MR. BOROWSKY: Now we'll transition to the roadway severe fire accidents that were analyzed, including Caldecott Tunnel, MacArthur Maze, and the Newhall Pass Tunnel fire scenarios.

I just want to mention that as with the Baltimore Tunnel fire accident, none of these accidents involved radioactive material. The case studies described today are the results of essentially numerically placing a transportation package within an environment defined by real world accidents. Next slide, please.

The first accident study was the Caldecott Tunnel fire, and you see the picture below. It's the roads leading to and from the tunnel. West Portal bore number 3 is where the accident actually occurred, and that's the opening on the far left. In this scenario, a tanker truck and trailer overturned and caught fire within the tunnel. The tank trailer cargo included 8,800 gallons of gasoline and the overall fire duration based on NTSB investigation is 2.7 hours, but the intense fire duration was determined to be 40 minutes. Next slide.

The analysis methodology undertaken include using NIST's Fire Dynamic Simulator code to determine the thermal boundary conditions. These thermal boundary conditions were then applied to the ANSYS on an element model, NAC-LWT transportation package.

Some conservatisms of the model include using the peak tunnel temperatures, even if the package surface could not see that particular location, and also neglecting the thermal shielding effect of the package conveyance. Basically, the package was suspended at an elevation corresponding to the height of the flatbed transporting the package. Next slide, please.

The FDS 3D model was approximately 787-foot long, 18-foot wide, and 28 -- excuse me, 18-foot high and 28-foot wide. For the 40-minute duration fire the FDS code showed a maximum gas temperature of 1965 degrees Fahrenheit. The figure on the right shows the temporal temperature distributions at three tunnel elevations, basically the ceiling, the wall midline, and the floor center line. Using these boundary conditions, they were then applied to the ANSYS finite element analysis model to perform thermal analysis on the LWT transportation package.

The results from the analysis showed a peak cladding temperature of 544 degrees Fahrenheit, peak clouding temperature of 1288 degrees Fahrenheit, and the gamma shield temperature of 622 degrees Fahrenheit. Next slide.

The next roadway fire accident --

CHAIRMAN BLEY: For these -- that one and the rest we're going to see, did you guys do something similar to what Harold described where you ran multiple cases and tried to draw some conclusions? You still not doing anywhere along the line of best estimate in looking at uncertainties. You're always doing a conservative, what you think is a conservative calculation.

MR. BOROWSKY: Yes. We basically apply the -- I'll say what we feel are boundary conditions that are beyond -- they may be even beyond what the accident described.

CHAIRMAN BLEY: Okay. And ran notable cases to kind of bound the results?

MR. BOROWSKY: Yes. In fact, for the Caldecott Tunnel fire, for example, the LWT can be transported either within or outside of an ISO container, so you'll see some of the results presented later on, the -- you'll see that basically the temperatures, different temperatures associated with those two conditions.

CHAIRMAN BLEY: Okay.

MEMBER SKILLMAN: At the bottom of that slide you show the 622 Fahrenheit, 328 C for the gamma shield. Is that temperature constrained by the latent effusion of the lead? Is that what keeps that temperature from going above that?

MR. BOROWSKY: That's essentially right. The lead shield reached 622 degrees Fahrenheit at different points within the package. So it's not like it was uniformly at 622, so there wasn't -- let's put it this way. There wasn't a complete phase change that occurred.

MEMBER SKILLMAN: Okay, thank you.

MR. BOROWSKY: The next roadway fire accident studied was the MacArthur Maze fire scenario. Next slide, please.

The MacArthur Maze fire accident took place on the I-880 connector of MacArthur Maze interchange. A tanker truck and trailer overturned and caught fire on I-880. This was actually a single vehicle accident. The tank trailer cargo included 8,600 gallons of gasoline. I show two figures in order to put this accident in a little bit of perspective. On the left you see the lower I-880 roadway, and the collapsed I-580 overpass resting on top of it. On the right you see the intense fire in the area between the lower I-880 road and the I-580 overpass.

Now this intense fire weakened the steel girders collapsing the two spans on the roadway below it, and so it formed an enclosure because of that collapsed roadway. But this -- even though it was an enclosure there was sufficient opening in order to allow combustion air flow.

It's also worth mentioning that the timeline information about this fire was available because it was recorded by camera from a nearby municipal waste treatment facility.

MEMBER SKILLMAN: Before you change that image, would you explain what we see basically dead center? It almost appears as though the concrete has changed form. It appears to be contoured as opposed to cast slab. Maybe my eyes are deceiving me, but that's what I imagine when I see this, and I'm wondering if there is another phenomenon on concrete degradation that we haven't thought much about? In other words, is that concrete --

MR. BOROWSKY: The picture on the left?

MEMBER SKILLMAN: Yes, on the left.

MR. BOROWSKY: Well, again I'm not quite sure what you're necessarily seeing, but the roadway sagged. Basically, the steel girders sagged somewhat and so I would suspect that the overlaying concrete kind of followed that form to a certain extent. But in terms of the details of the -- of any type of concrete behavior, I really can't speak to that.

MEMBER SKILLMAN: It just appears to me to be an odd configuration of concrete that I would think is generally brittle, it fractures, it comes apart in pieces. That almost gives the appearance of having flowed, and I just don't know what I'm looking at. And I'm not trying to create a stir, I don't know what I don't know, and I'm thinking oh, that's odd.

MR. BOROWSKY: Yes, I just don't know at what point that picture was taken, whether it was taken a few hours or days, and there was some clean up. I'm not familiar with at what point that image, that photograph was taken.

MEMBER SKILLMAN: That was a curiosity question. Thank you.

MR. BOROWSKY: Oh, sure. Next slide, please.

For analysis purposes, there were three events associated with this accident. The fire before the I-580 collapse, and the fire after the collapse, and the Fire Dynamic Simulator code was used for both events. The pre-collapse fire duration was 37 minutes, and the fire temperature was 2012 degrees Fahrenheit. And this was taken to be a fully engulfing fire. The post-collapse fire duration was 71 minutes, and the fire temperature was 1652 degrees Fahrenheit. And this was also taken as a fully engulfing fire.

It's also useful to point out that there was some metallurgical analysis performed on the samples from the accident site, and depending on the particular sample temperatures between 1228 degrees Fahrenheit to 1657 degrees Fahrenheit were determined. And these temperatures basically confirm that high temperatures existed within this fire.

CHAIRMAN BLEY: Joe, when you say it was taken as, it sounds like one more conservatism. You had movies of this one. Was it fully engulfing, or essentially fully engulfing from what you could see?

MR. BOROWSKY: Right. Specifically for post-collapse fire duration, you know, the I-580 collapsed on that, and so that would have prevented, just because of blockage, a truly fully engulfing fire. So during the post-collapse fire duration, that 71-minute duration, we assume it was fully engulfing.

CHAIRMAN BLEY: Okay.

MR. BOROWSKY: And the effect of the collapsed overpass was only during the cool down phase after the fire was extinguished. I'll mention this a little bit later. This I-580 acted as a blanket, a thermal barrier, so that thermal barrier, the blockage was taken after the -- or during the cool down phase such that the post-collapse was treated, or how we envisioned it to be a fully engulfing fire. Next slide, please.

Now there are many aspects of the fire scenario that are more severe than the hypothetical accident condition fire defined by 10 CFR 71.73. For example, for the pre-collapse fire there was a higher temperature and longer duration, 1100 degrees C for 37 minutes versus 800 degrees C for 30 minutes for the regulatory fire. And for the post-collapse fire, again a higher temperature and in this situation a much longer duration, 900 degrees C for 71 minutes.

Other severe aspects of the fire included the impact of the free-falling overhead span on the package. And the post-fire cool down of the package assumed the covering by the concrete blanket. And that's kind of what I alluded to earlier. The package was also chose to be in the most adverse location during each stage of the scenario. It was on the roadway in the fully engulfing fire for both the pre and post-collapse fires. Again, it speaks to what I had mentioned earlier about not taking into account the shielding effect from the collapsed roadway. And, in addition, this also ignored the shielding effect from the package conveyance.

Another item to note is that the impact

location and orientation was determined by analysis of multiple cases. Basically, which location would form or have the greatest potential for deformation by the falling of the I-580 overpass. And, again, the other adverse location was the fact that it was under a concrete blanket for the extent of the post-fire cool down.

In addition to using the FDS code in order to determine the thermal boundary conditions both COBRA-SFS, which was developed by Pacific Northwest National Laboratories, and ANSYS were used to evaluate the General Atomics GA-4 LWT package. And, in addition, LS-DYNA was used to model the effect of the falling I-580 overpass. Next slide, please.

So here we have some temperature results of the COBRA-SFS and ANSYS thermal analyses of the GA-4 package. For the pre-collapse portion of the fire, the first 37 minutes, the peak cladding temperature was found to be about 1020 degrees Fahrenheit. There was an O-ring temperature of 250 degrees Fahrenheit, and the gamma shield was 250 degrees Fahrenheit.

The results show for the post-collapse portion of the fire, the results show a peak cladding temperature raised considerably, 1,425 degrees Fahrenheit, an O-ring temperature of 770 degrees Fahrenheit, and the gamma shield temperature of 1,490 degrees Fahrenheit.

I'd like to point out the top picture on the right. This picture represents the post-collapse situation where the I-580 span covers the GA-4 package and hinders the removal of heat during the post-fire cool down. And for the post-fire cool down period, the results show a peak cladding temperature of 1,400 degrees Fahrenheit, and a high O-ring temperature of 1,150 degrees Fahrenheit.

I mentioned a little bit earlier that an ANSYS thermal model of the I-580 span was also made in order to determine a temperature for subsequent structural analysis. And for this particular LS-DYNA analysis, steel girders at 1,800 degrees Fahrenheit were used in order to impart the impact load of the falling I-580 overpass on the package. And four impact orientations were considered, basically the girders along the package or across the package, whether they impacted the lid or the trunnions. For all these conditions there was only local classic strain at the package outer wall. There was no gross failure or rupture of the package.

And as shown in the lower figure on the right, relatively speaking the girders are thin and somewhat weak at high temperatures, and so they're the ones that actually deform on impact.

MEMBER SKILLMAN: Joe, how did you choose the impact geometry? A long cylinder is weakest at its dead center on its longitudinal axis, and so had you chosen perhaps one orientation versus another you might have had greater deformation and hence, either rupture or deformation leading to leakage, particularly on the seal. So how did you choose what is a defendable orientation?

MR. BOROWSKY: Right, that's a good question. There were a number of what I'll call orientations that were analyzed. The image that you see on the bottom right was the case where the girders were what I'd call across the package. And that was considered because in that particular situation you actually have two girders contacting the package just by the space between the girders. But there were three other orientations considered; one was, and this may be kind of what you're saying, there was one where the package was positioned so that it would be aligned with the entire length of the package. And then there was one that was also oriented so that it would impact the lid or the seals would be -- you know, would have the most direct effect on the seals. And then the final orientation was on the trunnions itself. And again, in all these orientations the classic deformation essentially is just at the outer wall. It never penetrated deep into the package. The local classic strain was small. I think the reason why the classic strains were small is kind of like you see at the bottom image there, is these steel girders, yes, you know, we're familiar with them when they're at ambient temperature. You know, they're strong but, you know, assuming that they're at 1,800 degrees Fahrenheit, they become relatively weak. And from the LS-DYNA result that we see at the bottom image, you know, that's the one that deforms, basically. That's the one that -- that's the component that gives. It's not the package, it's --

(Off microphone comment.)

