

United States
Nuclear Waste Technical Review Board (NWTRB)

Transcript
DOE Research and Development Related to Packaging, Drying,
and Dry-storage of Spent Nuclear Fuel

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PROCEEDINGS

BAHR: OK, well, good morning and welcome to the U.S. Nuclear Waste Technical Review Board's public meeting on DOE Research and Development Related to Packaging, Drying, and Dry-storage of Spent Nuclear Fuel.

I'm Jean Bahr, I'm the Chair of the Board. And I'll introduce the other Board members in a moment. But first, I will briefly describe the Board and outline what we do. As many of you know, the Board is an independent federal agency in the executive branch.

It's not part of the Department of Energy or any other federal organization. The Board was created in the 1987 amendments to the Nuclear Waste Policy Act to perform objective, ongoing evaluations of the technical and scientific validity of DOE activities related to implementing the Nuclear Waste Policy Act and to provide independent expert advice to the Department of Energy and Congress on related technical issues.

The 11 Board members are appointed by the President from a list of nominees submitted by the National Academy of Sciences. And we're mandated by statute to report Board findings, conclusions and recommendations to Congress and the Secretary of Energy. The Board holds public meetings like this one and provides technical and scientific comments in letters and reports to DOE following the meetings.

The Board makes all its official documents and information including its reports available on the Board's website, that's www.nwtrb.gov, and copies of some of the Board's most recent reports can be found on the document table that's outside the meeting room today.

So now, I'll introduce the Board members and then tell you why we're holding this meeting. First, for the introductions, I'll ask that as I say their names, the Board members raise their hands so that they can be identified.

I'll begin. I'm Jean Bahr, the Board Chair. All the Board members serve part-time, so we also other positions, in my case, I'm a professor emerita of hydrogeology at the

University of Wisconsin-Madison. Dr. Steve Becker is professor of community and environmental health in the College of Health Sciences at Old Dominion University in Virginia.

Dr. Susan Brantley is a distinguished professor of geosciences and is director of the Earth and Environmental Systems Institute at the Pennsylvania State University. Mr. Allen Croff is a nuclear engineer and adjunct professor in the Department of Civil and Environmental Engineering at Vanderbilt University.

Dr. Tissa Illangasekare is the AMAX Distinguished Chair of Civil and Environmental Engineering and director of the Center for the Experimental Study of Subsurface Environmental Processes at Colorado School of Mines.

Dr. Lee Peddicord is director of the Nuclear Power Institute and professor of nuclear engineering at Texas A&M University. And finally, Dr. Paul Turinsky is professor emeritus of Nuclear Engineering at North Carolina State University.

So, you'll see that I've just introduced six Board members plus myself, not the full complement of 11. Due to some other commitments, Dr. Efi Foufoula-Georgiou and Dr. Mary Lou Zoback are unable to join us today.

Dr. Foufoula-Georgiou is distinguished professor in the Departments of Civil and Environmental Engineering and Earth System Science and the Henry Samueli endowed Chair in Engineering at the University of California Irvine.

And Dr. Zoback who is assisting with the birth of her third grandchild today is consulting professor in geophysics at Stanford University. And the Board currently has two vacant positions.

As I usually do at Board meetings, I want to make clear that the views expressed by our Board members are their own. They're not necessarily Board positions. Our official positions can be found in our reports and letters, and those are as I mentioned available on the Board's website.

If you'd like to know more about the Board, there's a one-page handout summarizing the Board's mission and presenting a list of the Board members and that can be found on the document table near the entrance to this room. And, again, you can find this information on the Board's website, www.nwtrb.gov.

During this meeting, members of the public will have two opportunities to make comments, once before lunch and at the end of the meeting. If you'd like to make a comment, I'd ask that you please add your name to the signup sheet at the registration table that's outside this room.

Time for each speaker may be limited depending on the number of people who want to speak, but if you want to submit written comments or any other written materials, you can submit them to our staff members today or you can send materials by mail or email to the points of contact who are noted on the press release for this meeting and that press release is posted on our website.

Documents submitted by the public will become part of the meeting record and will be posted on the Board's website along with the transcript of the meeting and the presentations that you'll see at this meeting. If you want to make a comment during the period, please use one of the microphones. We have one in the center of the room back there and be sure to state your name and your affiliation so that you'll be identified correctly in the meeting transcript.

The meeting is being webcast live, so you'll see some cameras in the room. And depending on where you're sitting, you might be part of the webcast. I encourage presenters to speak loudly enough so that those in the back of the room can hear you, and it will also be helpful for those who are watching the webcast if the presenters will summarize any questions prior to answering them.

The webcast will be archived after a few days and then it will become available on our website to view at a later time. To assist those who are watching the live webcast, the meeting agenda has been posted on the Board's website

and can be downloaded, and the presentations will be part of the webcast. Those will be posted on the website shortly after the meeting.

So, why are we holding this particular meeting? Well, first of all, there's a large inventory of spent nuclear fuel from the U.S. defense program and from research reactors that's currently managed by DOE at a number of sites around the country. And this spent fuel is in many ways distinct from the even larger inventory of commercial spent fuel that's currently managed by the utilities.

And while disposal of both the DOE-managed and the commercial spent nuclear fuel in a geologic repository remains the ultimate objective, there is significant uncertainty about when such a repository will be constructed. Until disposal occurs, it's essential to manage both the DOE spent nuclear fuel and the commercial fuel in ways that will facilitate its eventual disposal.

Now, speaking specifically to the DOE spent nuclear fuel, it's important to improve the understanding of processes

related to packaging and storage of that DOE spent fuel that could affect future transportation and disposal activities.

The Board produced a report in 2017 on the management and disposal of DOE-managed spent nuclear fuel and the Board recommended at that time that DOE conduct research and development activities on drying DOE spent nuclear fuel, particularly aluminum-based fuel, and also made recommendations on the DOE standardized canister. So, today, as part of our ongoing review of DOE activities, we're going to hear about DOE's efforts related to those recommendations.

Similarly, prior to accepting commercial spent fuel from the nuclear utilities for offsite transport, the Department of Energy will need to understand how processes related to packaging and storage of commercial spent nuclear fuel could affect future transportation and disposal activities. And DOE continues to conduct research itself to better understand these issues.

So, the Board's objectives for this meeting are to review DOE research activities related to drying, packaging and dry-storage of both DOE-managed and commercial spent nuclear fuel. The Board also expects to elicit information that will be useful to the Board in its review as well as to the Department of Energy in its management of spent nuclear fuel.

And as the Board has indicated in the past, we believe it's important for the Department of Energy to maintain awareness of and take advantage of work being done in other countries that can inform the U.S. program. And to that effect, we've invited a speaker from the United Kingdom to take part in this meeting.

So, the meeting begins this morning with an opening statement by Dr. Bill Boyle from the Department of Energy, Office of Nuclear Energy, then we'll have speakers representing the DOE Office of Nuclear Energy, the DOE Office of Environmental Management and national laboratories. They will report on research related to drying, packaging and dry-storage of spent nuclear fuel.

A computer modeling of thermal behavior of spent fuel casks and canisters will also be discussed, and a member of the Board staff will summarize the Board's 2017 report that I referred to previously on management and disposal of DOE spent nuclear fuel, that's in order to provide a context for some of the subsequent presentations.

Information on the development of the DOE standardized canister for DOE-managed spent nuclear fuel and research on long term drying of aluminum-clad spent nuclear fuel be presented. Additionally, the Board will hear about research in the United Kingdom where the impact of drying and dry-storage on characteristics of spent nuclear fuel is also being investigated.

We'll conclude the meeting with a panel discussion followed by the second period for public comments and we expect the meeting to end at approximately 5PM. I will be the timekeeper and I'll do my best to keep the presentations and the questioning on schedule so that we can meet that target.

A lot of effort went into planning this meeting and in arranging the presentations, so I want to thank all of the speakers who've travelled here, especially our speaker from the United Kingdom.

I also want to thank Board member, Dr. Paul Turinsky and Board senior professional staff member Mr. Dan Ogg who acted together as leads in coordinating with others on the Board to put this meeting together.

So now, please mute your cell phones and let's begin with I'm sure will be an interesting and productive meeting. And it's my pleasure to turn the podium over to Dr. Bill Boyle who'll get the meeting started.

BOYLE: Good morning. Thank you for the introduction. The public may not know, but I know the Board and the staff know that yesterday you met with Assistant Secretary Baranwal from the Office of Nuclear Energy. If you had any questions for her, I hope you asked them of her. You can ask them of me if you forgot to ask a question and I'll do my best.

She's confirmed, we're not really waiting for any other confirmations except Deputy Secretary Brouillette who had his Senate hearing last week. He's been nominated to be the Secretary of Energy. Secretary Perry is leaving, I think, at the end of the month. And that's where DOE stands right now.

Of more importance to me and many people in the room is the status of the appropriations for this year. The Board's appropriation is in the same bill as the Department of Energy, so we're in the same boat. We're in a continuing resolution right now and I think it expires Thursday.

Now, I heard news reports this morning that there was an agreement reached yesterday between the House and the Senate as to the path forward that they need to get passed by Thursday, otherwise, there will be potential consequences.

And the news reports I heard is that it will be another continuing resolution, but for four weeks to add to people's holiday spirit just before Christmas facing a possibility of bad consequences. So, we'll see how that turns out with the

hope that they would do a full appropriation for the rest of the Fiscal Year.

The House has already passed their version of the appropriation through the entire House of Representatives. The Senate version was passed unanimously out of the Committee, but has not come up before the entire Senate. The bills are I would say more similar this year than they have been in prior years, the House and the Senate versions, in terms of what they want to do with respect to this topic area, storage, transportation and disposal.

They're quite different in terms of the amount of funding they want to put up, so we'll see how that turns out. It does cause some uncertainty. It makes planning a little more difficult when you really don't have a firm number to plan to. But that's where we stand now.

My last topic is, I'm pretty sure Ned Larson has already mentioned it to Dan Ogg, a number of the attendees here at the meeting today were members of a team that is going to

receive an award this afternoon, Annual Secretary of Energy Awards.

And so, some of the - people who are going to attend the meeting this afternoon, raise their hand so that - OK, if you want to talk to one of these people, me included, you better talk to us before lunch, because they probably, they're going to leave around that time to go attend the award meeting with the Secretary which is quite formal.

There's singing to start it off and a parade of flags and the team gets - all the teams, all the teams, all the winners get to have their picture taken with the Secretary and so it's quite a nice thing.

So, again, if you want to talk to one of these people at a break or something, make sure you do it this morning. And those were the only remarks - oh, as to what is the award for, it's for the next topic up by Ned Larson, it was for the high burnup demo. And with that, I'll take questions.

BAHR: Thanks, Bill, and congratulations to the team on your award and we look forward to hearing more about that shortly.

One of the things that we discussed briefly with the Assistant Secretary during our meeting yesterday is with the priorities that she has laid out and looking at advanced reactors.

And even prior to that, advanced fuels we, of course, since our emphasis is on the backend of the fuel cycle, it seems really important that as those developments are in process that there be adequate consideration to what might be the implications for ultimate disposal in terms of fuel composition, heat loads, waste packaging requirements and things like that. Do you have any comments on where your program might be going with respect to that?

BOYLE: Yes. Yes, a few remarks. One is if there is some different fuel cycle in the future, even if it starts tomorrow, somebody makes a decision tomorrow, its actual implementation will take a long time. So, unless somebody

makes a decision tomorrow that the waste stream is boiling hydrochloric acid or something completely unacceptable, odds are the disposal and storage people will have time and be able to deal with it.

And this is not the first time people have considered, well, what if we had different reactors, different fuel cycles. A colleague of mine in the Office of Nuclear Energy, BP Singh, for a few years led an effort to look into that whole issue of different reactors, different fuel cycles and the disposal and storage and transportation and people participated in that effort.

So, people know that if they want to do something different, they have to make the people on the backend aware of it so that people don't go down a road and at end go, "Oh my gosh, what have we done."

So, yes, we are aware. For the United States, we have multiple waste streams that exist already. And so, again, unless somebody comes up with something completely different, we should be able to accommodate it, give it the

due diligence that it deserves, but there really hopefully won't be surprises for us.

BAHR: Yes. Paul Turinsky?

TURINSKY: Paul Turinsky, Board member. I mean, your term is accident tolerant fuel which DOE has been funding along with the industry and there are actually, lead demos are going into reactors today.

And within a few years we're going to see very different cladding materials. We are already seeing different basically pellet make ups being loaded in reactors. So, that's something that's here now.

BOYLE: Yes.

TURINSKY: What has DOE done since you are funding part of that development, what has DOE done specifically on the backend aspects?

BOYLE: Yes. Yes. The Office of Nuclear Energy funds it, not my part of the Office of Nuclear Energy. It's under Bill McCaughey. But Ned Larson and I'm sure others in the room today a few weeks ago attended EPRI's Extended Storage Collaboration Program meeting where this topic came up.

For example, for people who weren't there, OK, it's a different cladding material and the spent fuel ends up in the pool. Does it affect the chemistry of the pool? Does the chemistry of the pool affect the cladding material?

And so, there are some questions apparently with respect to the different fuel formulations, the assemblies weigh more. Do you utilities have sufficient crane capacity to do things with what looks to be the same but actually weighs more and things like that. So, it is known that there are issues and I think there will be closer cooperation between Bill McCaughey's side of NE and my side of NE to make sure that something doesn't fall through the cracks.

But as a resident of the United States, the utilities and the vendors really need to pay attention to - they deal with it way before I ever do, right?

I'm at the backend. So, a lot of the potential issues do crop up under somebody else's responsibility like the chemistry in the pool, which I would have to eventually deal with potentially if it changes the cladding material in some deleterious way. But they'll have - the utilities and the vendors will have an interest in it because they'll see it first.

TURINSKY: Is there anything planned for F.Y. '20?

BAHR: Paul, can you get closer to the mic?

TURINSKY: Yes.

BAHR: Thank you.

TURINSKY: Is there anything planned for F.Y. '20?

BOYLE: Well, as of this moment, maybe not, but back to what I started off my presentation, with, this state of uncertainty over the appropriation, we could easily get more money than we have already planned for. We could also get less. So, there is an opportunity to even tweak Fiscal Year '20; it's not completely baked yet.

BAHR: Are there other questions from Board members?
Questions from staff? Nigel?

MOTE: Nigel Mote, Board staff. Thanks, Bill, for the overview of this current situation. Given the rethinking about potentially introducing reprocessing and recycling, what impact do you think that will have on, for example, congressional determination to try and support a repository program?

DOE completed an assessment five years ago or so that said if we do start reprocessing, we'll never going to touch fuel that's more than five years old today which would leave something like 70,000 tons of fuel that still will need disposal.

I can hear that the suggestion of going to recycling, particularly if the concept is reprocess all fuel, that may allow a view that developing a repository program is not urgent when if there's still 60,000 to 70,000 tons to be disposed of, that still is an urgent proposition and the utilities would find it difficult as we've all heard to develop plans for new power stations if those waste problems are not being addressed.

BOYLE: Yes. I don't know what affect this would have on Congress. I don't own a crystal ball that's that good. A number of other observations, Nigel mentioned a report that said you might not want to reprocess the existing spent fuel. The reference is Wagner et al 2012, right?

And that recommendation is largely based on economic reasons, right? It's given how heterogeneous the existing spent fuel universe is, it's not really how you'd want to run a factory. If you think of reprocessing as an industrial process, everything else being equal, you'd prefer to have uniform inputs and give uniform outputs. But

we don't have uniform inputs. So, that was the main reasoning behind you wouldn't reprocess what there is today.

Now, the thing about economics is prices change every day, right? Maybe somewhere down the road, the economic situation changes and it does make sense to reprocess the existing spent fuel, I don't know.

Back to Congress and how anxious they are for a repository, again, I don't know their thinking but I know the end results of what they vote on. Ever since 2010 which is multiple Congresses, a lot of people who were there in 2010 are not there now, but one thing they've all been consistent on is they seem to be not urgent to have a repository. And I don't know when that's going to change or what will cause it to change.

BAHR: Bret Leslie?

LESLIE: Bret Leslie, Board staff and I'll follow up on something that you just said about if this was an industrial process, you'd want uniform inputs into reprocessing. But

I'll turn it around because you kind of said well, for the advanced or accident tolerant fuels, basically, it's the utilities that are going to have to deal with that issue, but at the same time, you're going to be the recipient of their inputs.

And so, not just the science but what things might impact the integrated waste disposal program regarding what you have to dispose of, and maybe have you guys thought about that? I know you don't have anything planned yet, but not just the science but what might be the impact.

BOYLE: Yes. So, two points I'll try to remember without taking a note up here. One is back to the study that BP Singh managed for years, that the disposal and storage people are aware of all the ramifications from these different fuel cycles. And I can generalize it as people really haven't conceived anything that makes us go, "Oh my gosh, what do you think, we can't handle that."

I don't think we blackballed a single option, the disposal and storage people. Generally speaking, people are aware of

we don't want pyrophoric things and we don't want boiling hydrochloric acid, neither do they for the most part, the people that operate the reactors and that sort of thing.

Now, the other point is I believe it was somebody from EPRI, it may have been Keith, and it may have been at one of these meetings who, I was a public meeting where they - you know how many fuel cycles we have in the United States? Count up enough reactors and that's how many we have with different owners along the way, in contrast to France which is more vertically integrated, where everybody is related to each other and on the same sheet of paper, the electricity generators, right?

In the U.S., we have many, many different generators, none of whom are the federal government, yet the federal government has the disposal responsibility. So, it is a challenge in the United States in terms of what each group wants - does, what their portion of the responsibility does affect the others.

And the way it is in the United States, if a utility chooses to do something and they have a valid contract with the Department of Energy that we have to pick up their spent fuel, we have to pick up their spent fuel.

BAHR: Anything else from the Board members? OK. Well, thank you, Bill. And we'll move on to our next speaker who is Ned Larson, who's going to talk about the high burnup dry storage cask research and development project. And that is the project that's receiving the award this afternoon.

LARSON: Can you hear me OK? It sounds like it's working. I'm going to talk about the high burnup demo as we call it. A lot of work went into this. A lot is happening on it continuing, we still have a lot of work to be done.

As you can see, we updated our gap analysis. When we interacted with the Board, it was a little bit out of date and the Board encouraged us to update our gaps, and we did and we thought that was the correct thing to do.

One of the things that we did do that we have learned in doing that is it was 230 pages long or something like that, and it's hard to have a living document that is 230 pages long. And so, we also shortened it and so we're down to 18 pages, so we can update it quickly and keep it current to make sure that that it reflects the things that we're doing.

We talked about the accident tolerant fuels, what we're looking at doing now, we are working with Bill McCaughey. We're looking at increasing and adding the gaps that we feel exist for the accident tolerant fuels. We're looking at - we're doing a lot of laboratory testing and I'll get into that a little bit more.

But we anticipate having our hot cells cleaned with our fuel from the demo in probably two to three years. By that time, we should start having accident tolerant fuels coming out of the reactors. At that point, we hope to get our hands on some of that stuff and so some of the testing on that, because the burnups will be a little bit higher than what we've seen to this point and we would like to do that.

And so, we continue to update it. We continue to make changes to it and to make sure that we're trying to be -- so it's always current with the work that we're currently performing.

On the high burnup spent fuel data project, what we did is we let a contract with the Electric Power Research Institute. You can see the team members that they had in their team - Dominion, Orano, Westinghouse and NAC. They are the ones that actually loaded the cask and did this. What we wanted to do is take a cask and just load it using normal conditions, the things that would normally be done to any cask and then monitor and measure how it is performing with time and to make sure that we understand what it's doing.

Although we opened the cask around 2000 where we looked inside of it and it looked good and it was wonderful, we didn't get to do measurements, continued measurements of that cask. And so, this one we wanted to and then we have the national laboratories working with us. We have six national labs who all played a very important role with us.

On the cask itself, we worked with Dominion. Dominion was instrumental as well as EPRI in working this, we were able to get our hands on a Transnuclear 32 cask that had 32 assemblies in it, in which we were able to start doing work on.

We loaded that cask in 2017, we modified the lid so that we have thermal lances going through the cask and through the lid and we could measure. We had 63 thermocouples, seven thermal lances with nine thermocouples in each where we could measure not only measure the temperature inside but measure it at different locations within the cask itself.

What we wanted to do is understand the fuel temperature, the cladding temperature, we wanted to take gas cavity pressures as well as possible samples of the cask once it was loaded and we could see it perform. In addition, what we wanted to do is pull some rods, although we did not pull any rods from the assemblies that went into the cask, we did pull the sister rods or sibling rods so that they were the mirror image of where they were in the reactor.

We pulled 25 rods from them that would be as close as we could to the rods that were inside the cask itself. And these rods, the 25 sister rods that we're testing now, we call them - we will use that to make our baseline, because at the end of 10 years when we open the big cask, we want to have something to compare the rod performance to, the properties to.

And so, we pulled the 25 rods. We're doing those testing now so that we will understand our baseline and then down the road 10 years when we open it, we'll be able to do this. We've sent these 25 sister rods to Oak Ridge in January of 2016, 10 sister rods then went on to Pacific Northwest National Lab. They received these rods in 2018.

This is the as we call our testing summary for the high burnup rods, I'm not going to go through it. We shared this previously with the Board, so it's not an eye test or anything for anybody. But what we're going to do, the thing that I want to bring out is the testing that is done at Oak Ridge is with fueled rods. The testing that was done at

PNNL is with unfueled rods. And the half a rod that will go to Argonne will be unfueled rod also.

And so, we're going to be able to compare the fueled versus the unfueled, with the labs versus labs. We continually work together to make sure that we are coordinated and integrated as a program so that we know and understand what is happening.

When we took the sister rods, we were able to - one of the things we were pleased with working with North Anna plant is the variety of cladding that they have in their pools. We were able to get our hands on the M5 from Areva, the Westinghouse's Zirlo, the Zirc-4 as well as the low-tin and the standard rods. And they have a little bit more variety than most utilities do.

And so, we were able to pull rods that had as much variety as we could get our hands on. Oak Ridge National Labs, once they had the 25 rods, they did the non-destructive testing, the profilometry so that we could know what they look like, how they behave on the outside.

With that, we will compare that to the rods when we pull those in 10 years or so. And so, we'll be able to have a baseline not only of the internal but the external, how they measured, what they looked like and Oak Ridge did all that work.

When we loaded the cask, we started the thermal modeling and thermal analysis, you can see first off, you can see on the left there, we zone loaded our cask, putting the hottest rods that we could get, the hottest assemblies - excuse me - that we could get to the center of it with the cooler set of assemblies to the outside. This allowed us to be a little bit hotter, to get hotter assemblies temperature-wise into the center part of the cask where we could do the measurements.

As we started the drying, you can see as we started pulling the water up, the temperatures on the rods started increasing as they got drier and drier. And then you see it drop, that is when we inserted the helium into the cask.

Because of the wonderful thermal properties of helium, it immediately started dropping.

The TN-32 is an all-metal cask and it has wonderful thermal capabilities. And so, once we added the helium in, you see the drop in temperature, and then it started to normalize as it went with time.

Because of the cask, the cask itself and the whole test that we're working with EPRI and Dominion on, it's expensive, I'll just say. We're up to about \$30 million right now just for the cask itself and the activities to load it and to pull the sister rods and do that work.

We're not going to be able to do this on very many tests. It just isn't going to happen because it's so expensive. And so, we want to know and understand our modeling capability such that we can learn from this cask and that we can learn what to do and be able to model it using numerical models in the future so that we're able to take advantage of the cask that we have and apply it to other casks as we go down the road.

What we did and Dave Richmond will talk about this when he comes up shortly, we had other people model what we had. NRC modelled it, PNNL, even Transnuclear Orano did, they modeled it after we started measuring the data. Before we shared the data with them, they modeled it and told us what they thought we would hit.

And then we compared it and then once they gave us their results, we released that data. And you can see where they hit. They generally hit a little bit higher than where we were.

When we started this cask, we thought we were going to be loading it in the 375 range, that's what we - 375 centigrade. Then we modeled it carefully and we showed that it would probably be in the low 300s which bothered us a little bit because hydride reorientation happens in the 320 C range more or less.

And so then when we did even sharpen our pencil more and even modeled it more, we learned that it would not be - it

would probably be in the 275 , low 270 range, and we actually considered cancelling the test at that point because we said we're not going to be having hydride reorientations inside the cask like we once thought we were.

But we went ahead and we had a big meeting. I'll just say I remember the meeting well. And we said let's go ahead and do it, let's go ahead and perform it, because we have never seen inside a cask yet.

And so we said OK, so we went ahead and made the decisions to go ahead and continue with it. And the amount that we're learning and the things that we're learning relative to our numerical modeling has been incredibly valuable, the things that we've learned there. So, we continuing to do that and Dave will talk about the things that he's picking up there.

As far as the testing of the sister rods, we're just beginning work there. Oak Ridge has the dynamic test that they have already had in their hot cell and so they were able to immediately start working on the dynamic testing. Some of the other testing that is going to be done, the

stress, the compression test, the tension test, the four point bend test, we're just beginning to do those tests right now. We're just starting it.

We have to get all the - because they're hot cells and hot cells are hard to work in, we had to buy new equipment to go into those because we didn't want to put rad equipment into our hot cell and then have it break on us because it's hard to deal with anything in the hot cell. So, we bought new equipment, new test apparatus, new machines are being placed in our hot cells so that we can go ahead and do our testing.

Right now, we're already started with the cyclic test. You can see the things that we are learning. You can see the big - the black bar is where we believe it and with that being the case, our material properties of the test are actually pretty good. But what we did find is we did feel that we needed to heat some of our rods that came, some of the sister rods that came out.

We felt like we needed to heat them to about 400 C which is the limit that the NRC allows to go inside a cask, because

the cask, although the cask was cooler, the effect on the rods were still a concern to us.

And so we said well, let's heat a couple of the rods and let's see how they perform. We heated a rod and we've done four cyclic tests on the samples from a rod and they have all fallen in around the line right there, but there was one that was a real outlier, it broke at about 1,000 cycles and it surprised us, I'll just say.

When we went back and looked at it, we did not see any hydride reorientation. We didn't see radial hydrides in that sample which surprised us a little bit. We're still trying to understand why the rods that were heated tend to break a little bit lower. Not to the point where it gives us any concern for transportation or storage, but they are on the lower side of our population so far.

We're still studying that. We don't know and understand that yet. We're still looking at it. We'll continue to look at it. But at the same time, we continue to do more tests, as we learn more, as we learn more about our static

test, the compression and all that stuff, we will learn more and be able to compare back and understand what is going on.

We believe that by this summer sometime, that gives about eight months, we will start having data from these other tests coming and at that point we would ask the Board members maybe you would like a fact-finding. We believe that we will be at a point then to share some of the data with the Board members and staff to bring you current on where we are. We're still at the early stages of this activity right now.

And so, like I say, so there's still a lot of work being done there. But the big thing is as you see that the limits, the big red bar, we talked previously - we presented the test in which we took a loaded cask.

We took it from Spain by barge or by truck and then by barge and then by boat to the port of Baltimore and then a railroad across the country. Ran it through a number of tests at the Technology Transportation Center near Pueblo, Colorado. And the biggest impact that we saw on those rods

from transportation was at 1,300 PSI, when it went through a sorting yard and a coupling test. And it hit another railroad card about eight miles an hour.

And it went up the stress that they - the highest stress that the rods experienced was about 1,300 PSI. However, when you look at the yellow, using 4,000 vibration, shock and vibration and using that over a 12,000 - over a 2,000 mile trip, the highest that we experienced as it was being run through was 130 PSI from shock and vibration, which really doesn't surprise us when we think about it because the amount of energy it takes to do shock and vibration on a 200 ton payload, the weight of the cask with the impact limiters on and the cradle and all that other stuff.

The amount of energy it takes to shake and vibrate a 200 ton payload is a lot. And so, it just didn't experience the shock and vibration that you would expect to see that we sometimes see on the lighter loads.

And so, as you see that even though if it were breaking to this area, we're still studying that to make sure we

understand that. Even if it does break that low, it's still is way above what will be experienced by that cask from transportation activities and storage activities, if you will.

And so like I say, we're continuing to do that, continuing to do more tests to understand how it will perform and what it's doing.

The data that we have now, on the cladding, we believe tells us that we'll be able to ship and store everything that is loaded to date without any problems. We believe that the cladding will be sufficiently strong, will perform sufficiently well that it will create no problems for us in the future with the things that have been loaded.

At this point, what I'd like to cover is when we went in, we sampled - we took some internal samples of the gas, the helium. It goes in at 2.2 bars and is pressurized. We wanted to sample for krypton to make sure if any of the rods were splitting, any of the pins were splitting to tell us how it's performing.

We wanted to look at the water inside the cask, know how it was. And then we were going to check on the oxygen, nitrogen, hydrogen, carbon dioxide to make sure that it was there anything else going inside the cask that we didn't know and understand.

When we took the samples, we took two samples. We took one. One sample was sent to Sandia National Lab, the other sample was sent to the Dominion facilities. And they were both tested and run. We took three samples, one that shortly after it was loaded, one about 5 days, one at 12 days. What we found is that the two that we took early on, we had a lot of technical issues with that. We had equipment issues. We had pumps that were not - that were broken as we did our testing.

And we learned a lot in the procedures that we were using and how we could do it and the valves and all that. And so, the best one that we had was the one at 12 days, which was the most important to us anyway.

What we found is we didn't see any detectible krypton in it. We did have some carbon dioxide, which surprised us a little bit. We believe it could be from some of the oil in the pumps, in the vacuum pumps and stuff as they start pulling it and working through. We're not sure there yet. We've still got to do more work there.

We heated our sample bottles, so that we have no condensate inside the temperature or inside the bottles. But when we were done, I mean, what we believe right now is that if the gas inside the cask is well-mixed, which we believe it is, then we believe that there is no free water in the cask at the end of vacuum drying is what we believe. And so, that is an important learning or important point for us to learn. It's important for us to do.

Working with the samples, what we want to do at this point because we only had one sample, we would still like to do other samples.

We looked - we talked to Dominion about possibly, to North Anna people, about possibly taking samples out on the pad.

And that really isn't doable. It's just the risk of opening a cask out on the pad. We even looked at putting a temporary building on it with HVAC so that we could still process and filter all the stuff. The probability of doing that just isn't going to happen. It's just too risky for them.

And they're just not anxious to do that. So we said OK. We understand that. We're trying to work with other sites to understand once they finish and they - once they finish a vacuum drying and they seal it off, if they could let it set inside their building, their fuel processing building for 2 weeks - 12 days, 2 weeks somewhere in that range.

The trouble is is that it's an expensive process because all the people that are handling the cask and doing all that stuff are twiddling their thumbs for about two weeks. We're hoping that we can find one that is closer to their home office so they could go home and come back when we get ready to move it out of the building and sample the cask at that point.

There's a number of options that we're working on. We're even looking at seeing are there other ways that we can gather the data without doing it from an active cask, if you will. But we're working on that right now.