MR. ADKINS: One thing I was going to add just to give you some of the particulars. The girders themselves, the strength is reduced to about 10 percent of its capacity at these elevated temperatures, so that's one stray. The core of the package that's kind of the outer protection of the inner containment boundary is depleted uranium at multiple inches thick. And then this particular scenario that you're looking at, interestingly enough this kind of came out to be the worst case from the middle girder dropping through the center section like you had stated, as well as impacting the closure, because you get secondary stresses right where the bolted closure is and where it tapers out into the main body of the containment boundary, where the stresses were at the highest for any of the scenarios that we evaluated.

Now interestingly enough, when you look at the orientation, the way that cask is sitting on that, we had a picture where it showed the beams looked exactly like this, the bent structure that they dropped just to kind of do a rudimentary comparison, and the giggle test, if you will. But then for the thermal loading it's a super position of multiple things. It's this oriented so you end up with structural. Then with the package rotated up against the Jersey barrier with the roadway falling over it, and all of these things couldn't take place at the same time, a further conservatism.

MEMBER POWERS: What kind of peak temperature did you get in the depleted uranium?

MR. BOROWSKY: The peak temperature -- here, I have that. The peak temperature for MacArthur Maze depleted uranium was about 1,480 degrees Fahrenheit.

MEMBER POWERS: 1,480 Fahrenheit. Do you know how long that kind of temperature was like that?

MR. BOROWSKY: How long it was at that temperature?

MEMBER POWERS: Yes.

MR. BOROWSKY: Well, the fire itself, the total fire, the pre-collapse 37 minute, and the post-collapse 71 minutes, so the total fire was 108 minutes. It only -- I'm looking at the pre-collapse portion, the peak at the first 37 minutes was 1,250 degrees Fahrenheit so it reached the 1,480 somewhere between the 37 minutes and the 71 minutes. Once the fire ceases the outer -- what I'll call the outer portions of the package begin to cool. So assuming a step change from, you know, for the full 71 minutes, it could be approximately up to that period of time, but I suspect --

MEMBER POWERS: The reason I'm asking that question is, there is an inner-metallic reaction between uranium and steel. And these temperatures you ordinarily don't worry about it, but I'm used to durations that are short. I don't know what happens, and I don't -- I try to keep my uranium from getting hot. Do you guys worry about that kind of thing when people use depleted uranium in these packages?

MR. BOROWSKY: That particular issue was not addressed in this analysis that I know of, but I'd probably want to defer to like a material science type person for that. But I suspect it's two things, and basically what you had said. It's temperature and time, but I guess it -- there would have to be -- one would have to look at those two parameters together in order to --

MEMBER POWERS: Yes, I simply don't know. I mean, I know the interaction is exothermic, and if you were talking about molten uranium then I would tell you oh, my God, and I'd clutch my heart, fall on the floor, and all kinds of things like that. But to go from a solid into a selfpropagating exothermic reaction, that's a complicated analysis that I certainly can't do in my head. I know that it was an issue that Dr. Rempe raised in connection with a PRA analysis, and it was pooh-poohed fairly definitively by the speaker at the time, but I don't think he understood what exactly she was talking about. They know in these fires -- I mean, he had peak temperatures on the order of 1,000 degrees Fahrenheit which I think we could find, and they were very transient in nature. Here you're talking about like an hour, I mean, lots of minutes, somewhat higher, not enormously higher. But I can change the scenario a little bit and get into longer durations, little bit higher temperature. I just simply don't know what happens where with that depleted uranium. It is highly electro positive metals when they see iron are just going to certainly have the potential of having exothermic interactions. I mean, it's something to -- that your computer code doesn't have built into it, so you need to do something exogenous. And since nobody voluntarily does these things, you're not going to find a lot of data on it.

MR. BOROWSKY: Okay, thank you. That is a good point.

MEMBER SKILLMAN: I would like to ask a question, please. We had a marvelous tour up at NIST here not so long ago, and one of the laboratories that we visited was a laboratory where a gentleman was testing O-rings at high temperature, and they were O-rings that are intended to be used for these casks. And these were metallic rings, and he was driving temperatures of 12-1,500, 2,000 degrees Fahrenheit. He was really pushing the temperatures.

What are the O-rings in your analysis, and what are they -- what is their temperature limit? What is their composition, and what is their temperature limit?

MR. BOROWSKY: Right. I can answer that question now. It would also be discussed later on, but for the MacArthur Maze the O-ring temperature, excuse me, the O-ring material is EPDM, and its continuous -- let me see. Its continuous use temperature is 302 degrees Fahrenheit for EPDM. In the next portion of the presentation we discuss the consequences of these temperatures, and to make it short, we assume that the seal fails.

MEMBER SKILLMAN: All right.

MEMBER POWERS: I mean that is a fairly

conservative assumption. You mention that you have 1,150. We did look at some of these things, and I mean, you're right, you take it above 300 or so degrees Fahrenheit and it's not really an O-ring any more. As long as it remains bolted you don't really have like an open gap in there any more.

MR. BOROWSKY: That's correct.

MEMBER POWERS: Suddenly -- you're not going to use it again, but that probably goes without saying here.

MR. BOROWSKY: You probably not going to remove it either. It's going to be cinders.

MEMBER POWERS: Well, we did -- we ran these tests and looked at over-driving these things and whatnot, and they remained sealed and whatnot. When they opened them up you couldn't reseal them. Okay. But they didn't -- they were in operation and they were held for hours at these temperatures. They didn't open up making huge gaps that you would drive trucks through and things like that. So assuming failure is very conservative --

CHAIRMAN BLEY: And you did --

MEMBER POWERS: You had the complexity that the bolts are getting hot and so relaxing some of the temperature, I mean some of the strain on the -- the squeeze on the O-ring and things like that, I mean, it's not a catastrophic failure that occurs.

MR. BOROWSKY: That's correct.

CHAIRMAN BLEY: Well, you also have the report. I think you provided this, but it's available publicly on what Dick was citing. In NIST they're both metallic and polymer O-rings, so you didn't rely on that study.

MR. BOROWSKY: No. I mean, we took that --

CHAIRMAN BLEY: The assumption that they'll leak.

MR. BOROWSKY: That's correct.

CHAIRMAN BLEY: Yes, some rate, I forget.

MR. BOROWSKY: You're right, the experimental work that NIST performed showed that the seals, even though they were much higher than their continuous use temperature, and for a fairly long period of time, they still retained some sealing capacity, what I'll call sealing capacity. The material itself was degraded, but basically that degraded material gummed up the works so to speak.

CHAIRMAN BLEY: Right. That's kind of the same place Dana was. But this is recent work. They were still working on it when we were out there. But you didn't rely on that at all.

MR. BOROWSKY: No, we just -- we took a separate approach with let's just --

MR. ADKINS: Partly due to the fact that the two studies were being done in parallel, too.

CHAIRMAN BLEY: Yes. I kind of sense even if it had been done, you seem to like piling on the conservatisms.

MEMBER SKILLMAN: It's assumed here that the package was assembled properly. In other words, that the closure and the O-ring were in the geometry that they were intended for the design of this cask in accordance with the certificate of conformance. I wonder if you've ever considered what happens if the cask is really one bolt off, in other words the lid is not on, it's one bolt or two bolts off. And so while it appears sealed, in fact, it isn't sealed.

MR. BOROWSKY: Just real quick. For Part 71 transportation, we basically -- licensees typically have to file what's called the ANSI M-14.5 leakage standard. And in addition to testing the containment boundary during fabrication stage, after maintenance and stuff like that, one of the tests is the pre-shipment test, so they perform basically a pre-shipment leakage test in order to check the issue that you just raised, which was a good point. It's the hey, before we ship it out let's make sure everything is together, and so that is part of the procedures that they have to perform.

MEMBER SKILLMAN: Thank you.

MR. BOROWSKY: The final case study was the Newhall Pass fire. This is the Newhall Pass fire at the I-5 truck route underpass tunnel. And below is a photograph of the tunnel and the surrounding road system to, again, kind of put it in perspective.

This was a chain reaction traffic collision of 33 tractor trailer trucks. The first started near the tunnel exit and spread the full length of the tunnel. Twenty-four tractor trailers were destroyed. Although none were carrying hazardous material, there was combustible material.

MEMBER BROWN: Excuse me. I may be wrong, but where is the tunnel? This looks like nothing but roadways to me. Oh, it's underneath, okay. All right.

MR. FORT: The exist and then pass beneath the I-5.

MEMBER BROWN: Okay, thank you.

MR. BOROWSKY: Again, although none of the vehicles were carrying hazardous material, there was, of course, combustible material, including diesel within the truck tanks, tires, sheet aluminum on the semi-trailers, wood, cotton, sugar, cardboard containers, and fruits and vegetables.

MEMBER SKILLMAN: Did the sugar catch fire? That's a wicked fire, that's like charcoal. That's terrible.

MR. BOROWSKY: Yes, high-energy content, right. The fire duration was estimated between three and five hours, the local fires on the individual vehicles were estimated between a half hour to one hour as the fire spread through the tunnel, as it basically progressed. Next slide, please.

As with the other fire scenarios, the FDS code was used to determine the global boundary conditions but this was really an involved analysis, it involved tests for a number of reasons. First of all, of course, there were a large number of vehicles that had to be considered. There was also uncertainty associated with the combustible material for each vehicle, uncertainty in the burn rate of that combustible material, and the uncertainty of the fire spread rate, so the FDS code was put to good use and looked at a number of parameters.

Specifically, six cases were considered, a slow and a fast burn rate. There was a range of fire spread rates, and variation of fuel budget for each of the vehicles within the fire. The upper image on the right shows the severity of the local fire associated with a vehicle, and the lower image shows the extent of the FDS, the Fire Dynamics Simulator model. Next slide, please.

There are aspects that are more severe associated with this fire than the hypothetical accident condition fire defined by 10 CFR 71.73. The peak fire temperature, you know, varied from 854 degrees C to 1,088 degrees C.

MEMBER POWERS: The change in units that you made for the drug is to facilitate is our understanding?

MR. BOROWSKY: Yes, actually that is

why they did.

MEMBER POWERS: It's been Fahrenheit all the way through and now all of a sudden you switch to Centigrade. That makes it really easy.

MR. BOROWSKY: I was trying to help you.

Now, the purpose for that was I wanted to more easily visualize the difference with the 800 degrees C and the 30 minute fire duration defined by the regulations.

So, I want to quickly eyeball how much different that fire temperature is.

MEMBER BROWN: You could have specified the 800 and --

MR. BOROWSKY: I could have did that, too, that's right.

The local fire duration at specific truck locations range from 26 minutes to approximately 68 minutes, so again, for the most part, greater than the 30 minute duration.

And, for this particular scenario, there was another issue. There was the preheating of the package, depending on the location in the tunnel and especially the fact that the fire progressed from the end towards the beginning of the package meant that, especially the vehicles at the beginning of the tunnel saw a fairly large or long period of preheating. And, in some cases, it was up to four hours.

As I mentioned earlier, the FDS code was used to determine the most adverse condition from a matrix of cases. For the six cases studied, there were actually then two package or vehicle locations studied on the hottest fire location which took place in the middle of the tunnel. And, the longest preheating fire location which was just past the tunnel entrance.

And, based on these conditions, ANSYS and COBRA-SFS were used to perform thermal analysis of the GA-4 package for each case.

Next slide?

There are a number of conservativisms considered for this -- both for the COBRA-SFS and ANSYS models including choosing a conservative combustible mass for each vehicle within the tunnel, assuming the entire combustible mass of each vehicle was fully consumed by the fire.

There was a walk down or walk through after the fire and that showed that, in fact, not all of the carbo was consumed in the actual fire.

Assuming the peak local temperature was applied to -- or applied from the fire dynamic simulator code output, and again, we neglected the shielding effect of the package conveyance such that there wasn't -- or such that the heat input from the fire was all towards the package.

Next slide, please?

So, here are the results from the COBRA-SFS and ANSYS results that, you know, basically show high component temperatures.

For the longest preheating -- for the long preheating fire location with a 64 minute local fire duration, the decladding temperature ranged from 834 degrees Fahrenheit to 1,020 degrees Fahrenheit.

The lid seal temperature was 649 degrees Fahrenheit.

For the hottest fire location with a 78 minute local fire duration, peak cladding temperature varied from 994 to 1,217 degree Fahrenheit. And, there was a lid seal peak temperature of 545 degrees Fahrenheit.

Next slide, please?

So, you know, at this point, we'll transition from the description, so to speak, of the fire accidents in the area to the consequences.

We've seen that the Caldecott Tunnel, the MacArthur Maze and the Newhall Pass Tunnel fire scenarios were severe fires relative to the hypothetical accident condition fire defined by the regulations.

And so, again, we'll now look at the consequences of that.

Next slide, please?

First, we'll look at the various components of the NAC-LWT package as it relates to the Caldecott Tunnel fire scenario.

Now, the neutron shield is assumed lost as a result of the fire hypothetical accident condition. And, the dose is still within regulatory limits.

As mentioned earlier, this is a design basis assumptions satisfied by all the packages studied.

For the gamma shield, some of the lead reached its melting point between 23 to 34 minutes after the start of the 40 minute fire. And so, there's only the potential localized melting which would still, you know, it would still provide shielding.

For the metallic lid seal, the peak temperature, you know, varied from 735 to 794 degrees Fahrenheit, depending on whether it was within or outside the ISO container. But even so, it was below its 800 degrees Fahrenheit continuous use limit.

For cladding, its peak temperature varied from 535 to 544 degrees Fahrenheit, depending on, again, whether it was outside or within an ISO container. And, that's also well below its limits.

Next slide, please?

Now, the issue really comes up with the vent o-ring seals and the drain port o-ring seals. These are made of polymeric materials, TFE or Viton. And, the peak temperatures in these regions, again, varying between the 1,035 to 1,288 degrees Fahrenheit exceeded the continuous use limit for TFE. The continuous use limit is 735 degrees Fahrenheit and Viton is 550 degrees Fahrenheit.

And so, the seals were conservatively assumed to have failed at these high temperatures.

For this analysis, excuse me, and so for -- so the question becomes what is the potential release through these failed seals?

Since cladding was below its allowable temperature, the source of the released material could be CRUD part of this from the exterior of the cladding. And, this was calculated to have an activity of .01 curies which translates into a .001 A-2 quantity, and that's below the regulatory limit of an A-2 per week.

Next slide, please?

Now, for the MacArthur Maze fire scenario and the consequences for the GA-4 package, the peak temperature was approximately 1,480 degrees Fahrenheit and that's below its 2,070 degree Fahrenheit melting point temperature for depleted uranium.

The peak temperatures of the cask lid, the drain valve seal and the gas sample port seal were quite high from 1,130 to 1,170 degree Fahrenheit. And, you know, as mentioned earlier in our discussion, this exceeded the continuous use temperature limit of the EPDM seals.

And so, for this analysis, it was assumed that the seals failed.

In regards to the fuel, the peak cladding temperature is predicted for both the

ANSYS and COBRA to reach nearly 1,400 degrees Fahrenheit during the post-fire cool down. This is a high temperature and it exceeds the short-term and estimated burst temperature limits.

Next slide, please?

And so, it's worthwhile to take a little bit closer look at the potential for fuel failure.

The FRAPCON-DATING and the FRAPTRAN fuel performance codes were used to predict cladding behavior. FRAPCON-DATING relies on peak rupture models and FRAPTRAN relies on burst rupture models.

Both models predicted fuel failure of MacArthur Maze basically because the 1,400 degree Fahrenheit cladding temperature was above the calculated failure temperature before the cladding.

Next slide, please?

So, you know, with there being potential issues with the o-ring seals and the cladding, it becomes necessary to estimate a potential release.

The release model was based on the pressure in the package and the leakage between the lid and flange for the lid clamping force.

The potential release includes the fission products and spent fuel particles in addition the CRUD particles assumed to have fall from the cladding surface.

The total release was calculated to be 0.24 A-2 quantity which is below the regulatory limit of A-2 per week value limit value.

And, it's worthwhile to note that this conservatively neglects particulates settling once, or excuse me, after a rod bursts. And, it also conservatively assumes that there is no restriction on the size of particles passing through the small gap between the lid and flange.

Next slide, please?

Now, we'll discuss the Newhall Pass fire accident scenario and the consequences on the GA-4 package.

For the gamma shield, the peak temperature was calculated to be 1,200 degrees Fahrenheit. And, again, that's below the melting temperature of 2,070 degrees Fahrenheit for depleted uranium.

The o-ring seals for the lid, the drain valve and the gas sample port exceeded the continuous use temperature limit of the EPDM seal at 302 degrees Fahrenheit. And, as Matt has mentioned earlier, for this analysis, the seals are assumed to fail.

Next slide, please?

So, as with the MacArthur Maze analysis, the COBRA-SFS and ANSYS results were used as input to the fuel performance codes.

Based on that input, FRAPCON-DATING predicted no fuel failure, and likewise, FRAPTRAN predicted no fuel failure based on the COBRA-SFS results.

But, the peak cladding temperature predicted with ANSYS was generally higher than the COBRA-SFS for each case.

And so, for three of the ten analyzed cases, based on the ANSYS results, there was found that there was potential for failure from the -- based on the FRAPTRAN analysis.

And, again, I want to repeat that the o-rings seal failure also would allow the potential for release of CRUD particles that are on the exterior of the cladding.

Next slide, please?

Now, recall with the MacArthur Maze analysis, the release model was based on the pressure within the package. So, we see in the figure on the slide that the MacArthur Maze cavity pressure bounded, the Newhall Pass fire scenario cavity pressure.

And, basically, therefore, consequences were conservatively assumed to be the same as the MacArthur Maze fire scenario with the total release being below the regulatory limit.

MEMBER SKILLMAN: Why did you do that? Did you simply do PV = mRT on the Newhall Pass and say, golly, it's so far below MacArthur Maze that we don't have to do the analysis?

MR. BOROWSKY: Well, I mean in terms of all the analyses leading up to that, yes. I mean, once -- because it's the same package. The content's the same and so, the only thing that could drive any release was that pressure within the cavity pressure.

So, essentially, yes. I mean, the fact that that pressure was below -- much further below the MacArthur Maze, it couldn't be any worse than that.

MEMBER SKILLMAN: A procedure said MacArthur's bounding, don't do any more work?

MR. BOROWSKY: That's right.

MR. SCHULTZ: But, that's also combined with the fact that the fuel did not fail in this case?

MR. BOROWSKY: Well, it did, in three of the ten cases, based on the ANSYS results, it did fail.

MR. SCHULTZ: Okay.

MR. BOROWSKY: So, even in terms of potential release of content, MacArthur Maze bounded Newhall Pass because MacArthur Maze, all of the scenarios -- for all the scenarios and all the fuel rods were assumed to fail.

MR. SCHULTZ: Right.

MR. BOROWSKY: So, I guess in --

MR. SCHULTZ: So, in both cases, the consequences were more severe and then this demonstrates that the release potential is also more severe --

MR. BOROWSKY: For MacArthur Maze.

MR. SCHULTZ: -- for MacArthur Maze?

MR. BOROWSKY: That's correct. That is correct.

MEMBER BROWN: Can I ask just a simple minded question? MacArthur Maze was an open roadway collapse, Newhall Pass was a tunnel totally enclosed. Tons, I mean a long distance, lots and lots of fuel, different variety, yet the consequences in MacArthur Maze, you're saying were more -- they all failed? They were more severe in that?

That, for some reason, that just doesn't -- is there a physical way to explain why that -- to the simple minded person like me who's not an analyst?

MR. BOROWSKY: Well, I think a lot of it had to do with the boundary conditions for the MacArthur Maze fire. Yes, it was not in a tunnel, it was in an open environment.

But, the assumption made for the MacArthur Maze analysis was that you have this gasoline tanker fire, 8,000 and some gallons and you're putting the package within that fully engulfing fire.

So, the boundary conditions are much different than in the Newhall Pass tunnel fire where you have the fires based on the consumption of the inherent fuel of the individual vehicle.

MEMBER BROWN: And proximity?

MR. BOROWSKY: And proximity of -- versus MacArthur Maze and Newhall Pass.

CHAIRMAN BLEY: And, how important was the insulation of the ComBox?

MR. FORT: I think -- Jim Fort, again from PN&L.

But, I think that's the major point is that in the MacArthur Maze scenario, you had that blanket that was over the package. So, with the internal -- with the continued heating from the decay heat of the fuel inside of the package after the fire combined with the cool down, it was the temperatures were sustained for a much longer period of time. And, actually, that peak temperature for the fuel occurred in the cool down period post-fire.

MEMBER BROWN: So, in Newhall Pass, then you -- there was no collapse of the tunnel, no ceiling collapse, no --

MR. FORT: Correct, no.

MR. ADKINS: It's falling.

MEMBER BROWN: Yes, it's falling but that's relatively trivial, relative to having the concrete --

MR. ADKINS: Right.

MEMBER BROWN: Okay, thank you.

MR. BOROWSKY: Next slide, please?

So, at this point, I'd just like to summarize, you know, some of the information presented in the compendium and some conclusions.

CHAIRMAN BLEY: Can I ask one other question? You put these results in terms of the A-2. And, when I look at the A-2, it's a vast array of radionuclides I think might be in there.

But, can you relate that A-2 to dose at a distance from the fire or anything like that? I mean, it's a real mix of curies of everything and I just -- I have no idea what the hazard from that is.

MR. BOROWSKY: Right. I guess one way of -- I hope this answers your question.

One way of answering that is that for release purposes, the dose is basically defined by basically the effect of inhalation or ingestion of a particular --

CHAIRMAN BLEY: Yes, did you do any calculations like that to see what the dose is?

MR. BOROWSKY: No, we did not. I mean we basically said, okay, Part 71.51 says that the release must be limited to --

CHAIRMAN BLEY: A-2 in a week.

MR. BOROWSKY: -- an A-2 per week.

PARTICIPANT: At the boundary.

MR. BOROWSKY: Right, right. And so, we just checked and saw that, okay, since --

CHAIRMAN BLEY: I don't have a clue about how big a deal that is, I really don't from its definition.

MR. BOROWSKY: Right. You know, I'm not a health physicist, so I hesitate to translate and A-2 into an equivalent.

CHAIRMAN BLEY: Well, it depends on lots of things. It isn't a --

MR. BOROWSKY: That is true.

CHAIRMAN BLEY: So, we didn't do any calculations like that to see what these are worth?

MR. BOROWSKY: No.