We don't know the path that we're going to take at, but we'll see. But once we decide, like I say, if we can, we will keep the Board informed on that so that you know what we're doing, know our plans and what we're able to do or not do, because we would love to get our hands on more samples from the internal gas that exists inside the casks.

I'm going to talk about the transporting of the cask. Again, we loaded the cask at the North Anna facility, but at this point, we would have to take it to another facility in order to open it. We are relying on - although the TN-32 does not have a transportation certificate of compliance, it was designed to be transported. It is an all metal cask.

But the TN-40, which is very, very similar to the TN-32 does have a transportation. Nobody has just needed to ship a TN-32, so Transnuclear never bothered to issue an application

for transportation, but it's able to do it. It was designed to be shipped, and so it's a matter of getting the paperwork up-to-date and submitting it to the Nuclear Regulatory Commission.

The one thing that we do not want to do is we want to ship it as much as we can in its current condition. We do not want to take that cask back into the pool at North Anna and pull thermal lances out and retighten the lid and put new seals in it. We don't want to do that.

We don't want to re-irradiate the fuel in that cask again. We want it to stay because we believe that it could possibly change the behavior properties of the cladding when we open it 10 years down the road and we compare it to the baseline that we're doing now. We just don't want to do that.

And so, we have put the stronger bolts in the lid for transportation, but we're working on it right now. The thermocouples are not required for transport, but we do want to lay it on its side and measure it for a couple of weeks

to see how it behaves on its side, to see how the thermal properties of the cask behave.

Originally, we were scheduled to cut all the cables. We were going to weld covers in the lid to cut them open. We're hoping not to do that. We're hoping that we can work with the Nuclear Regulatory Commission to give us a one-time exemption. Maybe there's other things we can do. We don't know.

We're looking at them. We had a pre-meeting with them in July and to show them what could be done. We hope that we could even use on our impact limiters, we hope that we could use foam to do it, but the amount of testing it would take in the time that we have just would be too much.

And so, we're going back to balsa wood and redwood. We found the source for those materials to make our impact limiters. And so, we're continuing to do that. We're continuing to do the calculations to prepare the applications to get our COC for transportation.

We hope to submit a request in the second quarter of 2020. You see the schedule there. We hope to fabricate our components in 2023 and then 2028, we hope we're shipping again. We hope it's heading to Idaho is where we hope to ship it.

When it gets to Idaho, we're hoping it goes to Idaho. We just signed - the DOE just signed an agreement with the State of Idaho to let some nuclear materials in. When we have the 25 rods, there was a ban for all nuclear materials going into the state.

And so it went through - the rods went to Oak Ridge and PNNL. But Idaho has a facility, the CPP-603 is an old facility, but it's still fairly effective. We went in and looked at the cranes. It's a 125 ton cask more or less, a little bit less than that, without the impact limiters, without the cradle that holds it.

As you can see, we modified the crane so that we have two trollies on the train to distribute the load a little bit more. We have two cable systems with a big beam in between.

The reason we're able to do that is it's a fairly high bay. The cranes are fairly high in the air.

So even with the beam between the two cable systems, between the two trollies, we're able to pick it up high enough to do the work that we need to be done. This is already installed. It's installed right now. We have already done the readiness review and so the facility there is ready to take it. We did stiffening of the columns where we went in to make sure that the columns could handle everything.

We did the stiffening on the roof joists to make sure that it is stiff enough and that it could handle that extra weight than what the crane was originally - what the building was originally designed for.

We went ahead. We modified the trolley system. I'm not getting the advance -- advance it one, yes. We modified the trolley system so that the 125 - so that our TN-32 cask could go inside the trolley. You haven't seen - many of you haven't seen it. Some of you have.

We put it in a trolley and then shove it under a wall, a big thick wall of concrete for the shielding and shove it into the hot cell on the trolley to make sure that we can do that. The inside of the hot cell has been worked so that we can pull the lid. We can pull assemblies out of it.

We can then pull rods out of the assemblies to ship to the - a hot fuel examination facility, HFEF there at Idaho, where I hope where we can - a really nice hot cell for doing the work for - on the rods themselves.

We have a mock-up of the cask of the TN-32. This is actually a little bit bigger than the TN-32. The M&O - the management and operating contractor of Idaho, I said I want a mock-up. I want to be able to run this thing through, run it on the trolley, run it back.

I imagine just a water tank with trunnions on it or something, but they did this. I go, I don't know. That's a little bit more than I expected but it was impressive. We went in and checked the geometries. Made sure that the geometries would all work. Then we went in and put our cask

through. We've run that cask and mock-up of our cask inside the hot cell, was able to put it on the trolley, run it in, run it out and be able to check the results on that.

And we've had no trouble doing that so far. And so, we are confident that when it comes time to move the cask and to open the cask, we have the facilities and infrastructure to do that with. And so we were very pleased on the outcome of that.

In summary, we believe that - yes, just one. We believe that the cask demo, the data that has given it so far has been just tremendous. We've learned a lot from it. It is continuing to give us data and information.

The sister rods that we have - that we have tested are giving us insight as we compare those with the rods that come out of that cask in 10 years and understand the changes that happen will be a very important part to it.

The cask has given us a lot of data so far. And we believe it will continue to give us even more data in the future,

because we're hoping that we can ship it and we can start - continuing to take measurements on the temperature even when it's in Idaho. We don't know when we're going to ship it in Idaho.

But once we get our certificate and compliance, we don't need to wait 10 years to ship that cask. Once we get our COC, it can sit on the ground in Idaho and take the measurements just as well as it can sit on the ground at North Anna.

And so we may ship it before 10 years. I would hope that we could actually and get it out of their backyard and let us continue to measure it under a different environmental condition there in Idaho. And so - so that's all I have. If you have questions, be happy to take them.

BAHR: Thanks very much, Ned. I have a question, first you mentioned that you might be able to ship it to Idaho long before you're going to open it up, would that also offer you an opportunity to do gas sampling after five or six years that you can't do on the current pad where it's located?

LARSON: I would hope so. It is my hope, for instance if we get our certificate of compliance for shipping in 2023 and the components are made 2024, I would love to ship it to Idaho then and put it inside one of our buildings there and possibly take a gas sample in Idaho because it won't be in the open, if you're with me.

As long as it's in a facility where we have filters and air conditioning and everything is working, we're hoping that we could possibly do that. We haven't got to that point yet. I mean that's pure speculation on my part. But I would hope that we could do that.

BAHR: OK. Thanks. Paul?

TURINSKY: First, congratulations, Ned, for you and your team for the award you're getting.

LARSON: Thanks. It's an exciting time for us. I'll be candid.

TURINSKY: Yes. You've done a lot of work on basically thermal modeling, OK? And that work is actually continuing. You've done a lot of work on structural aspects during the transportation phase of it.

The one thing I haven't seen and maybe you're doing it also is on the fuel performance aspect. You're getting data that in the past, you didn't have open access to because of proprietary information and all.

And you do have program within DOE elsewhere in developing fuel performance modeling capabilities. So how is this program and that other program integrated and working together? Are there predictions being done? Is there modifications to their material models?

LARSON: We are still in the early stages there, I'll just say. We have been - our goal was to start testing some of these things and start getting the output, if you're with me. And so we have been fully focused on that.

I know Idaho has some modeling capabilities and things. At this point, everything that we had was paperwork, if you're with me where we've done some great paper studies. And they were very impressive. But we needed data.

And so now that we're starting to get data, we believe that we have information that we could start meeting with our modelers on and start sharing it with them so that they have that data. But so far, we've - like I say, we haven't done a lot of that yet, but we anticipate that we're ready to do that now.

TURINSKY: Is that in the FY20 plans?

LARSON: We touch on it lightly in our gap analysis. But that's one of the things - your point is well-taken, we need to strengthen. And we'll improve on that and put more detail on that. Your point is - I understand what you're saying.

TURINSKY: OK. Thank you.

LARSON: So we need to do that.

BAHR: Lee Peddicord?

PEDDICORD: Peddicord from the Board. And again, let me echo congratulations, and it's really great to see the breadth of the team here because I know you really brought a lot of capability and you showed us the team on your slides, so...

LARSON: Sure. We've got a great team. You're right, on all sides.

PEDDICORD: It's very impressive and really well done. A couple of questions. You talked about the sister rods in the series of tests you're going through there as well. We've gotten a chance to see some of those as well too.

As you go down the road, do you anticipate any other tests of the rods when they come out in 10 years from the cask that may not have been done on the sister rods, or will it

be really a duplicative sets so you can compare before and after?

LARSON: Yes. What we anticipate - when we did our test plan, we did it in kind of a stepwise - I call it the observational approach where we test and see what we learn and see what we learn and then make adjustments and test again and see what we learn.

We're focused on getting the 25 rods taking care of now and cleared out of our hot cell. But once those 25 rods are cleared out, we're looking at getting - we're trying to get our hands on some BWR rods that we're aware of that may be go into Oak Ridge that we would like to do.

Some of the other programs have other rods in the hot cell at Oak Ridge that we may try and get our hands on. Accident tolerant fuel, like I say, there is some fuel coming out of the reactors soon, but it's not high burnup and not our interest yet. But in about two years, there are some real higher burnup fuels coming out of the reactors and accident tolerant fuels. We hope to get our hands on that.

So if can clean out our hot cells as soon as we have, because as soon as we can with our current testing, then we would hope to move on to other stuff because we have all the equipment in place and all the lab equipment in the hot cells themselves.

PEDDICORD: Yes. Yes.

LARSON: Because when we clean it out, I mean, I'll just say it basically gets thrown away. You just can't decontaminate it.

PEDDICORD: Yes.

LARSON: And so it has to be thrown out. And so...

PEDDICORD: Yes...

LARSON: So we want to keep it busy as long as we can. Your point is right.

PEDDICORD: Well, I was going more to the database you're collecting from the sister rods. Then you're going to have the rods from the cask in 10 years. So my assumption is you're going to do pretty much exactly the same sorts of tests on the rods coming out of the cask in 10 years as you did on the sister rods.

LARSON: Yes. It'll be the same tests, the same parameters, the same testers.

PEDDICORD: Yes.

LARSON: So we can make direct comparisons, right.

PEDDICORD: And so - but I was wondering if there - I'd envision some additional set of tests on the rods coming out of the cask in 10 years and maybe didn't get done on the sister rods. You're not going to have the sister rods available...

LARSON: We could - yes. No, your point is well-taken. We could. I mean, once we start learning, we start watching our testing.

PEDDICORD: Yes.

LARSON: And we'll share that data with you when it becomes available. There are other tests that we could do. We didn't assign every section of the rod a test. We have held some back so in case we wanted to do additional testing or testings with different parameters we have the material to do it with, you're right.

PEDDICORD: Yes. May I continue?

BAHR: Yes, sure.

PEDDICORD: On slide 18, you talked about the - your meeting with the NRC pre-application and so on. This is more for my edification.

So as the application is made to the NRC on these issues, is this being specifically done by the utility, by North Anna, Dominion? Or is DOE a party to that or really providing information? Help me through the steps, so...

LARSON: Yes. How it works is North Anna holds the ISFSI license if you're with me.

PEDDICORD: Yes.

LARSON: And so they - North Anna and Orano are the two that are doing the discussions with the Nuclear Regulatory Commission.

PEDDICORD: OK.

LARSON: Orano holds their certificate, if you're with me, of compliance. And so they will be working on it together. We are a party in that. We're helping pay for some of it if you're with me. But they're taking the lead in that area. It's not like I - it's their lead.

PEDDICORD: Yes. And one last question, the investments you made, they're in Idaho at INL at CCP or CPP-603, are very impressive. This was the first time I'd heard about it at least.

And so the question that comes to mind is with that investment, are you thinking of other sorts of things you would be able to do beyond this particular cask test there, because you really put some capabilities in place that look very, very good and could open up a whole number of perhaps other kinds of investigations.

LARSON: We are hopeful, I'll put it that way, because when we first did it, we could have gone in with the temporary crane for one-time pop and just done it with that.

PEDDICORD: Right.

LARSON: Rented it and send it back. But we were hopeful that we could open more than just this one cask and so we went ahead and made the capital investment like that. We

just, like I said, the agreement with Idaho to move in nuclear fuels is a big deal for us.

PEDDICORD: Yes.

LARSON: It's a big deal for the Department. We haven't done a lot of planning along those lines yet because the borders were closed, essentially. But with that agreement, you're right, we would hope that we could. Your point is correct there. We would love to do that. We would love to get a few more materials and open them up.

PEDDICORD: I think it's a great capability to have for the country.

LARSON: You're right. It is.

PEDDICORD: Thank you.

LARSON: We could get a lot of work out of it.

BAHR: You're next.

TURINSKY: This has been pretty much focused on normal transportation.

LARSON: Yes.

TURINSKY: Are there any plans to look at the safety case, the drop events and related to that is examining what basically the clad pellet bonding will do in support of the safety case?

LARSON: Yes. We have focused now - the focus to this point has been on normal conditions that we would experience during transport, because we believe that that's going to be the bulk of shipments if you're with me.

We have talked about doing accident scenarios. We have communicated with the Nuclear Regulatory Commission about accident scenarios. We haven't put that in a test plan yet. What our hope was just - if we could nail down our normal conditions of transport and understand all the behaviors

there, then we felt like we would have some data to start looking at some of the other accident conditions.

We, like I say, we've still got to do that. That's still ahead of us. As we start knocking off some of the high priority items on normal conditions of transport, we would hope that we could move to some of the accident scenarios. But we're still a little bit away from that. We hope to get there within a few years. But we've not yet.

TURNISKY: And...

LARSON: You'll see us modify our gap analysis. We'll say the Paul Turinsky gap analysis.

TURNISKY: Yes. Like I have that persuasion power. You have done some work, right, like more on the analysis side of basically the clad bonding - pellet bonding. If I recall.

LARSON: Yes. It's an area that is important to us. Like I say Oak Ridge is doing their testing with the clad fuel.

When we did the heated rods, all we know is that so far they have broken faster than we thought - than we expected a little bit.

Not outrageously faster, but a little bit faster. We still got to do more testing and understanding. We don't know, when we heated them up to 400 C, did the metal expand more than the ceramic in the middle and did it break that bond? Or did it - how did that work. We don't know yet.

We've got to do - we've got still got to devise tests to understand that bonding and what breaks it and what doesn't and to know and understand that. And we still got more work to do there too.

Like I say, we hope to get that as we start getting it from the different labs on the different tests. We hope we can make some profound conclusions in that area.

TURNISKY: OK.

LARSON: But we're not there yet. We don't have the data.

BAHR: Sue Brantley?

BRANTLEY: Sue Brantley, Board. I wanted to thank you. That was a great talk. If my colleague Mary Lou Zoback had been here, she would have been extraordinarily happy that you're showing models against data, which is what we all want to be able to see, so that was terrific.

I also think it's great that you got an award and this is kind of an open-ended softball question. Can you tell me why you got the award?

LARSON: Sure. I'd love to, actually. Yes. What the secretary does is every year, he calls the - they're called the Secretary Honor Awards and what he does is he asks for projects that the Department has done during the year and this again, this is a multiyear project for us, the contract signed at 2013, where we discuss the outcome of the project, the long range use of the data and information of the projects, the number of people that participate in the projects. When you have large teams and you're able to

bring together large teams to produce a good result, that is important to him.

And you bring it in on schedule and budget, of course. And we did that. And so, the data - the use of the data into the future is the biggest issue of why we won the award. It's just the impact that it has on the industry will have far-reaching results. And so that is why we were selected as one of the recipients of the award this year.

BRANTLEY: And I think you also mentioned during your talk that either the project was almost canceled or some piece of the project was almost cancelled because it was so expensive, can you talk about that?

Like how did you - here's a project that's getting an award, but it was almost cancelled or some piece of it was almost cancelled. Why was it almost cancelled? How did you keep it from getting cancelled? And what lesson is there in that?

LARSON: Sure. When we were looking at it, like I say, many times when you do tests, so you don't know the outcome, of course, of the test itself. When we realized it wasn't going to be as hot as we thought it would be internally, we looked at it carefully to say is it still worth doing the test if it's not going to be as hot as we wanted it to be to get the hydride reorientation to having radial hydrides.

When we look at it, we talk to our management. We presented it to them. We talked among ourselves. And we believed that the outcome was still sufficient if we could understand the thermal because the thermal was showing it was lowest and thermal affects so many parameters in the behavior of the rods and the whole cask as a whole.

And we realized that we didn't have as much information on the thermal behavior and properties and how it would work down the road. And so we said, if we can get that thermal data and understand it well, then it's still going to be worth it.

And that's when David Richmond talks next, he's going to talk about how we modeled it to know and understand - I mean, if we're going to model it, what are the parameters that we need to adjust. What are the things that it's most sensitive to - how do we deal with this. And this task was able to give us that insight. And he'll cover that in his talk.

BRANTLEY: Another thing you said that I thought was interesting was that you had a document that was 200 pages and you thought that was too long, so you edited it to 18. That seems like a miracle to me that we should all learn how to do it. Can you talk about that? Like...

LARSON: Sure.

BRANTLEY: Could the DOE do that in more of its documents?

LARSON: Yes. I'll just say it. Dealing with ourselves and the national labs to go shorter was a task, but there's a lot of things that we had in our original plan, the discussion of the general parameters. And we could take

those out because we'd already covered them in previous documents, if you're with me.

They weren't changing. And so, we just dealt with the actual gaps and how they affected us. And so we were able to really, really shorten it. And it has - it will be a live document now, but you're right. We had a very creative young engineer do that work for us. And she did a great job.

BRANTLEY: I think she deserves an award too.

LARSON: We should have given her a big award too. You're right. But she's included in this one today, so...

BRANTLEY: OK. And then just about the gas sampling experiments, you said that the first couple tries, you couldn't get the gas or you had all these problems. That seems reasonable and normal to me.

And then you gave us the results of the 12-day experiment or whatever. Did you get any gas chemistry from the other

experiments that were sort of problematic? And was there anything there that was concerning in those other measurements? Did you find krypton, for example, or other species that told you something different?

LARSON: Yes. Yes, we had trouble getting the gas - getting it sampled and then getting it back out and running it through our equipment that does the analysis on the gases. We had trouble at the needle valves.

We had a pump break on us. And we lost one of them and pretty much entirely, we weren't able to redo it. It was a vacuum pump and it had trouble with our connectors and stuff.

Right now, because of that we're doing more work, PNNL is doing the work right now where they have blind samples and we're improving the connections and all that stuff, doing more blank tests, if you're with me, so that we're improving on our procedure, because when we do it again next time we have no room for margin.

It just turned out to be much more complicated than we anticipated. We thought it was going to be connecting it to pulling it out, filling it up, cutting off the valves and then sending it into the laboratory.

And our needle valves were leaking and we had trouble with them. They shouldn't have and it was just a headache. So, yes, we're doing improvements now to help us do that better in the future.

BRANTLEY: Did you get gas chemistry measurements in those early experiments that were somewhat problematic?

LARSON: We did some but we don't believe them.

BRANTLEY: Did you see krypton?

LARSON: Say it again?

BRANTLEY: Did you see krypton?

LARSON: See what, again? No, no, no.

FEMALE: No, we did not.

LARSON: No.

FEMALE: We did not see it.

BAHR: The answer was that there was - they did not see krypton.

BRANTLEY: Thank you.

BAHR: Tissa?

ILLANGASEKARE: Tissa Illangasekare, Board. Congratulations on the award again. I have a very general question related to modeling. You mentioned that because the tests are so expensive, you had to limit the tests and you had to rely on the numerical model.

But when you use the numerical models, sort of, the next speaker may touch this issue but the numerical models, the

test data itself is used to sort of calibrate or validate the model, or how do you build uncertainty associated with using less data to sort of test a numerical model?

LARSON: Going back, what we anticipated doing is doing the increment - the observational approach. First, we did this first step to see and - that we then did our numerical modeling on the thermal to see if we could draw a correlation, so if we could bring them together carefully and understand what the problems were.

We would like to build the next step. I mean if we could that were - this one was expensive. Don't get me wrong. But we're looking at other means and methods that we can try and get more data that we can validate our numerical models with and work with, if you're with me.

There are other means out there and we're - I'll just say we're still struggling with that right now. We're still - our heads are down trying to figure it out. We're not done with that. Don't get me wrong.

But we would like to still add more confidence to our thermal models, our numerical thermal models than we have now. In the Department, we've got great computers and great computer codes, but it's the data that we want at this point to give us the good benchmarks.

ILLANGASEKARE: Thank you.

BAHR: Other questions from the Board? Jean Bahr. I have one more. You said that your conclusion was there was no free water, but you said something about significant adsorbed water. And under what conditions would that adsorbed water be released and how - is there other work that's planned to try to track what happens to that water over time?

LARSON: Yes, there is a lot - and we still have work to do in that area. Like I say, we had one sample that we had confidence in and that we felt it was correct. We tried to account for adsorbed water and make sure it didn't interfere with our tests.

At this point, we just need - I mean, I'll just say we would like to do other - pull other samples from other casks at this point. We would like to go to other casks who are in the - within the pool handling building and just pull more samples.

That's what we need at this point, is just more samples. And they're not cheap because of the things that we have to do, but we believe that it could be money well spent as we get more data in that area. But right now we don't think it will affect us based on the one sample, but that's only one good sample. I would recognize we'd like more.

BAHR: Yes. I guess another question about doing things with other casks, how, is the primary expense of collecting the thermal data, the modifications that you need to make to the cask.

How much of the expense of this demonstration is the fact that you're planning to reopen it after 10 years or are there sort of less expensive modifications that you could make to casks that are now being loaded that would allow you

to collect additional thermal data without the need to be planning to reopen it again? But that could give you some additional thermal data to calibrate your models.

LARSON: Yes. But the changes that we would have to make to the cask would be none. But the cask itself is, it's our sampling equipment and our test equipment and stuff like this is where we've got to do the changes and improvements too.

BAHR: But now that you've developed prototype thermal monitoring systems, I mean there's certain expense in developing those, now that those exist, could you apply those to other casks at a lower expense than this initial demo?

LARSON: Yes.

BAHR: OK, thank you. Are there questions from the Board? Questions from staff? Dan Ogg?

OGG: Yes, Dan Ogg, Board staff. Ned, one question from Paul Turinsky I wanted to follow up on was the fuel performance modeling. I believe there is an integrated research project, it might not be full fuel performance modeling, but isn't there an IRP on hydride reorientation in the cladding that is attempting to model more of the fuel performance?

LARSON: Yes, yes, an IRP being an integrated research project that we have with universities, it's in it, I can't remember I want to say third year right now, usually we go four. But we were looking at data and trying to understand it and integrate the data and making sure we could understand it, put it into a database that we could handle.

The NRC has a database with a lot of the material properties we were looking up making sure that we understood that database, so we could add to that database is we could show the pedigree and quality of our data that's sufficient to do that, but you're right.

OGG: OK. And another question, you stated that based on the data and the information you're getting from the high burn-up fuel demonstration project, you feel comfortable that the existing inventory of commercials and fuel will be safe for extended storage and transportation, but the test that you've done includes only PWR fuel with certain fuel cladding types.

What gives you the confidence that your conclusion covers BWR fuel or fuels with other cladding types especially since some of the new BWR fuels are going to higher initial enrichment, higher burn-up, more pins in an assembly with thinner cladding and a number of those factors?

LARSON: Yes. No, there's a lot of work to be done there still. We would love to get our hands on some BWR, but right now, we believe given the thermal properties of the casks that the margins that have been included in the thermal properties, one of the things that surprised us a little bit is when we did the demonstration of modeling versus the actual, all of the modeling came to the high end if you're with me. We were hoping it would be scattered on

both the low and high and it would be in the middle, but all of them came in on the high side.

So we believe that we have made, we as an industry, as a group in this area generally make conservative decisions and so we believe that we make sure that it is below that 400 degree limit. And so with that being said, we believe that all of the casks deal with that bias, if you're with me. And so we believe that they've all been loaded cooler than what we originally had thought they have been.

OGG: Right, so that's...

LARSON: So that could cause the hydride reorientation issue.

OGG: That's a temperature issue, but different claddings will have different structural behaviors or characteristics and we look at...

LARSON: But we would like to get our hands on BWR, your point is well taken.

OGG: Yes if we look at what the NRC has done with their NUREG-2224 on high burn-up fuel, they, in that document said they're comfortable now with what's been done, the research on Zirc-4 cladding through the research at Oak Ridge National Laboratory.

But they sort of leave the conclusion at a point that says if you want to get approval or prove that it's safe to transport and do extended storage of other cladding types, you may need to do similar demonstrations as those that were done for the Zirc-4 cladding. So is that -- do you expect you need to do some additional R&D on some of the other claddings or other BWR fuel?

LARSON: Yes. The NRC like at Perry Island made reference to this demonstration and there was another one and I can't recall which one it was, Calvert Cliffs, I'm not sure, but anyway.

But what we anticipate is that the data that we're learning here can be used almost anywhere. The BWR fuels are

something that still give us a little concern and we would like to deal with that, but we believe that the thermal properties of the cask given the margin that are there, that they've all been loaded cooler than what we expected.

In the future, notice I qualified it, I said everything loaded to date we believe is OK, anything that changes in the future. I mean I can't extend that statement to the future, anything that we load in the future will be, I can't make that statement now because things may change in the future.

But yet given the experience that we have and our ability to model and predict what happens, we hope with what we learn now, we will be able to analyze those in the future and then be able to make a profound conclusion whether or not it's going to be OK or not. And we will continue to gather data in the future, don't get me wrong. It's not like we're going to be sitting still. We have a number of projects that we hope that we could gather data from. And so there's still a lot to be done.

BAHR: Bret Leslie from the Board?

LESLIE: Bret Leslie, Board staff. Ned, nice presentation. Sorry, we're going to miss you this afternoon, but you've got a more important place to be.

LARSON: I'm having a hard time hearing you, Bret.

LESLIE: OK. Bret Leslie, Board staff. Nice presentation. Sorry, we're going to miss you this afternoon, but you have some place better to be. I have three questions and I'm not sure you described the recent Idaho settlement agreement appropriately. My understanding this is a one-off for the Byron fuel and any additional transport of fuel to Idaho would still have to be renegotiated and still dependent upon meeting the milestones that are in the settlement agreement. Can you clarify that for me?

LARSON: Sure. No, I'll just be candid, the only thing I know about it are the things I've read in the papers, I'll be candid. It's not a free for all so to speak, you know, just start sending it, but there's a lot of work to be done.

LESLIE: I think Mike Connolly, could you identify yourself and just one sec, I mean just, he'll get it, go ahead.

CONNOLLY: It's on.

LESLIE: Yes.

CONNOLLY: You hear me now? So the settlement agreement...

BAHR: Could you identify yourself?

CONNOLLY: Pardon me? Mike Connolly, Idaho National Laboratory. So the settlement agreement that was just signed related to research quantity, the first initial shipment of Byron requires one canister from IWTU. Once they've generated a hundred canisters, then they could continue to make shipments, so there is no need to go back and renegotiate, it's a hundred canisters along with other things that are in there.

LESLIE: OK, thank you, Mike.

LARSON: Remember, as we do our laboratory testing, as we do the destructive testing, we box it up and ship it back out of the state, so it's got to be leaving Idaho too.

LESLIE: So a follow-up question, Bret Leslie, Board staff again, the cask will come from North Anna, go to Idaho, taken into the hot cell, will the rods then be transported back to Oak Ridge for testing or all the testing will happen at Idaho?

LARSON: Yes. Nothing will be going back to North Anna. Once it leaves their boundary, we own it. We will take the rods out at Idaho, but that cask will have to stay in.

LESLIE: The testing of the rods themselves, will that happen at Idaho, or will it happen at the other national labs?

LARSON: Say that again?

LESLIE: Will the rods, once they're taken out in Idaho be shipped to Oak Ridge or to Pacific Northwest Labs for testing or will all the testing still occur at Idaho?

LARSON: I don't know, and the reason I say that is remember, we purchased a lot of equipment already that went into the hot cells at the different national labs. I don't know that we will purchase all new equipment for Idaho, but I imagine there will be some, a lot of it that will be worn out and that we will purchase at and put it in the Idaho hot cell. We'll have to see when we get there what we're able to do, but we would prefer to leave it at Idaho as much as possible.

LESLIE: And Ned, my last question had to do with something you stated very early on, on the impact limiters on the transportation cask in the sense of you thought of going to foam because it was hard to find redwood and balsa and this is just for one transport cask. Do you see any issues in the future when transportation might be more prevalent where someone in the industry or DOE is going to say, "We want to license that the foam impact the limiters"?

LARSON: We've looked at a number of issues. On this one, like I say, this is a specific kind and quality of the impact, the redwood and balsa and we found a vendor that can give us that on this one. Down the road, you're right, the older ones use wood, some of the newer ones, mostly the newer ones use honeycombed aluminum, things of that nature. They're able to be a little bit smaller.

Eventually, we were even doing studies on Yucca Mountain is, could we move all of this stuff to honeycombed aluminum and to make them a little bit smaller and a little bit better.

We didn't finish that work, that isn't completed, but if we ever came to a massive shipping campaign, those are things that would be evaluated and looked at again. Because you're right, the big 12-foot plus diameters, we even looked at reducing these a little bit, but because of the way the trunnions are put on it, we've got to have it at 12, but we would like to reduce this as much as possible.

BAHR: Anything else? OK, well we've finished this presentation well ahead of schedule. We were scheduled originally to have a break at 9:45, but I suggest we take that now, and then it's 9:30. We'll reassemble at 9:45 and we can start with the next presentation.

(BREAK)

BAHR: OK, so we're going to get started on the next part of our meeting. If we can get people to sit down. I know there are lots of useful conversations going on in the audience. As Ned reported in his presentation, the thermal modeling of the high burn-up cask has provided a really useful data set with which to evaluate models of thermal conditions in spent fuel.

And the next presentation by Mr. David Richmond from Pacific Northwest National Laboratory and Dr. Sam Durbin from Sandia National Laboratories is going to go further in describing the work that they've been doing on thermal analysis. So I'm not sure who's going first, but OK. So that must be David Richmond. I'll welcome him up to the podium.

RICHMOND: OK, thank you. I'm David Richmond from Pacific Northwest National Lab. I'll be talking about the dry storage of spent nuclear fuel and our thermal analysis related to that.

It's going to be somewhat of a high-level overview presentation of all our activities, so I'm going to present on the recent thermal modeling PIRT activity and then our contemporary modeling, work on some future plans. If there's any more detailed questions about some of this work, I can go into that at the end.

First, I thought I'd bring us to a bit of historical context, because we've been thermally modeling cask for quite some time. This whole enterprise started in the mid-1980s, so then the question becomes why is there still all these questions about it.

And to bring us back, in those days, in the early days of cask design, the thermal modeling wasn't really a fully integrated part, because fuel temperature limits were not a

tightly controlled perimeter and there are large thermal margins to the limits even at normal operating conditions in that design basis. So when you're focused on offloading large amounts of cold assemblies, it's useful and expedient to buy as high temperature inputs in your thermal models to go for a limiting case for licensing and design.