CHAIRMAN BLEY: Somebody somewhere has, I'm sure.

MR. BOROWSKY: Well, I mean NRC has. The fact that --

CHAIRMAN BLEY: Because that's in the regulations.

MR. BOROWSKY: -- is A-2 -- less than A-2 per week means that --

CHAIRMAN BLEY: But, it must mean it's a pretty low release, yes.

MR. BOROWSKY: Right. But, what the -- how to translate or what to translate a .24 A-2 value is in terms of a dose, an internal dose summary --

CHAIRMAN BLEY: It's like 200 nuclides at various different concentrations. I mean, not concentrations, various different amounts of terabecquerels. Okay, thank you. I'll have to look somewhere else for that.

MR. BOROWSKY: Just want to, again, summarize some of the information presented in the compendium and some of the conclusions.

Four case studies were analyzed such as the fire duration and peak fire temperature were above those of the hypothetical accident condition fire defined by the regulations.

Again, the regulations, it's 1,475 degrees Fahrenheit at 30 minutes, Baltimore Tunnel fire was for seven hours at 2,084 degree Fahrenheit peak temperature.

The Caldecott Tunnel fire was 40 minute duration at 1,965 degree Fahrenheit peak temperature.

MacArthur Maze fire, there was a total duration of 108 minutes, 37 minutes of that had a peak temperature of 2,012 degrees Fahrenheit and 71 minutes was at 1,652 degrees Fahrenheit peak temperature.

Depending on the situation with Newhall Pass, there was a three to five hour duration and peak temperatures up to 1,991 degrees Fahrenheit.

There were a number of detailed analyses performed, thermal analyses using a fire dynamic simulator, COBRA-SFS and ANSYS and structural analysis using the ANSYS and LS-DYNA codes.

Next slide?

These case studies analyzed the potential impact on spent nuclear fuel packages due to severe real world fires. The four analyses have shown packages are robust in their response to conservative accident scenarios.

Dose requirement limits were met and less than an A-2 quantity of potential release.

CHAIRMAN BLEY: It's there again and I know you can't give me much more, but the assumption that the seals fail, in practical terms, you then -- do you then say all of the CRUD and any fuel that melts comes out?

MR. BOROWSKY: Well, it's -- for

release analyses, we used what are called release fractions. So, for accident --

CHAIRMAN BLEY: But, there are still some allowance for the mechanical small opening that's there?

MR. BOROWSKY: Yes. Well, the short answer is not all of the content -- not all of the radioactive content is available for release. Only a fraction --

CHAIRMAN BLEY: Right, but do you assume all that is available comes out or only a fraction of that?

MR. BOROWSKY: We assume that for the amount that could come out, we did not take into -- for example, we did not take into account the fact that there was potentially only a very small opening between the lid and the flange.

CHAIRMAN BLEY: You effectively assumed it was an open --

MR. BOROWSKY: Yes.

CHAIRMAN BLEY: -- open hole?

MR. BOROWSKY: Yes, we didn't take into account --

CHAIRMAN BLEY: So, this A-2 quantity is really a high upper bound --

MR. BOROWSKY: Yes.

CHAIRMAN BLEY: -- of what would come out?

MR. BOROWSKY: Yes. You know, a particulate maybe you could assume 90 percent settling, for example.

So, again, yes, less than an A-2 quantity of potential releases, you know, which overall show that, you know, the current NRC regulations and packaging standards provide a high degree of protection to the public health and safety.

And, you know, with that, you know, we thank you for the meeting and, you know, want to ask if there are additional questions.

MEMBER SKILLMAN: I would ask this question. In four out of four sets of analyses here, the temperatures that you predict are greater than the current regulation limit, regulatory limit.

Just from an academic perspective, why wouldn't you then change the regulatory limit?

MR. BOROWSKY: Well, I --

MEMBER SKILLMAN: I can understand the argument, hey, the 1,475 covered all of these, so what's the fuss? But, from an optics perspective, why wouldn't you just bump it up to a number that's a couple hundred degrees Fahrenheit higher?

MR. BOROWSKY: I think a lot of it depends or can be spoken to in regards to the 1,475 represents a good boundary condition to represent accidents.

The fact that there are potentially severe fires out there that result in temperatures higher than that doesn't necessarily point that the hypothetical accident condition fires should be higher. The hypothetical accident condition fire doesn't necessarily represent, you know, the most severe fire that's potentially out there.

I mean, I think the intent of the -- of it is to show that with those conditions currently as defined by the regulations, the package as a whole is robust to survive these accidents.

I'm not too sure if that satisfies your answer or your question.

MEMBER SKILLMAN: I don't want to be frivolous, but I just remember this discussion from over 30 years ago and the way we were thinking about the TMI-2 shipments. We said our wife and children are in the Interstate 95, the package is in a truck in the next lane. Will our wife and children be safe, yes or no?

And so, I'm unfortunately stuck in that paradigm and so, here I say, here are these four events, in each case, the actual analyzed temperature is higher than the current regulatory limit. I understand your point that through the analysis, the packages didn't breach or, if they did, the consequences are of no real significance. But, there's an optics piece.

So, that's my thought.

MEMBER RICCARDELLA: Is the hypothetical accident condition something that the vendors designed to with margin?

MR. BOROWSKY: Well --

MEMBER RICCARDELLA: And with safety factors or something like that?

MR. BOROWSKY: Yes, I mean we, you know, we would normally look -- basically an application comes in and reviewers look at the total package. And we look and see, for example, how much margin is the PCT relative to the allowable temperature?

Did the applicant use conservative boundary conditions? Is the model conservative?

So, you know, broadly speaking, yes, there is margin within that. But, in terms of the temperature -- in terms of temperature boundary condition that they apply to their analysis, they do use the 1,475 degree Fahrenheit value.

The application as a whole has conservatisms.

MR. CHANG: Plus, we look at how the model defines conservative. But, in my experience, the margins for the accident is very huge. It's much, much bigger 1,475 degrees. I believe at this model, like a 20 percent and we feel comfortable.

MR. ADKINS: One of the things that I think needs to kept in mind is the regs, the purpose they serve is to establish a package with conservatism and that it should almost be looked at as like a stoutness test.

And then, if you look at the background of that temperature itself, it's an internationally accepted temperature. And, there's a lot of things that feed into it all way from the '67 to '93 PATRAM conference proceedings that led into the establishment of this temperature boundary.

And, what it takes into account is the probability and likelihood for one, the likelihood for all these things that would compound and lead to a fire of such magnitude available products to, you know, start the fire, what the likelihood is that it would even be -- have the potential of being an engulfing fire.

And then, the last part is, all of the things that the surrounding environment can do to detract from the fire magnitude and the temperature magnitude.

And, unfortunately, I wish I would have reviewed a lot of those to establish how things come back to that 1,475. But, there is a substantial basis that IAEA is putting together some documentation where that number comes from and it is an internationally accepted standard temperature.

MEMBER RICCARDELLA: Okay, thanks.

MEMBER STETKAR: You gave me an opening which you shouldn't have. You mentioned the words probability and likelihood. I think you used probability and likelihood and I don't understand that, but that's okay.

NRC has a policy for using risk information to support regulatory decisions. I'm a risk analyst, we have evidence, I'll just follow up on something Dick sort of alluded to as did Dana.

We have evidence now, and you've run all kinds of simulations and done all kinds of fire burning, but we have evidence of four events where conditions could exceed our nominal design basis.

We have the Fukushima Nuclear Power Plant where conditions, indeed, exceeded the nominal design basis of that plant.

How do you guys account for actual risk? I mean, one could do some evaluation of risk in the way that we do it throughout the agency and ask the question, what does this evidence tell us about the frequency of events? What's the likelihood that those events could cause an undesired condition?

What's the consequences of those undesired conditions in terms of health and safety of the public, not looking at internationally accepted values that everybody agrees to today?

So, have you thought about this problem at all in that context given this now evidence that we have? We're not talking about 10^{80th} per year events. We actually have some evidence, we have some supporting deterministic analyses, if I can call them that, with ranges of assumptions applied to them.

MR. BOROWSKY: But, I guess I just would like to follow up a little bit with that comment with the idea that, yes, these are accidents that occurred. But, they did not occur with radioactive material.

So, the, you know, in terms of I guess risk and probability, and I'm not an expert at that, but, you know, what NRC analyzed in NUREG-2125 showed that, for radioactive material transport, the risks or the probability or an accident is very low.

I guess it's very --

MEMBER STETKAR: But that's an accident involving that particular transport vehicle, right? Driving -- we're not talking about it being exposed in a tunnel to a truck that catches on fire, you know, a quarter of a mile away. That wasn't analyzed in 2125 was it?

MR. ADKINS: I think 2125 and, I'm no expert on this one, are brethren. Sadia is the one that performed this work, but their intention was to take a look at the current conditions of what transport configurations could be without some of the recent no pass rules and things of that nature and weigh those in and take those into account.

And, that was the establishment of that document in particular is to identify, you know, what the associated risk and the potential accident frequency could be and then the probability of having an accident of such magnitude.

CHAIRMAN BLEY: I don't know these by number. Was that the study looking at transportation to Yucca Mountain?

MR. BOROWSKY: That was the CITRA report, spent fuel -- the 2125 was the spent fuel transportation risk assessment NUREG.

CHAIRMAN BLEY: Okay.

MR. ADKINS: So, if you think about that one, it's kind of a companion to these studies that have been performed.

In fact, one of the things that they did during their studies just to, I guess, cut to the chase quicker on what the implications would be regarding the accidents themselves is considered probably a little more conservative boundary conditions and consequences of packages being involved in said accidents and still kind of looking at accident frequencies on rail and road, the numbers are and the frequency are substantially low.

And, one more point that needs to be made is, when you look at the four cases that we evaluated, they are super positioned. It's expressed throughout each one of those evaluations where we make all the fuel pool up underneath the cask even though there was no cask involved.

And, there's the presence of buffer cars and everything else. There's quite a few assumptions that you need to perform to even get to -- and to establish and veer away from the likelihood of something like that happening. And then, superimposing all these things to happen as an occurrence in the same location.

MR. SCHULTZ: Joe, in the summary discussions you have made today, in the case of MacArthur Maze, you presented results of metallurgical evaluations that showed what the expected temperatures were in the fire situation.

With regard to Caldecott Tunnel and Newhall Pass, is there also evidence that was used to benchmark the results of the computer analyses?

MR. BOROWSKY: Yes, in both -- in those other instances, the relevant NUREGs speak of material analysis that were performed.

Some of it maybe was focused more on the concrete, like the fact that the concrete grid is such a value in the case of certain potential temperature.

And, I think in some of the early -- in some of the NUREG/CRs that are listed in the early slides, those are the -- some of them are the material analyses that were performed specifically for those accidents.

MR. ADKINS: In support.

MR. BOROWSKY: In support of. So, for example, NUREG/CR-6799 was one and NUREG/CR-7101 was also.

MR. SCHULTZ: Great, thank you.

MR. CHANG: Yes, in your slide number five.

MR. SCHULTZ: Thank you.

MEMBER BROWN: I have another question. Throughout your presentation, you discussed about releasing quantity, A-2 quantities, whereas the NUREG also discussed -- it talked about Type B quantities which includes spent nuclear fuel materials, and yet, which are more hazardous than the A-2 quantities.

And yet, these were exposed, your

scenarios were greater than the hypothetical regulations go. And, but yet, you never talked about the impact on the specific subject which is spent nuclear fuel type packaging. Did I miss something --

MR. BOROWSKY: No.