Where today we're focusing on much higher, operations are loading higher decay heat assemblies, we are analyzing the as loaded conditions, not just the bounding conditions, especially for aging management. In this type of environment, a more best estimate analysis is needed for an integrated decision-making approach.

That brings me to our PIRT activity, the Phenomena Identification Ranking Table process is something that's used by the NRC, nuclear industry broadly. It helps inform all sorts of best estimate analyses, experimental programs and research. So briefly on the schedule and team, it includes Sam Durbin who you'll be hearing from shortly at Sandia National Lab, Chris Bajwa from the NRC, Jim Fort from

Pacific Northwest National Lab and Victor Figueroa from Sandia National Lab.

We had our deliberation meeting in October, just a month ago roughly, and we'll be drafting a report for our team's internal review and planning to publicly publish it in the summer of 2020. So definitely still very much in-progress work, but I'll present some of the initial -- I'll present on our process and some of the initial thoughts that came out of it.

The first part of the PIRT process is to identify the scenarios at play. This helps limit the scope and make it really useful to our particular field. So we're discussing thermal modeling and we broke it down into bolted storage casks, vertical ventilated casks and horizontal ventilated casks for storage because that represents every major piece of the U.S. market.

And then we also looked at short-term operations which includes modeling related to loading, draining and drying and transfer if you're in a canister system, and then we

also looked at transportation where any of these systems and their transportation configuration is, thermally has very similar behavior, so we took that all as one category.

The next part, this is to give just a broad overview of the parameters that we consider. These are what the panel narrowed down to every primary modeling input that one might need for a thermal model of the spent fuel cask.

There's over 20 there and they break down into a few broad categories like geometry, boundary conditions, material properties, source term and that's where we include the decay heat which is one of the critical values. And then some of the modeling equations and techniques, you might call them sub-models in certain cases here and a few other categories.

With each of those parameters, we ranked them by knowledge level and importance level. For us, our knowledge level was defined as what is -- is the state of the art knowledge, our understanding of this parameter acceptable for a best estimate plus uncertainty calculation.

So do we understand both the nominal value and the extents of the uncertainty range, the type of uncertainties that might be associated with that? And then importance can also be called sensitivity perhaps for our case, and we look at our figure of merit as temperature and that includes any temperatures important to safety and design such as clad temperatures, neutron shielding temperatures, seal temperatures, canister surface temperatures, anything that one might use for safety analysis.

Lastly, once the panel went through the entire exercise, ranking, knowledge and importance, we looked at how do we prioritize, what do we recommend prioritizing in reduction of uncertainty and there's going to be a lot of detail on this in the report into what we recommend prioritizing and how one might reduce some of the uncertainties associated with this.

In the figure there, you see one of kind of the areas where automatically you might need to reduce your uncertainty. If you have something with a high impact at a medium or low

knowledge level, then it is expedient to reduce your uncertainty in that because of the high impact associated with it.

I'll just say for this exercise, there was no parameter that we found had a high impact and a low knowledge level, and I think that's really typical because thermal modeling especially for a dry storage system, it's a very mature engineering field, mature industry, so you really would expect that anything with a low knowledge of what a high impact would have been already sorted out by now.

One of the key takeaways from this is that looking at the mature industry, like I said we have, the thermal models can support a large variety of evaluations, more than just a peak clad temperature or minimum canister temperature.

There's a lot of modeling that can be used to look at total clad surface area temperatures, axial temperature profiles which are really critical for fuel performance analysis, and also canister temperatures where the most important cold

temperatures might be in the welded regions if you're looking at a problem like stress corrosion cracking.

Now, we are taking that PIRT activity and we will be in the future taking that activity and applying to our modeling. So here's some contemporary modeling that we've done. And I'll say again, echo what Ned said, the high burn-up demo cask is just -- it's an invaluable resource to us as thermal modelers because there has been extremely limited data on operational systems available to this point.

The only others that we have compared against are the TAN facility tests, those were very useful, however, this provides us a lot of insight into the vacuum drying process which those casks did not go through, not the industry vacuum drying process anyways.

Now the initial steady state modeling, I think most of us have seen before and I'll brief -- this is just my only slide on this, but it goes back to the PIRT exercise where the inputs are so critical to our accurate results and if we have biased inputs, then we will have biased temperatures.

In this case, the left-hand side is our initial blind steady state temperatures and the right-hand side is with the adjusted best estimate. So when we adjust for some of these biased input parameters, these conservative input parameters, we believe our models can capture the behavior of the cask very effectively and predict within 10 degrees Celsius of the temperature.

Now, for the transient, this is latest work, is we analyzed the draining and drying transient from the North Anna cask. The time zero here starts at the end of drain. Vacuum drying starts at 6.5 hours and then the end of the transient analysis is the start of the helium backfill, and you can see our models in the solid line go up right to the start of backfill and I just put the data in, so you can see as how it starts to drop after that.

This is our STAR-CCM+ modeling in the center of the cask and it shows a really good agreement with the data. One important thing about this for leading into our future work is there is -- we made some assumptions about the cask

atmosphere during drying and we are planning to do further modeling and testing work about those assumptions.

I'll also show, this is briefly the COBRA-SFS model of the same assembly, thermocouples and this is the entire axial length. So you can see overall it predicts the behavior really, really well. This starts at, again starts at draining and ends at the start of the backfill.

One of the key pieces to validating some of these assumptions is small-scale tests, and this is the vertical dry cask simulator. Sam is going to present next on the horizontal configuration of this which we'll be modeling in the future. This is part of a round-robin modeling exercise, and what it gives us is a test bed where we have very high control over the input parameters or knowledge of the input parameters and really high control over the boundary conditions.

So what that does is it eliminates the variability that, some of the variability that you see on the demo cask because we really know those input parameters down to an

extremely fine level. And any differences we can start to separate out into model approaches as opposed to just an input.

This shows a brief smattering of results from that exercise. It included models from Pacific Northwest National Lab, three of those models are from us. One model from the NRC, one model from CIEMAT in Spain and one model from ENUSA in Spain.

So with all these different codes, different modelers for all of these and you can see the overall capture of the behavior well of the fuel in this particular test case, and there were different test cases run as part of this including lower canister fill pressure and different heat loads.

So if we have the demo cask, we have our small scale experiment and now applying that looking towards the future a bit, looking to analyzing closer to a real system and what systems are expected to be loaded in the future, this is an extension of some work that we did modeling a loaded cask

where Duke Energy helped provide us with actual loading data on their heat loads, on their actual load patterns. So at the top is a real loaded cask for their analysis of the heat load for that cask. And this is a MAGNASTOR system, so it's a vertical ventilated cask.

In the as loaded system, they loaded to 30 kilowatts which is well under the design -- current design basis of the cask, and as expected the temperatures are well lower than the design basis temperatures.

And what we did next is try to extend the modeling to see, have some idea of what the real peak performance of these casks are. We talk about, will industry, can industry cut their margin down and load truly to the design basis temperatures. This gives us an idea of what might happen as they start to do that.

For the current design basis -- excuse me -- current design basis of the cask is 35.5 kilowatts and these views, preferential loading patterns to load high heat load assemblies. In those cases, the peak clad temperature comes

in right around 370 Celsius, and then if we push those to the limit, so we pushed the heat load up until -- in an even fashion until we found the temperature to be right just above the peak ISG-11 400 degree Celsius limit.

We found we could get to a heat load of right around 40, 42 kilowatts. And with all of these, the last column I think is very important and it shows that even at design basis, only 1% of the clad surface area is above 350 Celsius, so getting to what we might consider really elevated temperatures for fuel performance, and only 25% of that surface area, 20-25% for our highest heat load cases reaches that elevated temperature region.

And this is the same, this is just the 4 Zone, a total histogram of that, so the same type of information in graphical form. And an important note about these fuel temperature area limits is that they're still spread across multiple rods and multiple assemblies, and I think for fuel performance, one of the key aspects is going to be the axial temperature profile. So on a particular rod, there's still

an extremely small amount of clad surface area at these elevated limits.

Bringing us to the future, a key focus for us is moving towards looking at can we accomplish a best estimate plus uncertainty analysis. These types of analyses usually require an extreme amount of modeling simulations, and we are working to develop a technique, a method for doing that.

COBRA-SFS is going to be a key piece to that because it's an extremely fast code, so we can run it on a time scale that is practical compared to some of the other codes and also on hardware that is practical because although, at the national labs, we do have some access to high-performance computing and large amounts of hardware, this is not really the type of problem that we would suggest applying that extreme computing capability to, because it is hard to repeat it on an engineering scale.

Our other main focus of the future is just methodology development and further validation work. I mentioned the HBU demo transient cask, we need to refine our assumptions

and our techniques. We have a -- we defined a method that we believe can very well characterize the HBU demo cask and now, the question is how do we apply that in a general case and what do we need to know to apply that to a general case.

Next is BWR assemblies, although the BWR dry cask simulator, we predicted that well, there are some particulars we found with modeling BWR assemblies especially as we move towards more modern designs that have higher amounts of partial-length rods and different types of water rods which take up more positions. There's some particularities to getting accurate best estimate temperatures of those.

We have good understanding of how to create a conservative estimate, but to get a best estimate is going to take a little more development. And then horizontal system, Sam will mention, we are going to model that.

There is going to be another thermal round robin for the horizontal configuration of the dry cask simulator. And then as we have all this, we're developing our methods and we're testing against more experiments, then we look at -

can we go back and apply that to a full scale system and see how we do.

So going back in time, obviously we can't be blind for the demo cask, but we can look at how our methods might improve there. If there is horizontal data, that would be another good test and then any other data that's available from a more full scale, more full size system, that's the type of final test we would use for our models. And that's all I have prepared. Thank you for your time.

BAHR: OK. So I think we'll have time for a little -- few questions for you before we turn it over to Sam while your presentation is fresh in people's minds.

Jean Bahr from the Board, in Ned's presentation, he showed us some preliminary modeling results that had been done for the high burn-up cask, all of which were over estimates of the temperatures that were actually observed. You showed us a round robin exercise with a bunch of different models, and I think you said that they all actually matched fairly well. So what is it that has changed in these models?

And a second question is how similar or different are the underlying physical processes in the models, are the differences that you see among the models due to the differences in discretization or are there actually differences in processes that they're capturing and can you -- is there anything that you can learn about which are better models of the processes from this comparison exercise?

RICHMOND: OK, yes, I'll take the first, so the first one how is this different from the demo cask and it is down at the inputs where the demo cask, the data, the design information available after we looked, especially after we looked at the as built information of the cask was clearly biased high as far as the thermal analysis is concerned.

And in this case, we have very good measurements of all of the necessary parameters for the simulator test. So that's the main difference, is what kind of inputs are available and whether those are biased or not. So we don't believe

there's any bias in any of the design information, the inputs that we were using.

So then the differences come down to some modeling choices that were made and there is going to be just some variability, minor variability in codes and modelers. Overall, all the models are trying to model the same physical processes but using slightly different methods.

It's hard to go into, especially because I don't know some of the details of the models presented by Spain and the NRC, but I'll talk just about our PNNL modeling, we used what we call a detailed CFD model, so a pin by pin model of each of the entire -- we actually use the symmetry model pin by pin of the assembly.

We also used a porous media model which is more computationally efficient because it takes the fuel region and uses an averaging scheme called the K-effective, effective thermal conductivity to model it as a single material.

And then that's really the primary way of modeling a full size cask at this time, just because of that hardware needed to do it. And then we also used our COBRA-SFS which uses a sub-channel method and finite difference method to model pin by pin - a detailed model, but a different modeling structure for some of the other structures.

And each of those, there are some advantages and disadvantages for different areas of the model. I mentioned the BWR assembly. In terms of the COBRA, we found some limitations in representing the part-length rods, so overall our temperature profile, in this case, there's a lot of flow in the cask, so it's hard to see, but the COBRA temperature profiles are flatter because of how we represented that assembly. But that's a known issue, a known difference I guess.

BAHR: When you use an effective thermal conductivity, is there a way to calculate that independently or is that a fitting parameter in the model?

RICHMOND: Usually, that is using a detailed model, so you would do a detailed model of the assembly and then calculate the effective thermal conductivity there. So for that, we can use our COBRA model or our detailed STAR model to calculate that.

BAHR: OK, thanks. Other questions from the Board, Turinsky?

TURINSKY: Turinsky, Board, when you get into the uncertainty analysis other than sort of the expert solicitation, are you planning any experiments or anything to actually measure the uncertainties and the closure relationships that you're using within these codes?

RICHMOND: The closure, I'm not sure I understand, the closure relationships?

TURINSKY: Heat conduction as a closure relationship.

RICHMOND: Oh, OK.

TURINKSY: Pressure lowest coefficient as a closure if you're going to use a COBRA type of approach.

RICHMOND: Yes. I think some of that, most of our uncertainty is going to be focused on model inputs, not model specific because in the types of models we're applying, they're pretty well formulated and widely used at this point. So I think a lot of the variation here is not really in the modeling techniques quite as much except for specific locations.

TURINSKY: Well closure relationships are mainly those inputs, sometimes they're actually imbedded in the coding rather than input. So if that's your primary source of uncertainty you're going to treat, where are you going to get those uncertainty distributions for the, I'll use your language, input parameters?

RICHMOND: That will be developed. For some things like gap relationship, gap thicknesses, those are from design drawings, design inputs, so we can make -- not make

assumptions, but we can look at the drawing in manufacturing and tolerances there and look at that.

TURINSKY: OK.

RICHMOND: I'm not sure I'm answering your question satisfactorily.

TURINSKY: Well what about like physical parameters rather than geometric, like thermal conductivity, do you use a sub channel approach? You have all the cross flow correlations that are built in the code but they're basically - they're parameters.

RICHMOND: Uh-hmm. I think the - I mean, thermal conductivity there, that's a material property and those types of things are well characterized by the manufacturers, what kind of acceptance testing you have on your materials and...

TURNISKY: But really do they have uncertainties like nuclear data does.

RICHMOND: That goes to some of the methodology development and some of the PIRT activity. And I'll say for thermal conductivity we just know from our experience that it is a very small range. So parameter like that, you might not need to treat with an uncertainty depending on what type of range there is in the value, in the nominal value.

PEDDICORD: Lee Peddicord from the Board. Looking at this slide, which looks good, but in comparing the model calculations and the data, there - at the top end, there's this trend where the data really flattens out while the predictions continue to rise slightly.

So is there some, sort of, systemic difference in the input to these models that is not a big huge thing but it impresses me that you're following a fundamentally different trend at the top of these and I don't know if there's something there that would distinguish why that data flattens out and the models continue to rise.

RICHMOND: I will say that that's just one of the models, I think they do.

PEDDICORD: Well you've got several models there, don't you? I mean you got...

RICHMOND: Yes.

PEDDICORD: ...a whole bundle. So I'm a professor, this is a homework assignment, OK? And I'm looking forward to hearing from you later on this. So let's back up to slide 12 and here...

RICHMOND: Twelve.

PEDDICORD: In here, you got this interesting inflection point at six and a half hours and the models that's not in the data. What'd you change?

RICHMOND: It is slightly in the data, it's hard to see, but...

PEDDICORD: Sure is.

RICHMOND: ...it's more dramatic in the model, that's - you're definitely correct there. So the inflection point there is due to the change from helium atmosphere to a vacuum atmosphere.

PEDDICORD: OK. Thank you.

RICHMOND: Vacuum - or a low pressure - extremely low pressure.

PEDDICORD: You don't have to put that in your homework assignment though. And then on your PIRT team, it's a little bit interesting. I mean, good folks and so on. I'm so surprised you don't have any representation from industry on this in terms, I don't know, whether it be a vendor or utility or...

RICHMOND: Yes. I should have - you're right, I should have mentioned that. So the vendors and utilities were active participants in the exercise. We have them there as

observers and not as panel members. So as not to invoke any bias, any economic concerns.

PEDDICORD: And I don't know that you would have reached any other conclusions...

RICHMOND: Yes.

PEDDICORD: ...but it was, kind of...

RICHMOND: So we included representatives from each major task vendor in the US; NAC, Orano TN, and Holtec, and then we also had a representative from a utility perspective provided by Zita Martin who operates - she manages spent fuel - all the fuel at TVA and she helped give us a utility perspective on how these models are used in the field.

PEDDICORD: OK. Then finally, you mentioned about COBRA that you can run it a lot quicker, is that - is that the version that runs at a desktop? Does that...

RICHMOND: That's correct.

PEDDICORD: Yes. So that's quite good that you could use this because you're really talking about large number of runs possibly to get to some of the...

RICHMOND: Yes. I'd estimate potentially thousands depending on what angle we go for. And with COBRA, we run single core on a desktop and roughly one to two hours compared to upwards of a hundred core - well it depends on type of analysis, but upwards of a hundred cores and possibly 24 hours for a STAR CCM plus run.

PEDDICORD: Thank you.

BAHR: Are there - Tissa?

ILLANGASEKARE: Tissa Illangasekare of the Board. So these are general question again, so your model is pretty complex because there are different processes you're trying to model. It seems like the new model, you had a couple different processes into the model.

So when you answered the question earlier that the material properties, where material properties are very well known, but in many coupled systems there are some parameters in the coupling itself. So are there any parameters associated with the coupling, for example, gas flow and heat. Are there any parameters which are basically a result of the way you define the model, couple the different flow models, for example, the heat conduction models?

RICHMOND: Is there any - I'm not sure I'm - is there any - are you asking...

ILLANGASEKARE: Yes, for example, if you have situations where - for example, porous media is coupled to free flow.

RICHMOND: OK.

ILLANGASEKARE: OK. So you solve the porous media equation, you put the free flow equation, you put a free flow equation but when you have the interface of the coupling, there are other parameters which, sort of, define a coupling of these two systems. So I don't - you don't have to answer the

question, my question. More has to do with the fact that there are some parameters which has to be, sort of, calibrated or determined the way you couple these two types of processes.

RICHMOND: Yes. I think - and I think that's kind of typical of any analysis you might go in to. There's different assumptions that are made, there's different simplifications that need to be made for any numerical analysis of any system.

We do have through our - through our test data, our comparison to test data and our knowledge, I'm not a porous media person, I can answer more detail about the COBRA models, but through our use of this, we know where they are - where they are predicting temperatures most effectively and where we might need another model or more information to have information.

Specific to the COBRA model there are certain instances of if you are looking for flow rates, detailed flow information

that the COBRA, the way we model it in COBRA SFS cannot produce some of that information.

In that case, we look to our STAR CCM plus model for something, like, air flow, rates in ventilated canister or air flow, specific air flow distribution in a ventilated canister. However, we know that we can use our correlations and simplifications effectively to predict temperatures using these methods.

BAHR: Sue.

BRANTLEY: Sue Brantley, Board. Do you - do you have to model any chemical reactions in there? Are there any reactions that are taking up heat or giving off heat or anything?

RICHMOND: No. There's no - there's no chemical reaction at play. In the vacuum drying, there is evaporation happening, of course, as you drain the cask and dry. But that is not a significant form of heat removal, so it's neglected.

BRANTLEY: OK, thank you.

BAHR: So I think we should probably move on to Sam's talk to give him adequate time and we'll have some more questioning after that.

DURBIN: All right. Madam Chairman and the Board, thank you for inviting me to brief you on this subject. I wanted to start by saying in follow-up to David's presentation, this is a subject area that has received a lot of attention in the last several years, and what you're seeing is the result of an integrated and focused research effort to try and address some of these uncertainties that have been identified by both regulators and researchers.

As co-chair of the EPRI extended storage collaboration program, thermal modeling subcommittee, that's a mouthful, but I wanted to acknowledge that format for being kind of our big tent in this area and it really allows us to hear from the vendors, the nuclear power plant operators, and other components of the industry and I wanted to acknowledge EPRI for giving us that format and I'll just acknowledge

that the genesis for the thermal modeling PIRT was in the thermal subcommittee EPRI escape and I wanted to thank Al Csontos for hosting those PIRTs, they've been really useful. We're expecting the report to come out, I think, by the end of this calendar year and I think the Board will find those very interesting as well.

I'm here today to brief you on the horizontal dry cask simulator that was alluded to in David's presentation and give you a status on where we're at with that. So the Board was out in Albuquerque last year. At that time, we were transitioning from the vertical test to the horizontal configuration and the horizontal systems are a popular system in the domestic fleet.

Here you see a cartoon showing the major components of a horizontal system. The big difference is obviously is that the canister is laid horizontally and this configuration does lead to some different flow regimes and heat transfer mechanisms as opposed to the vertical - the vertical systems, the modern systems tend to rely on an internal convection component to reject the heat to the - to the

environment whereas the horizontal systems are primarily conductive. So they use thermal bridges to get the heat out to the canister wall and ultimately reject it to the air that's drawn in through natural convection into the vault.

So here you see a cross section of - this would be more like a prototypic system, the canister laid horizontally, gravity is down in this picture. There are air inlet vents at the bottom of the vault. So air enters into the vault, it's swept around the canister diameter and then out through these outlet vents. The horizontal dry cask simulator that we have is a single assembly represented by all these little boxes here. And then we also have a pressure boundary or representing our canister here on the outside of that assembly.

So we only have a single assembly, it's much more cost effective to use a simplified geometry such as this, but we do choose our parameters carefully such as the blockage ratio which is defined as the diameter over the horizontal opening of the vault and through some clever other tricks we

can make this system look as much as like this system as we can with the simplifications.

We have a BWR fuel assembly or components thereof. We've replaced the spent fuel with electrical heaters and we preserve the water rods and the spacer grids, the channel box, all of that is still prototypic, it's unirradiated, we tend not to put irradiated things into our experiments if we can help it. The cost savings are immense. But everything else is pretty much the same.

We do use the electrical heaters to simulate the decay heat and then over here, you can see our cross section again, so we do have the channel box, the fuel, the water rods, the basket, and then a pressure vessel representing the canister. When we attach our thermocouples, we attach them directly through the heaters, so the temperatures we measure are really indicative of the cladding temperature.

These are other photos of the - of the components. This is the basket, the pedestal that the fuel is received into at the bottom tie plate. This is the pressure vessel

representing the canister, and then this is the instrument well, because unlike the prototypic canisters, we have instrumentation leads that we have to pass through the pressure boundary and we have some plastic components that we don't want to see heat, so we funnel them down into this instrument well.

We had to make some other modifications to the vertical assembly. The entire system was made to have concentricity. So we wanted to maintain that when we laid it horizontally as you can imagine. If we did nothing, this assembly would shift and rest on this basket and the basket itself would lay so that the corners were on the pressure vessel.

Because we had already made electrical connections and instrumentation pass throughs, we really needed to keep the assembly centered, so we added these basket stabilizers as well as these set screws and then finally this aluminum bridge plate in order to keep everything centered when we laid it horizontally.

So here you can see some photos of those stabilizers that were welded to the basket. This is the bottom of the assembly, they're stitch welded at 24 inch intervals for one inch length weld. This is the middle showing the vessel as it was coming down and being installed and then this is final installation with the stabilizer showing there.

I don't recall exactly, let's see, I think you all were there in August of last year and so we had already moved it up to - or we had not moved it up to the top level, but you can see here, this was being lifted out of the vessel and this was in mid construction. So these are the vault components that you see here, these stainless steel panels. And then finally this is the insulated assembly with the air intakes and the hot wire instrumentation installed to measure the inner mass flow rate.

So this is the cross section, these are the air inlets and you can see we have those same type of slit inlets where the air is coming in, it's heating and going around the canister and the modified Rayleigh number, Reynolds number, and Nusselt number shown down here in these tables or this

table, and when we first looked at the - these are external dimensionless groups, when we looked at them first we thought, we really took a hit because now our scaling is based on the diameter, not the vertical length. And when we were vertical, we had good comparisons because of basically we had preserved the critical dimension.

But now that we've got a much smaller diameter, than what is prototypically found, we thought, "Well, we're going to take a big hit on our scaling arguments." And at first glance, you would say that our Reynolds number, depending on what power we apply so this is a half kilowatt, this is five kilowatts. We've got 280 for our Reynolds number and 730 for the high-end of the power that we apply.

Prototypic is about 2,000 and you might say to yourself, well that's quite a bit different, but when you look at the - what regime you're in for cross flow of a cylinder, it turns out we're actually in the right ballpark. This is the irregular regime where you start shedding Kármán vortex streets off of the cylinder. And it turns out that the regime goes up to about 5,000.

When you look at the modified Rayleigh number, this is the Rayleigh number based on the heat flux. We also see that we're actually not too bad. You just start getting 3D wake separation for turbulence in the range of about 3.5 ten to the ninth, and the lower value that we see for our experiment is about 1.3 ten to the ninth and we go up to about 1.3 ten to the tenth. The prototypic is about 1.4 ten to the thirteenth. So even though we're not that high, we are in the right physics regime as far as the external flow.

So this time around, we are selectively publishing our results, we are limiting ourselves to two cases that we're going to share with the modelers, we have commitments from PNNL, NRC, and ENUSA in Spain. So these are three entities that provided modeling results previously.

And we are going to give them two cases, 2,500 watts, 2.5 kilowatts and 100 KPA for both helium and for air. And these cases are marked in green, you can see there are additional cases marked in yellow, these are data sets that we have already collected and intend to look at blind

comparisons with the model. So, all of these conditions will be submitted as models, but the ones in green have been provided for calibration purposes for the modelers.

We're looking for several different comparison metrics, peak cladding temperature, of course, peak cladding temperature location, air mass flow rate, and we're also looking at temperature profiles.

Since this is not a vertical system, we actually have some texture in our temperature profiles. So we have interesting temperature profiles in both Z, X, and Y. And I'm going to show you some of the initial results. So this is a temperature profile in Z and here you can see this is the Z coordinate on horizontal axis, this is temperature in Kelvin on the vertical axis.

Here the cross section of the assembly has been lined up with the figure, so you can see that our reference zero is shown here, and then this is the temperature as you go along the assembly.

Now those red boxes that you see there, those are the data points that we're asking the modelers for, and we have also plotted other locations, so the red box there is at the very center of the assembly, but you can also see these blue diamonds in the location of that rod is shown right there in the cross section as well as the green triangles which are this location right here in the assembly. But we have a higher density of data available for comparison, but just to show you, we're only asking for those limited red squares.

So this goes to those comparison metrics listed before, the peak cladding temperature of the location as well as the axial profile, the T of Z and that kind of turquoise star hiding right there, that's the peak cladding temperature for the entire assembly. This is the same result for air.

If I go back one, you could see the relative difference here, this is the same scale, 700 degrees Kelvin up here. The peak cladding temperature was right here around 550, same result for air. Now you're up here around 650. So I won't dwell on this, but I did want to include it for completeness. It's the same metric.

Here we have the temperature profile in X. So here on this graphic you can see the temperature locations marked by these red boxes here and each one of those boxes slide over and equate to that marker. So now we have temperature on the horizontal scale, and then this is the X coordinate here.

So the peak cladding temperature or the peak temperature in this profile is, again, a little bit shifted above the center of the assembly. This is the pressure vessel bottom, this is the vault top, this is the vault bottom down here. We are asking for all these temperatures for comparison as well and that's this metric shown in that table from before.

Same thing for air, again, if I go back, let's see, this is 558 degrees right here. For the air case as you might expect, it has an elevated temperature of equivalent location of 645 Kelvin.

Finally, this is the temperature profile that we're asking for in Y. So this is at a prescribed location of Z and here

you can see these red boxes, again, showing the locations that we're asking for. At zero, the water rod EU location, that's the one in the very middle of the assembly. And as you march out, you can get to the channel, the pressure vessel, as well as the vault.

This is the final metric that we're asking for for the comparisons. If I do the same comparison for air, again, this is held constant at 650, you could see that the helium result is here at about 550, air is up here at 634 degrees Kelvin.

This shows the response of the system in time when we apply the heat. We don't start from the same initial conditions because we were running an accelerated testing schedule. We don't start from ambient conditions every time, so really what we are interested in are these steady state results. And so, this is peak cladding temperature.

The blue is for air and the red is for helium, and so, you can really see the difference there between air and helium. And then over here we have the air mass flow rate for the

total assembly for the helium and air. Here you don't see much difference between the amount of air drawn in for the assembly.

And in summary, I will just leave this up and point out again that we are giving limited data sets, the ones marked here in green. So helium at 100 KPA and 2,500 Watts simulated to K heat, as well air at the same conditions. Those were being provided to the modelers for calibration, and then we are asking for the same information from the modelers for the expanded data set that we will compare in a blind validation study next year.

We expect strong results. We are expecting some variation because of the horizontal nature of the configuration, but we are looking forward to processing those and making conclusions on them next year. So thank you.

BAHR: Thank you, Sam. Jean Bahr, Board, just so that I understand what you are doing, are you giving them those red data points so that they can then calibrate their models to

fit those data or are you asking them to predict those data points from a set of inputs and boundary conditions?

DURBIN: So we are providing the, basically all of these data points to the modelers, not just the red squares, but the red squares are all that we are asking for in return. And we are going to be asking for those for this data set, the 2,500 Watt, 100 KPA, but also the other decay heats, as well as, we are only asking for the 100 KPA for 500, 1,000, 2,500 and 5,000 watts for helium and air.

BAHR: So that means that they can adjust parameters in their model in order to fit that as opposed to giving them physical properties of the system and asking them to see if their model generates this data.

DURBIN: So we do provide initial conditions of course, the pressure, the decay heat but we also give geometry, so we've provided CAD representations of the system for them to generate a mesh. And the idea is that we bring everybody to the same point as best we can on the input side to reduce a lot of those disparities on interpretation, and really get

to the meat of the question which is how well do the models agree?

BAHR: But you could conceptually have a number of different models that if you tweak parameters in different ways in each of the models, they could all agree, and yet the models themselves, if you took them to another set of conditions might give you different outputs because the conditions are changed and they are not calibrated. What are the calibration parameters that are available within these models?

DURBIN: That's left to the modelers and I can tell that you've worked with modelers before based on your question. But we are providing this limited data set so that they can perform those internal checks. Am I using the right thermal properties? Did I miss something? Does this boundary condition look weird? And they can do that fine tuning, but they can't do it for the entire data set that we intend to compare them to.

So if you recall from this table, that we selected the decay heat for 2,500 watts so it gave them something in the middle but they can't necessarily fine tune it to nail the 2,500 without having potentially some implications on this higher decay heat or this lower one, if that makes sense.

BAHR: It still concerns me that I - I know that many of these kinds of models are non-unique in the more adjustable parameters, you have the more chance, you have fitting things, and showing that several models can all match the data doesn't really then tell you whether you have the right parameterization, and the right understanding of the processes and the right underlying model.

DURBIN: Yes, and in my experience the more one hard wires the model to get the result that you want, the less flexible you make it, and so, if we have models that really dial in to get this calibration data set, I feel they are going to suffer when they extend to these other conditions.

BAHR: Do you understand enough about what the differences in the underlying models are that are being used to then be

able to learn something about what makes one a better model than another?