MEMBER BROWN: -- in one of your --

MR. BOROWSKY: No, no, that's a good point.

I mean, the information is included in the NUREG/CRs, but you'll see, for example, I believe it's MacArthur Maze, for example, in Chapter 8, you'll see the inventory, the spent fuel inventory, the content basically within that package.

And, the resulting number of curies associated with that and what the overall content activity would be.

And then --

MEMBER BROWN: For a Type B?

MR. BOROWSKY: Yes.

MEMBER BROWN: I mean because Type B has a -- according to this, it has a -- can carry more than an A-2 quantity --

MR. BOROWSKY: That's correct.

MEMBER BROWN: -- of radioactive material.

MR. BOROWSKY: That is correct. Yes, I mean, the Chapter 8, again, I'm really speaking to the MacArthur Maze, but the other rates you guys also mentioned, the total content inventory --

MEMBER BROWN: Okay.

MR. BOROWSKY: -- which is, you know, much more than an A-2.

What we just presented here were the back end results, you know, what could actually -- of that, what could get out and that's where it becomes less than an A-2 quantity.

MR. ADKINS: I believe we even gave a total of possible inventory, complete inventories, to do a rudimentary comparison.

MR. BOROWSKY: Yes.

MR. ADKINS: Because one A-2 is insignificant, obviously, compared to what the total payload would be.

MEMBER BROWN: Well, the reason -- one of the reasons for asking the questions, it talked about the, I guess, 10 CFR 71 says in this package, and if you have the hypothetical circumstance, it's supposed to release less than an A-2 quantity per week.

Now, if these were scenarios that exceeded the hypothetical scenario which would imply that you could have releases greater than the regulatory basis of one A-2 quantity per week. So, that seemed to be a little bit of an inconsistency when we draw our conclusions that everything seems to be --

MR. BOROWSKY: I think --

MEMBER BROWN: But, there's not many accidents that could result in this. I mean, I'm not arguing with that conclusion. It's just that there are circumstances under your all's scenarios seems that would release more than this A-2 quantity. That's the point of my question.

MR. BOROWSKY: Okay. Again, I hope I'm answering this correctly. And, maybe it's just more of a semantics. What we're trying to say in this presentation is, you know, the packages studied, whether it's LWT or GA-4 or the others, they were carrying spent fuel which has an activity, an A-2 value because it's Type B, you know, very high.

And, when we numerically placed that package with that content with the high activity in it within these severe fire accident scenarios, even though they are beyond the hypothetical accident condition fire boundary conditions, they still meet the regulatory limit. The released amount, the potential release amount would still be --

MEMBER BROWN: Less than an A-2.

MR. BOROWSKY: -- below A-2 per week.

MEMBER BROWN: Okay, I missed the nuance, excuse me.

MR. CHANG: Yes, when we say less than A-2, this means out of continuum --

MEMBER BROWN: I got that based on the -- yes, thank you. Okay, thank you very much.

MEMBER SKILLMAN: Your backup slide 50, please?

That second bullet is interesting. You say when the package is cooling, the lid tightens. What you don't say is when the lid is heating, the lid relaxes. How come?

MR. BOROWSKY: Do you want me to speak to this?

MR. ADKINS: Yes, it's probably good.

MR. BOROWSKY: So, one of the things that we did, and I guess maybe it's just a poorly worded slide, but one of the things that we did is we tracked temperature, time, real time throughout the fire scenario, right, and the transients for every one of these sensitivity studies.

And some designs are where they tighten up as they get hotter, some designs not so much. This particular GA-4 cask, it has HeliCoil threads for key inserts that actually, unfortunately, their temperature capacity is lower than the base materials of the bolt and the flange itself.

So, one of the things that we had to do as an exercise when we realized that we were getting close to the temperature margin of the threads itself and for the purpose of answering your question, we had to do evaluations on how much this would be loaded and whether it got loaded to a plastic regime and then, if so, how much strain hardening would occur during that loading.

And then, after it cools off, whether it was a gap that resided between the lid and the implants. Right?

And, this was to coincide and actually led into some of the testing that was done in NIST where they just bolted a flange together with no o-ring and saw what kind of leak rate they could get because we knew full well that the assumption was that the o-ring was going to fail straight out of the gate, right, because we were far beyond its service temperatures.

So, we ended up having to do these types of analyses and figuring out what the clamping force was. The net effect is the clamping force in this particular instance on this cask, which I believe is probably one of the weaker casks in its bolting flange area, the bolted flange area, is still, it -- even with this beyond regulatory condition accident simulated, it's the clamping force is still 80 percent after cool down. I think it was like 80, 82 percent, somewhere in there. So, still substantially high.

One of the, you know, sister studies, of course, was done over at NIST. There were two findings that came out of that.

When they tried to pressurize and have a substantial leak rate with the machine finishes that are provided on a lot of these flanges is they could not establish a substantial leak rate.

And then, one that's a really important key factor is, when they started their studies and tests, started their tests themselves on some of the polymeric seals, they actually started the test at one or a couple of hundred degrees above what the service temperature was of that particular o-ring material and then went up.

So, instantly exposed it to something that it wouldn't normally be accustomed to or be designed to withstand and then went up from there.

And the net influence was the polymeric seals had a notorious tendency to flow, as we talked about earlier, and actually plug the leak. And that happened in a number of the cases at MIST during their studies.

So, to get back to this, this was probably poorly worded on our part and we apologize for that because, ultimately, the question that you probably had is, well, does it leak? Is there a gap? Is there compromise of that bolted closure after it cools down or during the thermal excursion? The answer is no.

Hopefully that answered that.

MEMBER SKILLMAN: That was my question. Thank you.

MR. BOROWSKY: Okay, you bet.

CHAIRMAN BLEY: Any more questions from the members? Chris, can we get the phone line open?

While we're waiting to open the phone line -- I'm sorry, yes?

MR. BOROWSKY: I just wanted to mention something. We were talking in the hallway during the break and I just wanted to clarify a comment about the TN-68 impact limiters.

CHAIRMAN BLEY: Yes, go ahead.

MR. ADKINS: I misspoke. So, one of the things that we did is, you know, there's this assumption of what kind of conditions these packages reside in and, you know, if you don't have an impact of the package like where we're superimposing, the fuel rushes over and lights up underneath.

We did a couple of different evaluations and it was through the course of actually building the model, and so I need to correct, on the TN-68, as our final analysis, what we did is we kept the wood material in its pristine state so it would have its highest conductivity state, bringing heat into the cask and then directly at the point of cessation turned it into charcoal so the conductivity would be muted.

And, the reason being is, as you get

the burn front and the consumption front of the wood as it migrates to the interior, what you end up with is, you know, like a charcoal type state, but also a boundary that becomes more radiative, inner exchange in nature, you know, comprised of almost exclusively radiation because you don't have as it burns back until there's a substantial amount of material. You don't have a void or a volume that's large enough to support substantial convection.

So, that is a clarification for that analysis. That was the end state analysis. And, the reason being were for two things, there wasn't a compelling reason the impact limiter would gone and the other one was there was no confirming reason that there would be substantial damage to the impact limiter, especially when you look at some of these cases where we tried to superimpose and put the cask at any location within the tunnel that would subject it to the most thermal insult.

Does that make sense?

MEMBER SKILLMAN: Well, it does, but I think you've changed the tone of your answer. I'm the one who asked the question the use of the impact limiters are assumed to not be there.

MR. ADKINS: That's correct.

MEMBER SKILLMAN: Therefore, we've got full flow heat onto both ends.

MR. ADKINS: That's correct.

MEMBER SKILLMAN: What you just said is --

MR. ADKINS: That's not, yes.

MEMBER SKILLMAN: -- with the impact limiters there, there is a different thermal conductivity and convection thermodynamic occurring.

MR. ADKINS: You are correct, that's correct.

MR. BOROWSKY: And, that was for the TN-68, but for the MacArthur Maze analysis, there were two analyses studied, one with the impact limiter and one without the impact limiter.

So, it wasn't a TN-68 that didn't have the impact limiter not modeled, it was the GA-4 in MacArthur Maze that also -- where we also did an analyses without the impact limiter.

MR. ADKINS: And, I was confused. I forgot the details of this because it has been quite some time since we did Baltimore. It was over ten years ago.

But, the one point being made is, when you look at something that has substantially lower thermal inertia like those playing out, the NAC-LWT, it only holds one fuel assembly, GA-4 only holds four.

Each one of these fuel assemblies have -- they weigh 1,550 pounds of uranium and cladding material and, you know, upper and lower tie plates and things of that nature. So, essentially, the heat up, regardless of what it's being exposed to, unless you have a dramatically higher temperature difference, you can only drive so much heat into a cask.

So, we think we've bounded it with a smaller scale cask.

MEMBER SKILLMAN: Thank you.

CHAIRMAN BLEY: Thank you.

The phone is obviously open. If there's anyone on the phone line who would like to make a comment, now is the time. Please announce your name and give us your comment.

MS. GILMORE: This is Donna Gilmore in California.

CHAIRMAN BLEY: Hello.

MS. GILMORE: My question is, in terms

of the assumptions, I know the welded canisters, you have no way to inspect what condition the baskets are in and recently, Pepco inspected a Fukushima aluminum basket and found they didn't think it would last more than 40 years.

So, I'm just wondering if there was any assumptions made about the integrity of the baskets considering you can't inspect those at all in the welded canisters, anyway?

CHAIRMAN BLEY: Thanks.

This is just information gathering for the committee at this time, but we will certainly consider your question as a comment, something for us to consider.

Does anyone else have a comment or do you have any further comments?

MS. GILMORE: Yes, in terms of transport, currently the thin canisters cannot be inspected for cracks. So, I don't know the assumption, whether the canister had full integrity as required by NRC regs. So, I just that -- I'm hoping that issue gets addressed.

CHAIRMAN BLEY: Okay. Thank you very much.

I would note that the NRC reports, reg

reports, for all of these analyses are publically available on the NRC website now.

Is any other comments from the phone line?

MR. HOFFMAN: Hi, this Dave Hoffman.

CHAIRMAN BLEY: Please go ahead.

MR. HOFFMAN: Thank you.

I wanted to comment on the, let's see, the hypothetical condition fire and some of the other hypothetical conditions seem to be of not -- they are not a design that includes the accidents that were even discussed during this hearing.

And, it sounded like the person who said that they were designing with margin. One person asked if there was a design with margin and the person that answered seemed to give a very circular answer that says that the NRC and the industry do, in fact, rely on margin. And, I would think the NRC would be the last organization that would be allowed to rely on a margin above their regulations.

So, that scares me quite a bit to be hearing that.

And then, likewise, the concept of probability and likelihood just bothers the heck out of me especially when it sounded like if a bridge girder were to -- an entire bridge assembly were to fall on one of these casks, you're assuming there'll be a very tiny leak. And, I would think there would be a full breach in that case. And, I'm wondering what causes the difference.

And, that's all I have for today. Thank you very much.

CHAIRMAN BLEY: Thank you very much.

Anyone else on the phone line care to make a comment? We'll take these under consideration. We'll close the phone line now. There were no people in the room who wanted to make comments.

At this time, I'm going to poll the members for any closing comments they'd like to make.

Charlie?

MEMBER BROWN: I have no more comments.

CHAIRMAN BLEY: Ron?