DURBIN: I personally do not because I am an experimentalist but it's my hope that the modelers that are submitting their results for this comparison will have that type of insight.

BAHR: OK, thank you. Other, Paul Turinsky?

TURINSKY: One just to refresh my memory, what was the axial power density profile that you used, was it uniform?

DURBIN: It's uniform, yes, sir.

TURINSKY: OK. And back to Jean's point, when these models are used for the real system, there is no calibration point is there?

DURBIN: The dataset, the validation datasets available for horizontal is much more sparse than what you see for vertical systems.

TURINSKY: Are there any plans to look at real horizontal systems?

DURBIN: So I don't know of any that I can point to for, let's say, like a NUHOMS actual canistered, system but there are discussions to leave the high burn-up demo, thermocouples intact for transportation which would include a horizontal configuration, so that is one example I could point to as a potential for gathering data in a horizontal configuration.

BAHR: Are there questions from the Board? Questions from the staff for Sam or also for Dave since we let him go before the staff could ask questions. Nigel Mote?

MOTE: This is a question for David. And I'd like if you can to go back to slide 17 of his presentation. No, no, the previous presentation.

Thanks, Jason. So there's an apparent anomaly in both of those, so I take it that it's not random. On the top curve

it's between 350 and 340 degrees, in the lower case it's between 360 and 370 degrees.

The eye finds that the bar and the bar is charted at those levels to be an anomaly. So my first question is and this is not on the chart but the units, the units on the Y axis are% of the clad surface. And I don't know whether that is the% of rods that reach that at some point or whether it is the percentage total area of all the cladding.

So question number one is, is it really almost 10% of the area that reaches that temperature? As it seems like an anomaly in this curve I would have expected to see some sort of discontinuity in the axial profiles, that represents that there is not an apparent continuity in this presentation. But I've not seen any discontinuity. So can you tell us why there is a discontinuity here when the axial temperature profiles are without that anomaly?

And lastly what is that caused by? If it was the low end I could believe it was maybe better conductivity at the grids and spaces, for example, but this is at the high end, so

there is something which is causing a higher than, a higher temperature at some localized points, but I wonder how that plays into the accuracy in modeling and the possibility that a larger percentage than expected may be at the high end of the range?

RICHMOND: So first off on the units is percentage of clad surface area so since we do a detailed model we have, in our model we can tell you how much surface area is being modeled and then take the temperature on those, discrete points. It is discretized so there is a certain limit to how fine that is.

But the reason you are seeing this here is because it's a preferential loading pattern, so that discontinuity, as you put it, that is in different assemblies, so you have in the 4 zone, you have I believe it's four assemblies at very high temperature, very high decay heat and higher temperature at different points in the cask and in different zones of heat load.

So if it is a flat pattern, then you would expect a very, and probably the distribution you are expecting of much more even and predictable, but since it's a zone loading pattern there are specific areas of high heat within the cask. So it's more on an assembly basis is what you are seeing, not on an axial profile basis.

MOTE: To what extent, I may follow this up, to what extent is that not represented by having, I think was it 7, yes, 7 thermal lances in for example the HDRP cask. If this is a phenomenon that is playing out in real loading at utility sites, to what extent does this question that an average model which is what I think the cask loading is based on or not a precise model for each assembly says we need to be looking at margins to take account of that?

RICHMOND: No, it just has to do with the load pattern selected, so even at the demo cask and I had mentioned they selected high heat load assemblies for the center in that case.

Typical practice involves finding a mix of assembly heat loads, and those are analyzed and the pattern is defined in the certificate of compliance or in the Tech Specs for the cask at least, where you will put high heat load assemblies in specific locations. And those are chosen to balance out the thermal performance of the cask, maintaining peak temperature below 400, and also to balance the dose consequences for loading the cask.

So thermally you would really want to have your hottest assemblies at the far edge because the heat will get out easier, but in reality you have to balance the dose, in which case you put those high decay heat assemblies equating to high radioactivity. You put those towards the middle of the cask to help shield them with older and colder assemblies.

MOTE: Great, thanks.

BAHR: Dan Ogg?

OGG: Dan Ogg with the Board staff. I've got a question for David and then a question for Sam.

First, David, when you discussed the PIRT process and looking forward, you are expecting a final report sometime in the summer. My question is what happens next? So you've identified the most important parameters or phenomena, who has action to do something with those and what's the plan?

RICHMOND: I think anyone that's doing thermal modeling will have some action based off of it. For us we are looking at it to inform our best estimate methodology and we'll use that in a very similar manner that is used other parts of the industry like fuel performance, for instance.

As far as the industry we identified some areas where a bounding approach is used on parameters where it may not be necessary, and that's really up to the cask vendors and utilities to decide for themselves what type of cost is associated with that, because we definitely wanted to try to develop an activity that would be useful for NRC, DOE and the industry which is hard to serve all three of those.

So in that vein we didn't really make much judgment about what the true cost of reducing some of these was, because there are costs associated with more licensing activities, possibly more monitoring of temperatures, and certainly more modeling effort, so that's not really up to us to determine.

OGG: OK, thank you. And for Sam, again, Dan Ogg with the Board staff. Could we go to Sam's presentation now slide 7? And this has to do with the centering apparatus that you have here for this horizontal configuration. Can you talk a little bit about how this is the same as an actual spent fuel assembly in a basket, in a canister in a horizontal configuration, how is this the same and how is it different, and what are the effects of those differences?

DURBIN: Great. So the artificiality that's introduced by this aluminum bridge plate, you are right to point that out. If these were an actual assembly in a prototypic basket, you'd have repetition of these basket cells with interstitial spaces formed where the baskets are joined.

The assembly itself, by gravity, would come to rest on the basket directly, so there would be a conductive bridge between the channel box and the basket intimately. But because we cannot afford to have the assembly slump, we introduced this aluminum bridge plate which as far as conduction, offers a really good bridge between the channel box and the basket. And it may actually spread the heat a little bit more to the basket from the channel box.

OGG: OK and what about the basket and the canister, is that prototypical or are there differences between the two?

DURBIN: This is also an artificial construct of the assembly or this apparatus. You'd have mechanical clearances for construction purposes of the baskets sliding into the canister. As you would get thermal expansion, as was seen in the high burn-up demo, you would expect - this is exaggerated, you would have a much tighter gap for a prototypic system. But you would expect this basket structure to come near intimate contact with the canister.

Now, I didn't mention this, but one reason why we went full length on this centering stabilizers was also to limit the natural convection that could occur from this cell to this cell. So you could imagine there could be kind of a little bit of a funky convection cell set up right here. But by putting this in this configuration all the way down the assembly, we've limited how much internal convection can actually occur.

But, no, you're right. In a prototypic system you would have some closure of that mechanical gap, especially toward the bottom where you have gravity pulling the basket down. You would have intimate contact on the bottom. And then as the basket expanded, you would probably get better thermal contact throughout the remainder of the canister.

OGG: And then finally, do you expect that there is much of an effect in real life of the canister sitting on the rails in the horizontal storage configuration and would that affect the thermal connectivity and temperatures?

DURBIN: The contact of the rails to the canister is fairly limited as far as the surface area of the entire canister, so I expect it to be fairly limited. We do have some contact points on our assembly but they are not the full axial length as you would have in the rail. But because they're really almost line contacts with the canister I think it's going to be fairly limited.

OGG: OK, thank you.

BAHR: Yes?

PEDDICORD: Lee Peddicord from the Board. Just to follow up, I mean the phenomena you outlined, I think your assumptions are correct but you can go ahead and model those and see the effects of the aluminum bridge plate compared to the actual situation and also possible convection around those corners, I mean...

DURBIN: Yes, sir.

PEDDICORD: That's something you can make as a, I think your assumptions are correct, it would be nice to go ahead and do that.

DURBIN: So this geometry that you see before you, this was what was provided in the CAD model to the modelers. We were a little bit more restrictive on what we provided for the fuel because we think that there are some choices to be made by the modelers that we didn't want to influence. But we have defined this geometry, the contact area of the basket and the size of the aluminum bridge plate. So that's a common starting point for all the models.

PEDDICORD: No, I was thinking more in terms of comparing this and the fuel assembly going into an actual horizontal storage facility following up on Mr. Ogg's questions as well.

DURBIN: You are right. You could probably do just a two-dimensional simulation to see what the fundamental difference is between having the bridge plate and not. And these convective cells, yes, sir.

BAHR: OK, Paul?

TURINSKY: Turinsky, Board, and this for Dave. Are you modeling thermal expansion also? Tissa's question reminded me the multi physics aspects. So that gap was such a big deal in that demo and that's going to be clearly affected to some extent by thermal effects.

RICHMOND: So we are looking at thermal expansion and how best to implement that. Clearly one can calculate thermal expansion and do that, right. But then how do you effectively implement that into the model, with our transient model, this is the part that I was talking about with generalization.

The transient model and the COBRA SFS, we didn't model an idea of what we have for the thermal expansion as it progresses through the transient. However, it's difficult to make an a priori determination that that's correct because there are, as you have all of these components expanding at some point they may lock up and it's hard to

predict that. So that's where we need to get to if we want to just absolutely dial that particular aspect.

TURINSKY: And is that in the plans to actually do?

RICHMOND: We are going to look at that in the future for sure. Yes.

BAHR: Bahr, from the Board. This is a question for Sam. You mentioned slumping of the fuel, if you didn't put that bridge plate in, but in a real system where you don't have those bridge plates there will be that slumping?, is that what I infer from what you said?

DURBIN: Perhaps a bad choice of my vocabulary. It wouldn't be a slump so much as it would be just a translation. The entire assembly would move down with gravity until it made contact with the basket.

BAHR: And there, would there be any physical effects on the assembly from that downward migration, any stresses placed on the rods or any...

DURBIN: I'm not an expert on how they transfer the system, from when they load vertically, to when they go horizontally, to insert into the vault. But it's my understanding that's a pretty gentle process, so you would expect the assembly probably to make contact at the top first and then just kind of rotate more gently as the basket and the canister are transitioned to horizontal.

BAHR: OK. Are there any other questions from the Board? Any other questions from staff? OK. Well, thank you both very much. And we'll move on to our next speaker, maybe I'll go up to the front for a second.

So our next speaker is our own Bret Leslie. It's a little unusual for the Board to make a presentation at its own meeting. But this is a public meeting and we have people in the audience, both here and on the Web who may not be intimately familiar with things that the Board has done in the past.

And to set some context for the presentations that we are going to have after lunch, what Bret is going to do is he is going to review some of the recommendations and conclusions that came out of a report that we issued back in 2017, and it's in response to some of those recommendations that some of the work that we are going to be reviewing this afternoon was done. So I welcome Bret up to do that.

LESLIE: So good morning and thank you. As Jean said in her opening remarks today, the Board is tasked with an ongoing review of the Department of Energy's efforts. And this afternoon we are going to have two presentations, one by Josh Jarrell and one by Mike Connolly that we felt partially that there is a sufficient background that's needed to understand what they are doing, because they are going to jump straight into the technical details.

And so, partially I am providing some background and context for the audience to understand both the Board's recommendations but also for the subsequent speakers. So as Jean identified, the Board, from 2013 through 2016, was doing a multi-year review of the Department of Energy's

activities to manage and dispose of the DOE's spent nuclear fuel. So the meeting itself has now switched from commercial spent nuclear fuel to DOE spent nuclear fuel, and that's an important point.

And as because there's approximately 250 types of DOE spent fuel, not the two that are in the commercial side, boiling water reactor and pressurized water reactor. So what we'll be talking about this afternoon, I've highlighted a few samples of aluminum-based spent fuel. You'll hear about the Advanced Test Reactor that Josh will talk about, and some aluminum clad fuel and we'll show an example of how badly degraded that cladding is and what the implications are for storage and packaging.

So we conducted this review. The Board conducted this review and we included site visits and public meetings around the sites, Hanford, Savannah River and Idaho. The Board examined the technical issues related to DOE spent fuel package and storage that might affect continued storage, transportation, and disposal into the future.

The result of our review was captured as Jean said in a pretty big report in December of 2017, on management and disposal of DOE's spent nuclear fuel. We'll have copies of that report at lunch time so people can take a look at it.

What it did is for the first time since the mid '90s is systematically recorded the quantities and characteristics of DOE's spent fuel at all of the facilities. So it is basically an encyclopedia of where all of the materials are, what their characteristics are.

The Board analyzed the packaging and storing activities and DOE's plans for the continued management and disposal of this material. As part of its review, the Board identified issues associated with aging management and packaging and also disposal. I will only really talk about the aging management and packaging, because those are the most relevant to our presentations this afternoon.

And as Jean indicated, our reports go to Congress and the secretary and the recommendations that we provided in there. So I am going to continue to provide a little bit of

background kind from a big programmatic standpoint and then I will start going in and addressing some of the topics that both Josh and Mike will talk about later this afternoon, after lunch.

So aging management really is the program to manage the aging of DOE spent fuels at some of the sites. Well, what is aging management? As materials age they can degrade and those degradation processes can affect the material properties, how one might handle a particular material.

And so the Board observed that the DOE spent fuel will be stored decades longer than expected. That, in general, DOE spent fuel is more degraded than commercial spent fuel. And aging management is a concern on the commercial side, and so, there are techniques in terms of managing aging, which include prevention, mitigation, condition monitoring and performance monitoring.

And I would point out the high burn- up demonstration cask as an example of monitoring. They are monitoring thermal, they attempted to monitor the water chemistry. So if you

are going to do that monitoring that means the package must be able to be monitored for whatever you want to want to monitor. And I will get to that in a little bit when I talk about the DOE standardized canister.

So overall, the DOE approach for its spent fuel is some of that fuel is already in multi-purpose canisters. And when I say multi-purpose I mean storage, transportation and disposal.

And I will be talking only about the non-naval fuel. DOE manages the naval fuel, but that's not the subject that we are going to be talking about. And DOE has indicated that it plans to package their remaining spent fuel in a multi-purpose canister, the DOE standardized canister and we'll talk about, a little bit more about that.

So that one canister has to fit the jigsaw of 250 types of fuel that has a variety of different fuel compounds, uranium aluminum will be the one we'll be listening to and learning more about this afternoon.

A variety of cladding, again, the aluminum cladding. Unlike commercial fuel, the DOE spent fuel has a wide variety of enrichment, up to a highly enriched fuel. So criticality concerns are a little more sensitive for the DOE spent fuel. Not that they are not sensitive for the commercial fuel, but there are some added considerations as you go to that higher enrichment.

And the fuel that's stored is stored in a variety of settings, both wet and dry. And in dry storage it doesn't necessarily mean that it's sealed, so Mike is going to talk a little bit about some of the activities associated with dry storage, but these casks are vented, so that they are not sealed like the commercial casks that we see on the storage pads.

Two examples, this is research reactor fuel going into storage at Savannah River Site, and this is Advanced Test Reactor fuel, or the ATF fuel, that's coming out and going into dry storage at Idaho. And so there are operations about putting the fuel in the wet pools or into pools and taking it out and taking it into dry storage. And that's

some of the materials that we'll hear about today from Josh and Mike.

So kind of a context, so like there's a standard contract between DOE and the utilities for DOE to be able to dispose of the waste, there's something similar for its own waste and that's because the person or the entity that was going to dispose of the waste was the Office of Civilian Radioactive Waste Management and they wanted to make sure that whatever the other part of DOE gave them was going to be disposable.

So there was this Memorandum of Agreement between the Office of Civilian Radioactive Waste Management, the Navy, and also the Department of Energy Environmental Management. And I will give you a little more about DOE Environmental Management because they are the ones who are managing the fuel on the DOE sites.