MEMBER BALLINGER: No more comments.

CHAIRMAN BLEY: Pete?

MEMBER RICCARDELLA: I have no comments.

CHAIRMAN BLEY: Harold?

MEMBER RAY: No.

CHAIRMAN BLEY: Dick?

MEMBER SKILLMAN: No more, thank you.

CHAIRMAN BLEY: Dana?

MEMBER POWERS: Well, I think the studies probably accomplished what they wanted to be. What I have -- what I find distressing is these are the kinds of calculations that were done 25 years ago for the reactors. They are deterministic calculations done with hodgepodges of things that people suspect are bounding in some sense for some purpose.

And, we've found the failure in that kind of mode because, often times, we have conflicting safety objectives where bounding assumptions in one regard are not bounding in other. And, we've abandoned that and gone to more realistic calculations for propagations of uncertainty ranges through the analyses.

And, it just strikes me that these are throwbacks to a previous era and in calculational analysis. And, I think we've found enough flaws in that kind of approach within the reactor community that we've been forced to abandon it and I think we ought to come into the 21st Century and abandon it here as well.

CHAIRMAN BLEY: Thank you.

Mr. Stetkar?

MEMBER STETKAR: I don't have anything to add, but I agree with Dana fully.

CHAIRMAN BLEY: And, our consultant, Steve Schultz? You'll send us a report, I assume, but if there's anything you'd like to say now, we will appreciate it.

MR. SCHULTZ: Nothing further.

CHAIRMAN BLEY: Thanks, Steve.

I have nothing more to add but I really appreciate that you came to us today and presented this work. We've been interested in it for some time, so we're pleased you were here.

Thanks very much and, at this point, we will adjourn this meeting so we can start the next one very soon.

(Whereupon, the above-entitled matter went off the record at 11:41 a.m.)

A Compendium of Spent Fuel Transportation Package Response Analyses to Severe Fire Accident Scenarios

Jimmy Chang and Joseph Borowsky
Containment, Structural, and Thermal Branch
Division of Spent Fuel Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
March 2, 2016

Outline

- Motivation for Severe Fire Studies
- Regulatory Requirements for Transport of Spent Nuclear Fuel (SNF)

  10 CFR Part 71 Subpart F

  71.71 Normal Conditions of Transport (NCT)

  - used as initial condition for accident conditions

  71.73 Hypothetical Accident Conditions (HAC)

  - <u>regulatory fire is 1475°F (800°C) for 30 minutes</u>
- Fire Scenarios and Consequences for SNF Packages
- Conclusions

Severe Fire Topics of Study

- NRC recognizes that some <u>real-world</u> fires may exceed conditions of the regulatory fire and investigated how spent fuel transportation packages would perform in those fires.
- National Academy of Sciences (NAS) study in 2006 recommended additional emphasis on severe fire studies

"The committee recommends that the U.S. Nuclear Regulatory Commission (USNRC) undertake additional analyses of very long-duration fire scenarios that bound expected real world accident conditions."

  - From *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*, National Academy of Press, 2006

Severe Fire Topics of Study

- NRC has conducted fire studies to understand:
  - Types and quantities of fuel available in actual fires
  - Possible ranges of temperatures in realistic and idealized fires
  - Duration of fire in real accidents
  - Effect on packages (size and mass of the package)
  - Behavior of important-to-safety components during fire
  - Additional actions, if any, that may be needed to address real-world fire accidents

Completed Investigations

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

NRC worked with PNNL, NIST and CNWRA to perform numerous analyses and studies, including

- Rail car components to a tunnel fire (NUREG/CR-6799, 2003)
- Rail accident database review (NUREG/CR-7034, 2011)
- Roadway accident database review (NUREG/CR-7035, 2011)
- Structural material analysis reports (NUREG/CR-7101, 2007)
- Testing O-ring materials at high temperatures (NUREG/CR-7115, 2015)
- Baltimore Tunnel fire scenario – railway (NUREG/CR-6886, 2009)*
- Caldecott Tunnel fire scenario – roadway (NUREG/CR-6894, 2007)*
- MacArthur Maze fire scenario – roadway (NUREG/CR-7206, 2015)*
- Newhall Pass fire scenario – roadway (NUREG/CR-7207, 2015)*

* **None of these fire accidents involved radioactive materials**

NMSS
Division of Spent Fuel Management

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Railway Fire Accidents

NMSS
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Railway Fire Accidents

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Potential for higher temperature and longer duration fires

Environment	Rail Bed Material	Pool formation	Oven Effect	Space Restriction	Oxygen Supply
Open Fire	Porous substrate	less	no	less	more
Tunnel Fire	Rock, concrete, pavement	more	more	more	less

Fire accidents can be more severe in tunnels than in open environment

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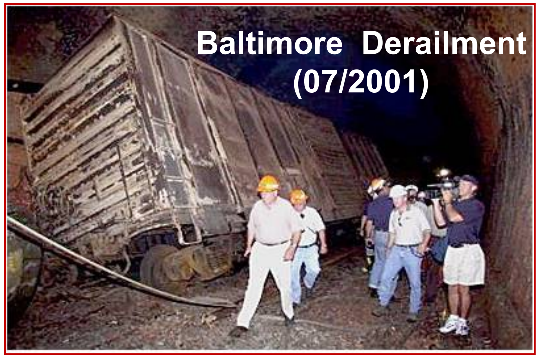
Baltimore Tunnel Fire Scenario

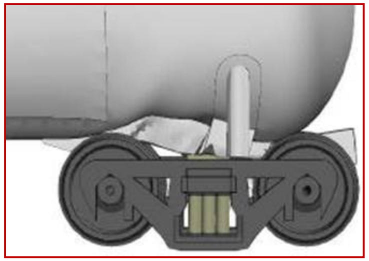
(Howard Street Tunnel Fire, Baltimore, 2001)

Baltimore Tunnel Fire

CSX Freight Train Derailment (single track tunnel)

- Train carrying flammable material, including HAZMAT (not SNF) derailed; tank car carrying liquid tripropylene punctured by brake mechanism; flammable liquid formed a large pool on tunnel floor
- Ignition of spilled liquid tripropylene led to severe fire lasting ~3 hours (as estimated by NTSB investigators)
- Conservative modeling of fire predicted that if fully oxygenated, the fire could have lasted ~7 hrs with peak gas temperatures of 2084°F in flame region and 1958°F at 66 ft downstream of the fire (> 1475°F fire defined in Part 71)





Baltimore Tunnel Fire

Analysis of Fire Accident Scenario

NIST FDS (Fire Dynamics Simulator) → COBRA-SFS (PNNL)/ANSYS

Used to predict fire conditions in the tunnel and provide tunnel fire boundary conditions to COBRA-SFS and ANSYS models for thermal analysis of SNF transportation packages

Conservative assumptions –

- Fire fully oxygenated, burned until entire fuel supply fully consumed.
- Peak gas temperatures (T) in tunnel zones as boundary conditions (BCs) for thermal model.
- Peak surface T on tunnel floor/walls/ceiling as BCs for thermal model.

Baltimore Tunnel Fire

Analysis of Fire Accident Scenario, cont.

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COBRA-SFS (PNNL) and ANSYS (thermal models) – Predict transient thermal response of the package during fire and extended post-fire cooldown.

Conservative Assumptions

- Rail car and package support structure are neglected to allow maximum heat transfer into the package during the fire.
- Forced convection in fire and natural convection in post-fire cooldown.
- Impact limiter & neutron shield retain nominal properties during fire and degrade in the post-fire cooldown.
- Maximum design basis heat load is used for the packages.

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Baltimore Tunnel Fire

Accident Scenario Analysis Results

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Package	**TN-68** (large)	**HI-STAR 100** (large)	**NAC-LWT** (small)
Peak cladding temperature (PCT)	< 1058°F	< 1058°F	< 1058°F
Peak temperature Lead gamma shield	NA	NA	> 622°F

- 1058°F (570°C) - limit of fuel cladding
- 622°F (328°C) - lead melting temperature
- Packages with loss of neutron shield in the fire still meet dose limit requirements

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Baltimore Tunnel Fire

Accident Scenario Analysis Results, cont.

Seals	TN-68	HI-STAR 100	NAC-LWT	
Locations	Closure Port	Lid/Drain/ Vent Ports	Lid	Drain/Vent Ports
Max. Seal Temperature vs. Limit	Helicoflex **> 536°F (limit)**	Metallic **< 1200°F (limit)**	Metallic & Teflon **> 800°F (limit)**	Teflon **> 735°F (limit)**

TN-68 and NAC-LWT have maximum seal temperatures above seal material thermal performance limits. Therefore, there is potential for radioactive release from these packages

Baltimore Tunnel Fire

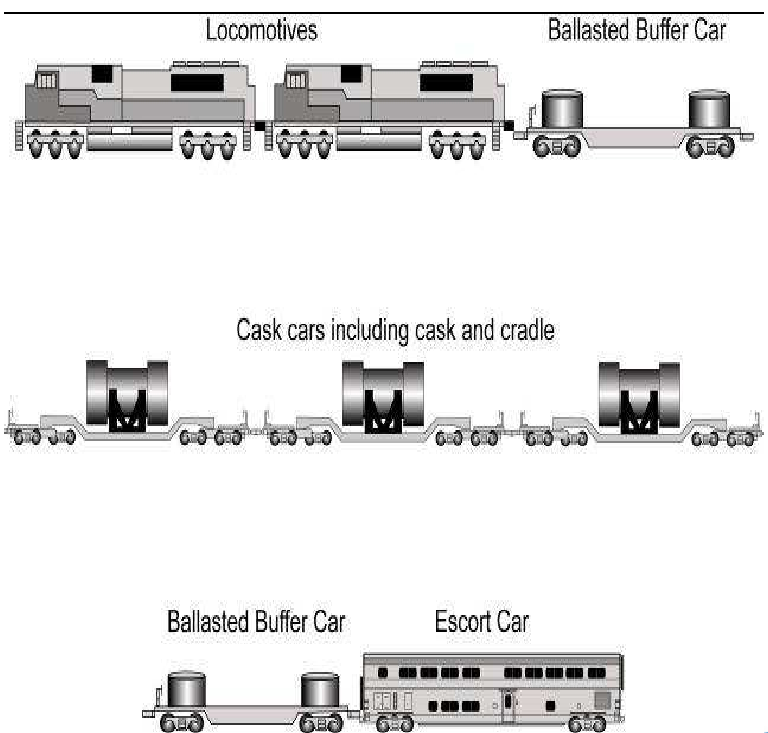
Accident Scenario Consequences

- Failure of neutron shielding is not an issue; all three packages meet regulatory requirements for accident conditions (including HAC fire) assuming loss of neutron shielding as design basis.
- No fuel rod cladding failure predicted in this tunnel fire, so no release of spent fuel particulate or fission gases
- For packages with failed seals, potential release due to Chalk River Unknown Deposit (CRUD) detaching from fuel rods less than A_2 quantity.
- No loss of gamma shielding for TN-68 or HI-STAR100 in this severe fire scenario.
- Lead melting in NAC-LWT not severe enough to lead to loss of gamma shielding; and no dose consequence.

SNF packages survive the severe rail fire with fuel integrity maintained and radiation dose below regulatory limit.

Safety of Spent Fuel Packages
Shipped by Rail

- Robustness of the design (the focus of 10CFR Part 71)
- Transportation elements associated with DOT regulations, 10 CFR Part 73.37, and administrative controls.



✓ **DOT 49 CFR 174.85:** Requirement of buffer car

✓ **AAR OT-55:** no-pass rule - limit 2-track tunnel to single SNF train

✓ **AAR S-2043:** design standard ballasted cask cars, buffer cars, and escort car

✓ **Preplan and coordinate shipments**

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Conclusions

- Packages evaluated are shown to be extremely robust in response to a real-world railway fire of significantly longer duration and higher peak temperatures than the HAC fire.
- Current NRC regulations and packaging standards provide a high degree of protection to the public health and safety against releases of radioactive material during real-world railway transportation accidents

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Roadway Fire Accidents

Roadway Fire Accidents

Caldecott Tunnel Fire Scenario

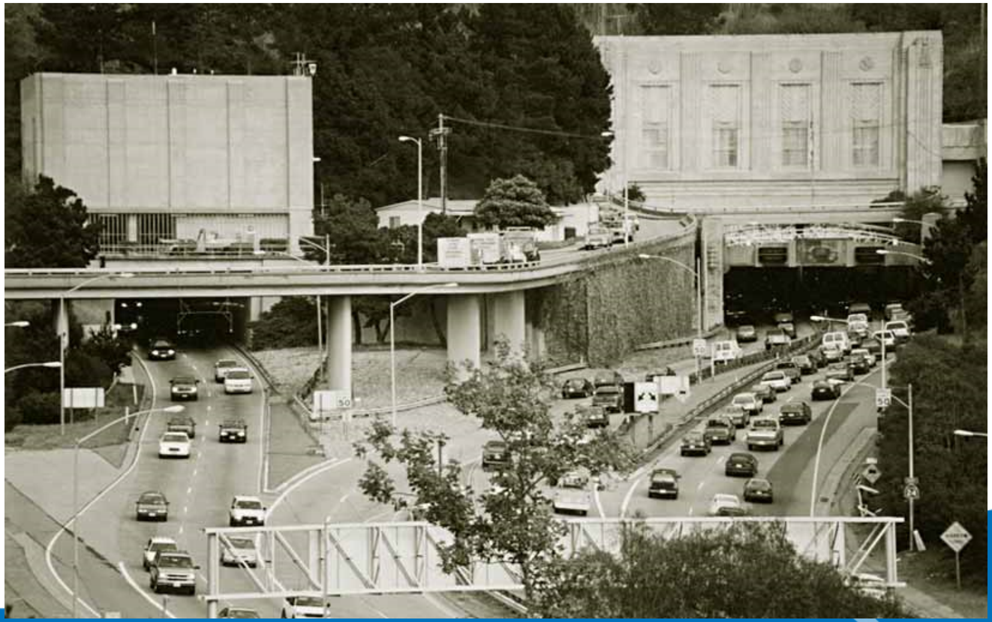
MacArthur Maze Fire Scenario

Newhall Pass Tunnel Fire Scenario

Caldecott Tunnel Fire

State Route 24 near Oakland, CA, 1982

- Tanker truck and trailer overturned and caught fire in tunnel
- Tank trailer cargo: 8,800 gallons gasoline
- Fire duration (based on NTSB investigation):
  - Overall duration: 2.7 hours
  - Intense fire duration: 40 minutes



NUREG/CR-6894

Caldecott Tunnel Fire

Analysis of Fire Accident Scenario

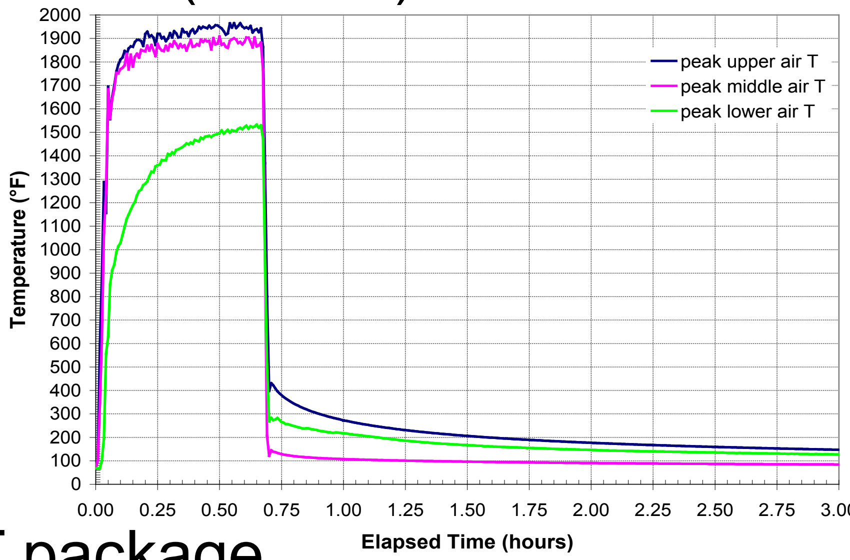
- Analysis Methodology
  - NIST's Fire Dynamics Simulator (FDS) code to determine thermal boundary conditions
  - ANSYS FEA thermal evaluations of NAC-LWT
- Model conservatisms
  - Use peak tunnel temperatures even if the package surface could not see that particular tunnel location
  - Neglect thermal shielding effect of the cradle and package conveyance

Caldecott Tunnel Fire

Accident Scenario Analysis Results

- Fire Dynamics Simulator code (NIST)
  - Maximum gas temperature: 1965°F (1074°C)
  - Fire Duration: ~ 40 minutes

Tunnel air temperature histories
Fig. 5.12 of NUREG/CR-7209



- ANSYS thermal analyses of LWT package
  - Peak cladding temperature: 544°F (284°C)
  - Peak O-ring temperature: 1288°F (698°C)
  - Gamma shield temperature: 622°F (328°C)

Roadway Fire Accidents

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MacArthur Maze Fire Scenario

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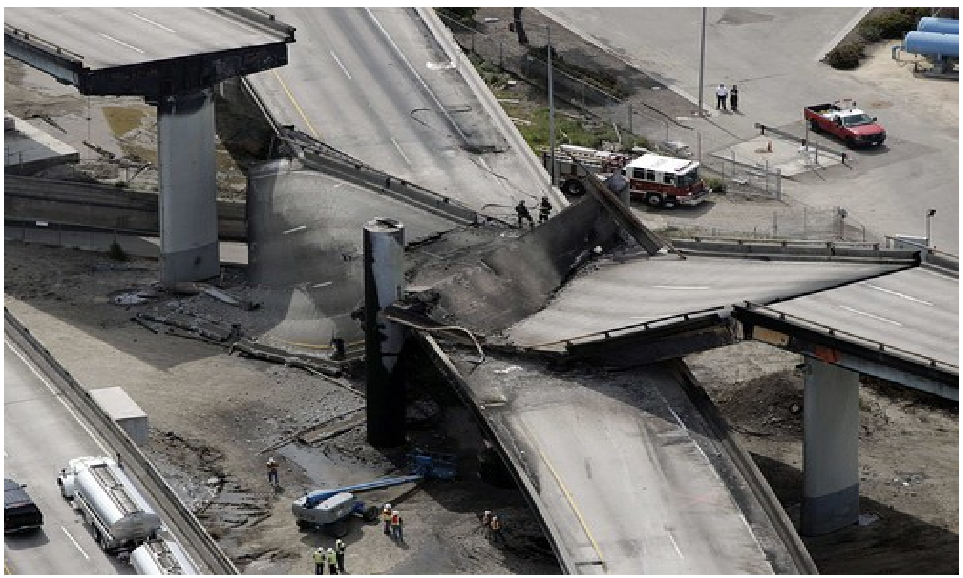
MacArthur Maze Fire

I-880 Connector of MacArthur Maze Interchange Oakland, CA, 2007

- Tanker truck and trailer overturned and caught fire on I-880
- Tank trailer cargo: 8,600 gallons of gasoline
- I-580 roadway located above the fire
- Intense fire weakened steel girders, collapsing two spans onto tanker
  - Enclosure formed by collapsing roadway
  - Opening sufficient for combustion airflow



Spans of I-580 collapsed onto tanker fire on I-880

NUREG/CR-7206

MacArthur Maze Fire

Analysis of Fire

- Analysis with Fire Dynamics Simulator code (NIST)
  - Pre-collapse fire duration: 37 minutes
    - Fully engulfing fire with uniform flame temperature of 2012°F (1100°C)
  - Post-collapse fire duration: 71 minutes
    - 1652 °F (900°C) flame temperature
- Metallurgical Analysis
  - Steel girder: 1652°F (900°C)
  - Truck radiator: 1328°F (720°C)
  - Truck engine bolt: 1657°F (903°C)

MacArthur Maze Fire

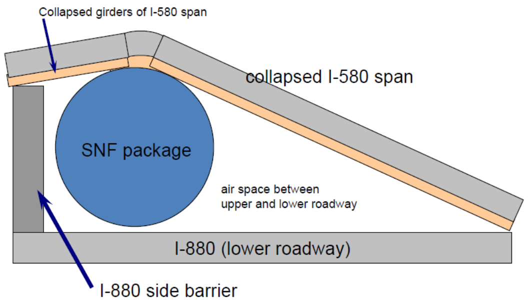
Fire Accident Scenario

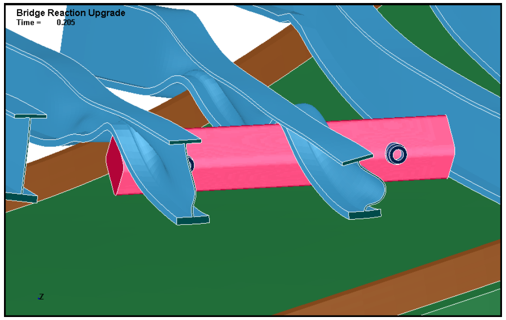
- Aspects of fire scenario that are more severe than hypothetical accident condition fire (800°C and 30 minute duration, per 10CFR 71.73)
  - Pre-collapse fire: higher temperature and longer duration (1100°C for 37 minutes)
  - Post-collapse fire: higher temperature and much longer duration (900°C for 71 minutes)
  - Impact of free falling overhead span on package
  - Post fire cooldown with package assumed covered by concrete “blanket”
- Package location in most adverse location during each stage
  - On roadway in fully engulfing fire for pre- and post-collapse fires
  - Impact location and orientation determined by analysis of multiple cases
  - Under concrete “blanket” for extent of post-fire cooldown
- Analysis Methodology
  - Fire Dynamics Simulator (FDS) code for thermal boundary conditions
  - COBRA-SFS (PNNL) and ANSYS FEA thermal evaluations of General Atomics GA-4 LWT package
  - LS-DYNA to model the effect of the falling I-580 overpass

MacArthur Maze Fire

Accident Scenario Analysis Results

- COBRA-SFS (PNNL) and ANSYS thermal analyses of package
  - Pre-collapse of I-580 span (37 minutes)
    - Peak cladding temperature: 1020°F
    - O-ring temperature: 250°F
    - Gamma shield: 1250°F
  - Post-collapse of I-580 span (71 minutes)
    - Peak cladding temperature: 1425°F
    - O-ring temperature: 770°F
    - Gamma shield: 1490°F
  - Post-fire cooldown
    - Peak cladding temperature: 1400°F
    - O-ring temperature : 1150°F
- ANSYS thermal model of I-580 span
  - Steel girders of I-580 at 1800°F for impact analysis
- LS-DYNA structural/impact model of I-580 span
  - Model the effect of the falling I-580 overpass on package
    - Four impact orientations were considered
    - Local plastic strain at package outer wall
    - No gross failure or rupture of package





NUREG/CR-7206

Roadway Fire Accidents

Newhall Pass Tunnel Fire Scenario

Newhall Pass Fire

I-5 Truck Route Underpass Tunnel
Los Angeles, CA, 2007

- Chain reaction traffic collision of 33 tractor-trailer trucks
  - Fire started near the tunnel exit and spread full length of the tunnel
- Twenty-four tractor-trailer vehicles were destroyed (none carrying hazardous material)
  - Combustible material: diesel (in truck tanks), tires, sheet aluminum of semi-trailers, wood, cotton, sugar, cardboard containers, fruit and vegetables
- Fire duration (for intense fire within tunnel):
  - Estimated as between 3 and 5 hours; local fires on individual vehicles estimated as 0.5 to 1.0 hours, as fire spread through tunnel

Location of fire in truck route tunnel

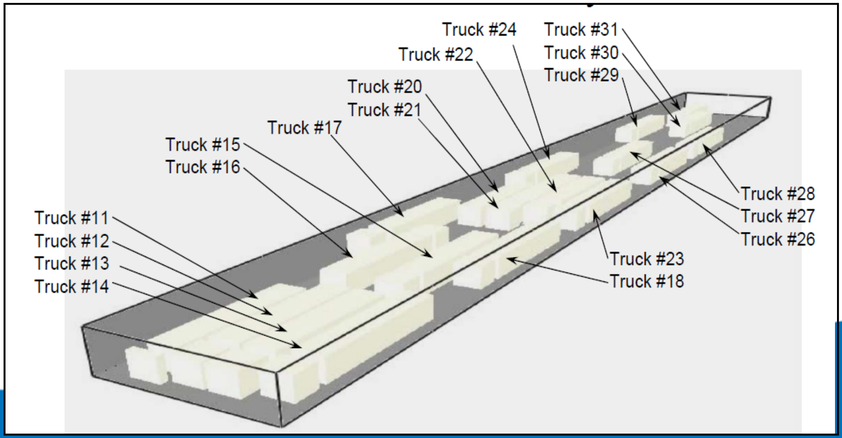
NUREG/CR-7207

Newhall Pass Fire

Fire Accident Analysis

- Fire Dynamics Simulator Analysis (NIST)
  - Fuel budget established for each vehicle
  - Six cases considered
    - Slow and fast burn rates
    - Range of fire spread rates
    - Variation in fuel budget

NUREG/CR-7207



NUREG/CR-7207

Newhall Pass Fire

Fire Accident Scenario

- Aspects that are potentially more severe than hypothetical accident condition fire (800°C and 30 minute duration, per 10 CFR 71.73)
  - Peak fire temperatures (854 °C – 1088 °C)
  - Local fire duration at specific truck locations range from 26 minutes to approximately 68 minutes
  - Preheating of package depending on location in tunnel
- Determine most adverse condition from a matrix of cases
  - Six fire cases developed with FDS
  - Two package locations
    - Hottest fire location (middle of tunnel)
    - Longest (preheating) fire location (just past tunnel entrance)
- Perform thermal analysis of GA-4 package for each case
  - ANSYS
  - COBRA-SFS (PNNL)

Newhall Pass Fire

Analysis of Accident Scenario

- Model conservatisms
  - Conservative combustible mass for each vehicle within tunnel
  - Assumed the entire combustible mass of each vehicle was fully consumed by fire
  - Assume fully engulfing fire at peak local temperature from Fire Dynamics Simulator code
  - Neglect thermal shielding effect of the package conveyance

Newhall Pass Fire

Accident Scenario Analysis Results

- COBRA-SFS and ANSYS thermal analyses of GA-4 package
  - Longest (pre-heating) fire location
    - 64 minute local fire duration
    - Peak cladding temperature: 1020°F/834°F
    - Lid seal peak temperature of 649°F
  - Hottest fire location
    - 78 minute local fire duration
    - Peak cladding temperature: 1217°F/994°F
    - Lid seal peak temperature: 545°F

Roadway Fire Accidents - Consequences

- Caldecott Tunnel Fire Scenario
- MacArthur Maze Fire Scenario
- Newhall Pass Tunnel Fire Scenario

Caldecott Tunnel Fire Accident Scenario

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Consequences for NAC LWT

- Neutron shield
  - Neutron shield is assumed lost as a result of the fire hypothetical accident condition; dose within regulatory limits
  - This is a design basis assumption, satisfied by all packages studied
- Gamma shield
  - Lead reaches melting point 23 to 34 minutes after the start of the 40 minute fire
  - Localized melting, which would still provide shielding
- Metallic lid seal
  - Peak temperatures (735/794°F with and w/o ISO container) are below 800°F continuous use limit
- Cladding
  - Peak fuel cladding temperatures (544°F with and 535°F w/o ISO container) are well below limits

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Caldecott Tunnel Fire Accident Scenario

Consequences for NAC LWT

- Vent/Drain Port O-Ring seals
  – Peak temperatures in seal region (1035/1288°F with and w/o ISO container) exceed continuous-use limit of TFE (735°F) and Viton (550°F) seals
  – Seals conservatively assumed to have failed
- Potential release through failed seals
  – CRUD particles from exterior of the cladding: 0.01 Curies
  – 0.01 Curies translates to 0.001 A_2 quantity, which is below the regulatory limit of an A_2/week

MacArthur Maze Fire Accident Scenario

Consequences for GA-4

- Gamma shield
  - Peak temperature of 1480°F remains well below the melting temperature of 2070°F for depleted uranium
- O-ring seals
  - Based on ANSYS results, peak temperatures of the cask lid O-ring (1160°F), drain valve seal (1170°F), and gas sample port seal (1130°F) exceed the continuous-use temperature limit of EPDM seals (302°F)
  - Analyses assumed seal failure
- Fuel cladding
  - The peak cladding temperature is predicted with both ANSYS and COBRA-SFS to reach nearly 1400°F during post-fire cooldown
  - This temperature exceeds short-term and estimated burst temperature limits

MacArthur Maze Fire Accident Scenario

Consequences for GA-4

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- Closer look at potential for fuel failure
  - Used FRAPCON-DATING and FRAPTRAN fuel performance codes to predict cladding behavior
    - FRAPCON-DATING relies on creep rupture models
    - FRAPTRAN relies on burst rupture models
  - Both models predict fuel failure

LOCA Burst Strain Model (FRAPTRAN)		Creep Rupture Model (FRAPCON/DATING)	
Cladding Temperature	Rupture Conditions	Cladding Temperature	Rupture Conditions
1,097°F (592°C)	rod rupture in end region	1,229°F (665°C)	rod rupture near end

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MacArthur Maze Fire Accident Scenario

Consequences for GA-4

- Estimate of potential release
  - Release model based on pressure in package and leakage between lid and flange for the lid clamping force
  - Potential release includes
    - Fission products and spent fuel particles
    - CRUD particles assumed to have spalled from the cladding surface
  - Total release calculated: 0.24 A2 quantity, which is below the regulatory limit of an A2/week
    - Conservatively neglects particulate settling
    - Conservatively assumes no restriction on size of particles passing through small gap

Newhall Pass Fire Accident Scenario

Consequences for GA-4

- Gamma shield
  - Peak temperature of 1200°F remains well below the melting temperature of 2070°F for depleted uranium
- O-ring seals
  - Based on ANSYS results, peak temperatures of the cask lid O-ring (668°F), drain valve seal (678°F), and gas sample port seal (562°F) exceed the continuous-use temperature limit of EPDM seals (302°F)
  - Analyses assumed seal failure

Newhall Pass Fire Accident Scenario

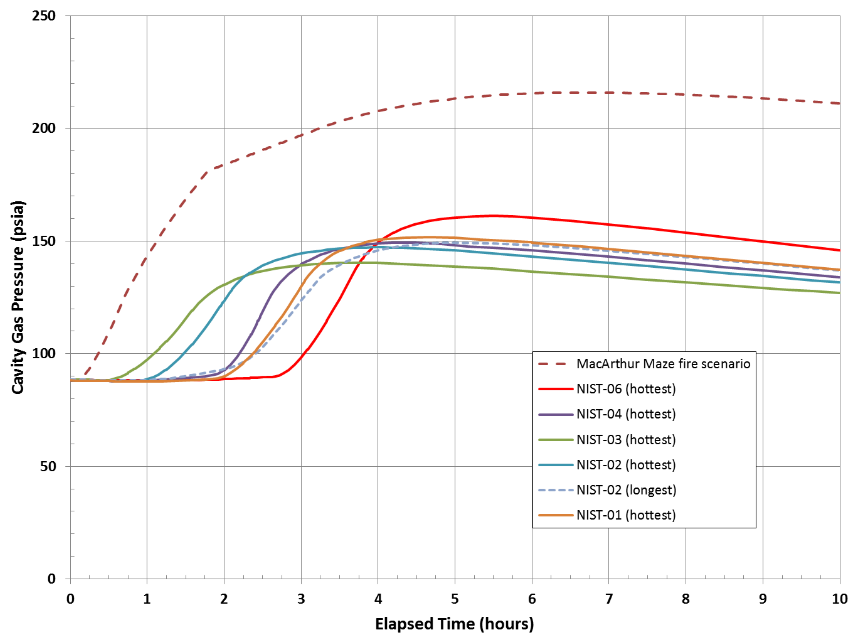
Consequences for GA-4

- Fuel cladding
  - The peak cladding temperatures predicted with ANSYS generally higher than COBRA-SFS for each case
  - Used input from COBRA-SFS and ANSYS for the fuel performance codes
  - FRAPCON-DATING predicted no fuel failure
  - FRAPTRAN predicted no fuel failure based on the COBRA-SFS results
  - Potential for fuel failure in three of the 10 analyzed cases based on the ANSYS thermal results
- O-Ring seal failure allows potential for release of CRUD particles that are on the exterior of the cladding

Newhall Pass Fire Accident Scenario

Consequences for GA-4

- MacArthur Maze fire scenario conditions bounded the Newhall Pass Tunnel fire scenario conditions



Cavity Pressure

MacArthur Maze

Bounding cases for Newhall Pass

NUREG/CR-7207

- Therefore, consequences were conservatively assumed to be the same as for the MacArthur Maze fire scenario

Summary and Conclusions

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- Case studies of severe fires
  - Baltimore Tunnel fire: 7 hour duration, 2084 °F peak temperature
  - Caldecott Tunnel fire: 40 minute duration, 1965 °F peak temperature
  - MacArthur Maze fire:
    - Pre-collapse fire: 37 minute duration, 2012 °F peak temperature
    - Post-collapse fire: 71 minute duration, 1652 °F peak temperature
  - Newhall Pass Tunnel fire:
    - 3 to 5 hour duration, peak temperatures up to 1991 °F
- Detailed analyses
  - Thermal analyses (FDS, COBRA-SFS, ANSYS)
  - Structural analyses (ANSYS, LS-DYNA)

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Summary and Conclusions

- Case studies analyzed the potential impact on spent nuclear fuel packages due to severe real-world fires
- The four analyses have shown packages are robust in their response to conservative accident scenarios:
  - Dose requirement limits were met
  - Less than an A_2 quantity of potential releases
- Current NRC regulations and packaging standards provide a high degree of protection to the public health and safety