So as part of that Memorandum of Agreement, it pointed out to a number of other documents that the Office of Civilian

Radioactive Waste Management wanted them to use. And one of them was this Waste Acceptance Systems Requirement Document.

And you'll see it's a 2008 but there was an earlier version that was cited in the 2007 memorandum that basically said for OCRWM, or Office of Civilian Radioactive Waste Management to accept this fuel for disposal, it will have to meet these waste acceptance systems requirements.

When DOE shut down the Yucca Mountain project, there was a closure memorandum and that's the 2010 reference, and basically DOE NE, the Office of Nuclear Energy, became responsible for OCRWM's missions and activities.

So under the framework back in 2007 and 2008, the roles and responsibilities were defined by the Department of Environmental Management managing the DOE spent fuel during storage at DOE sites. Now, you'll hear something from Josh saying, well, DOE NE has some fuel that it's managing. At a certain point the Department of Nuclear, Office of Nuclear Energy turns over its fuel to the Department of Energy Environmental Management for managing it further.

So for the Advanced Test Reactor, because it's an operating reactor run by the Office of Nuclear Energy, Office of Nuclear Energy is managing that fuel. Under the memorandum, the Department of Environmental Management was responsible for designing the containers that have to be acceptable for transportation and disposal. The Department of Energy Environmental Management was responsible for packaging DOE's spent fuel into containers, not only the design but the packaging as well.

And the Office of Civilian Radioactive Waste was responsible for acceptance of the fuel, transport and disposal, now that that until the Office of Civilian Radioactive Waste Management comes back or something else, the Department of Energy Office of Nuclear Energy is responsible for that.

So these acceptance criteria are, and these are the words, they are not the exact language, but the idea was that the Office of Civilian Radioactive Waste Management wanted to make sure that things like pyrophoric or combustibility were assessed such that you would not violate any of the

transportation regulations or safety regulations, or storage regulations if it was licensed by NRC.

So one important thing is that the waste acceptance criteria basically said DOE spent fuel will be in a DOE standardized canister prior to its acceptance for disposal. So waste form limits, contents limits, so that means anything other than the fuel you put into the canister has to make sure that it doesn't adversely affect gas generation. And then finally, there were requirements for limiting the potential for criticality during operations at a repository and after the repository is closed.

So now, I'm going to - now I'm going to segue from this overview of how DOE approaches things into the more specific of DOE's use of multipurpose canisters and these are for storage, transportation.

They developed two systems for the non-naval spent nuclear fuel. They developed one solely for the Hanford, which is called the multi-canister overpack. It was used at Hanford. Here's an example of the aluminum clad fuel and you can see

particles of corrosion products on the - on the examination tray.

So you get an idea that this cladding is not pristine and it can degrade. I will admit that the storage conditions for the Hanford fuel was quite a bit different than at Idaho. It was not well-constrained chemistry in terms of keeping the pool to minimize that corrosion. But the reason why I showed this example is just to show that it can happen. It's certainly not going to look like this, but nonetheless, it's helpful to visualize what's going on or what went on.

So the multi-canister overpack at Hanford, the packaging was completed. Drying this fuel including not just aluminum clad fuel but the uranium metal fuel, which was also degraded, was an issue and so they - we've - I think in 2014 we heard about Hanford, how they - how they tried to dry this fuel.

Because of the - some of the uncertainties they had in terms of the reactions in storage, they had 15 of the 394 that were monitored for pressure, temperature, and gaseous

constituents. And they were looking at hydrogen and they were looking at oxygen in terms of the gaseous constituents.

I would point out that these are no longer monitored. They were sealed. And like Ned said earlier, those - you would think those connections that go into a canister are really well-understood, well, it turned out that their sampling port probably was going to fail after the sixth or seventh sample. And so they basically welded them - the sampling ports closed on those 15 packages. So now, what we're going to hear about this afternoon in more detail from Josh is the DOE standardized canister.

It was not deployed. The development stopped before it was deployed. It's called a standardized canister. It's not really standard. It's four sizes with eight different types of baskets and all sorts of things that go into it, but it would - it would take into account all the remaining non-naval DOE spent fuel.

And based upon what was in the Yucca Mountain license application, that is about 3,500 canisters. Two heights,

two diameters. I talked about the basket arrangement.

Eight different types of baskets. Here is what was in the license applications for the aluminum fuels basket.

You'll hear something different from Josh today. The Advanced Test Reactor and some of the research reactors and these are all defined here, but what DOE is contemplating is a different loading or arrangement for the basket. One other thing is in the license application, they identified that they would be using advanced neutron absorbers and I'll provide a little more detail on that in a subsequent slide.

So criticality safety after disposals. DOE's approach in Yucca Mountain license application and it's codified in the waste acceptance systems requirements document. Basically, to maintain the possibility - the probability of criticality less than 1.0×10^{-4} , over 10,000 years. In other words, less than 1×10^{-8} annually. And that was for the entire inventory. So it wasn't by package, it was - you have to have the complete probability less than that.

With that in mind and because of higher enrichments associated with the materials and because DOE evaluated both the in package intact configuration and the possibility over time that these canisters would degrade and open, you could have a degraded - a different geometry inside these waste packages. And that's called a degraded configuration.

So in DOE's approach, they had this advanced neutron absorber, which is nickel gadolinium alloy basket material. And you can see it was going to be about a third of all of the DOE standardized canisters including for the aluminum-based fuels - and then addition for some of the most highly enriched fuel, they identified that they would have these baskets plus what are a gadolinium phosphate inside an iron pellet and they had - again, they hadn't finalized that design but at least in the license application process, DOE postulated this is what we're going to do ensure criticality is below the limit.

So, again, I said research and - R&D hadn't been completing, and I think I'm going to move on from that. So why did the Board focus on aluminum fuels and also the Department of

Energy has focused on this, it's because there's a lot of aluminum fuels out there in terms of the number of assemblies at Savannah River, but there's some also still at Idaho. And eventually it's about 30% of all the DOE standardized canisters will have this aluminum fuel. We know the aluminum fuel like the Advanced Test Reactor has a high surface area.

You can get thick - this picture on the left shows some of the corrosion that had happened in a pool where the water chemistry, again, was not well-constrained. So you can have a thick corrosion layer. That layer has a hydrous chemical composition that includes multiple minerals that I think Mike will talk about a little bit. And those minerals have different characteristics in terms of drying and their ability to generate or capacity to generate hydrogen as a result of radiation.

So basically, the Board review focused on the drying procedures and this afternoon, we're going to hear a little bit more about the R&D that they're doing. So kind of wrapping up and getting to the Board's recommendations, kind

of this overarching observation is it's really essential to manage this spent fuel in a manner that will not impede its eventual disposal.

And the Board observed that it was important to improve the understanding of the processes related to packaging and storage that could affect those transportation and disposal activities.

So the Board finding in - I'll say that the Board did a detailed review and the recommendations are quite detailed, and I'm not going to go through the full recommendations, but they are in the backup slides for the members of the audience so I'm kind of putting the overarching recommendation and there might six or seven other things that the Board said DOE should do related to the recommendation.

So basically, to implement plans -- and remember, for aging management, one of the concepts is monitoring. And so what the Board was interested to hear was how was - how were these aging management plans going to be completed for all

the sites and for the types of fuel that are currently in storage.

The Board made a finding that measuring and monitoring conditions of the spent fuel during dry storage is important. What we heard from Hanford and the information they got resonated with the Board, and so they basically said, you know, being able to monitor gas composition for types of fuels that are - that are hard to dry or where we don't - where DOE doesn't have a good basis right yet of how dry is dry, this is important to do.

So the Board recommended the capability for measuring and monitoring the conditions, and I just realized that I missed a crucial part of the DOE standardized canister. Right here at the bottom and at the top.

When DOE identified what the standardized canister had - design was - is they had optional plugs for draining and for monitoring. And so this was a critical point, is that if you're going to monitor the DOE standardized canister, this

plug has to be part of the baseline design, at least for the ones that you're going to monitor.

So I'm sorry I missed that earlier. We'll go back to the measuring and monitoring. So include the capability for measuring and monitoring the conditions of spent fuel in the DOE storage system including the DOE standardized canister. And at Hanford, they had the ability to go out to those 15 and actually do the sampling. So if you're going to store it in 603, can you actually do the monitoring if it's - if the design is such that it can be monitored.

So the Board, again, came to this recommendation that an improved technical basis is needed for the proposed drying procedures for DOE spent fuel before packaging it in multi-purpose canisters. And so this is - this is what you're going to hear about this afternoon. Some of the research that Mike will summarize is going to some of these things. This is the R&D that's necessary to have a good technical basis for understanding whether your drying procedure is good.

I think an important point is we don't know when disposal will occur, so if you have a reaction that occurs a certain amount each year and you have a limit, you'd better make sure you have enough margin to eventually get there if that storage period is pretty long.

So one of the points that we wanted to make in terms of thinking about drying is, these are multi-purpose canister, not just for storage and transportation but also for disposal. So think about how long that duration of canister use is.

And regarding packaging. While storage is happening at DOE sites, DOE is basically self-regulating. However, when it's time to transport and dispose of that package, there'll have to be regulatory approval by NRC for transportations - certificate of compliance for the transportation cask, but when Yucca Mountain project shut down, DOE had already engaged the NRC for maybe four, five years on whether the DOE standardized canister would be acceptable and be transportable with the design it had at the time.

So the Board recommended to minimize - to minimize complications in developing and operating and packaging facility DOE spent fuel at Idaho that DOE complete its R&D and make sure that it's going to pass muster so that you don't have to open up this later and that you already have the buy-in of the regulatory reviewer ahead of time.

So kind of - I started and said we started our review back in 2013 and it kind of ended in 2016, it took me a year to get the report out, actually it took a little longer than that. DOE had heard and was already starting to work on some of these same issues and so - and I think Mike will talk about it a little bit more, but they had set up a taskforce, a spent fuel working group.

And in 2017, around the same time that we were coming out with our report, they had come up with a report identifying pretty much the same sort of things and seemed to be aligned with what the Board identified.

This report, which is in the references that I've listed in the background of my presentation, dealt with the knowledge

gaps, the technical needs for aging management and drying spent fuel. In the intervening time, we haven't really had a meeting to catch up with all the activities that DOE has been doing.

Mike and a number of the - of his cohorts both at Idaho and at Savannah River this last March I think at the Waste Management presented a couple of papers on some of the details of the work that Mike will summarize. So in the intervening time, DOE developed an action plan and has taken on these experiments, and as I've said, Mike will talk a little bit about that.

Somewhat unusually, but the Board was grateful is, Congress actually took an action on the Board's recommendation in the sense that the House Appropriation Committee report associated with the Fiscal Year 2019 report basically said the national spent nuclear fuel program at Idaho would -- should spend five million of its appropriated - of the overall EM budget on addressing some of the Board recommendations. And so the House is still interested in

what DOE is doing to address the Board's recommendations, and so this is a really helpful meeting for us.

At the time that briefed DOE Idaho on our report back in early 2018, they indicated that they had plans for a DOE standardized canister demonstration project. And I know it's not part of either of the presentations today, but perhaps in the panel discussion someone will be able to explain where that is and where that's going. And finally, I think I've laid the framework for the presentations this afternoon, the DOE activities will be described by Dr. Josh Jarrell and Mike Connolly. And I think I'm done and...

BAHR: Great. Thanks, Bret. I don't know if there are any questions from Board members or staff for Bret, probably not. So at this point, we have time for public comments if there's anyone signed up to make a public comment. We have no one signed up. Is there anyone in the audience who would like an opportunity to make a comment at this time? I see someone standing up. They are walking to the microphone. Thank you.

AL CSONTOS: Hi. Al Csontos, EPRI. So Dan asked the question earlier about what we're doing next after the PIRTs. So EPRI led the PIRTs, there's more than one PIRT. It was thermal, fuels, and decay heat modeling. And so we're moving forward with those reports.

And thank DOE for their - for their significant support to all the teams, OK, and the technical expertise they provided. What we've done is working with NEI, OK, and the fuel vendors and the dry storage vendors to go forward with looking at how we move forward some of the recommendations coming out of these reports.

So from there, we have action plans going forward to look into taking those recommendations. There is a white paper that just came out as of yesterday at an NRC public meeting. NEI wrote up the paper. I helped write parts of it.

And in there, they talk about several recommendations, I can't remember how many but there are over a dozen. Sixteen? Sixteen recommendations. And a lot of them had to do with the PIRTs. And so we were - we already got them

done but that paper was already being written. So there's a lot of things that have been going on and there's a lot of activities coming up in this next year to recapture some of those margins.

BAHR: Thank you very much for that clarification. Yes, sure.

PEDDICORD: So, Peddicord from the Board. So presumably the PIRT reports will eventually become available to the public and the Board?

CSONTOS: Correct. And the end-of-the-year goal is to have a report created - the PIRT meetings all happened three weeks ago and - three to four weeks ago. And so we're getting the reports completed now and so those reports will be completed by the end of the year.

That will be then sent over to the panelists to make sure that their recommendations, their suggestions, their technical input was accurately portrayed in the report. And

then by March, we will have something available for comment to the public and then have a publication by June.

PEDDICORD: Again, Peddicord from the Board. So we saw - you brought together really a very significant collection of individuals for input. That'll be interesting to see. Following these are you envisioning with this kind broad team any sort of follow on actions?

CSONTOS: Yes, it's the propagation of uncertainty is a - is a key one because when you're looking at fuel performance as it's - as it's related to the NRC's regulations in terms of what is defined in 72 - 122 L which - or H, which is the gross rupture definition, what do we have to protect the cladding against to ensure that we have no gross ruptures.

And so that's a question that was requested from the group, that that required a larger group that was more than just the fuels folks. It had to deal with shielding, criticality and other folks. So that was one of the recommendations that hopefully we'll get together another group to look at

what that means, OK, because that has an impact on all the technical requirements after the fact.

The second big recommendation - second big follow-on activity was to pull into a larger discussion of how uncertainties propagate for fuel performance related to thermal modeling, decay heat modeling, all these things because it seems like what's been going on and the difference between what you saw from what Ned was presenting earlier to what David presented was one was blind, one wasn't. OK? And so we did a sensitivity analysis or PNL did a sensitivity analysis based on the information afterward, but what we found is that the design licensing basis were far off from reality.

And so as a result of that, we went back and did kind of an uncertainty, you know, discussion during the PIRT meeting. And what we found is that it is larger than just thermal. You need the decay heat folks, you need to understand source time, you need to understand a lot of other pieces. And we also have to understand what the material property variability is.

And so that piece of the pie - looking at the propagation of uncertainties or propagation of maybe biased uncertainties on the conservative side and how you propagate that through the whole calculation, then what we found in the blind round robin comes to - makes all the sense in the world. And what David was saying was that we found that it biased on the high side. And that's when you look at all the propagation of uncertainties, if you choose all the conservative values, then you're going to come to that decision.

PEDDICORD: I apologize. Could you say your affiliation again?

CSONTOS: Electric Power Research Institute.

PEDDICORD: Thank you.

BAHR: Thank you. Any other comments at this time? Bret?

LESLIE: Bret Leslie, Board staff. I just wanted to say we brought our fact sheet on the DOE spent fuel so you don't have to carry the big report home.

BAHR: OK. Well, if there's nothing else at this point, we'll break a little bit early for lunch. We will reconvene at the scheduled time of 1:00 PM and the Board have a place to have lunch, I think it's on the second floor so we'll gather there. See the rest of you after lunch except for those who are headed off for your award.

(BREAK)

BAHR: OK. Well, welcome back to our afternoon session. And following on the introduction that Bret Leslie gave before lunch talking about some of the Board's previous recommendations related to both packaging and drying of spent fuel, we're going to start out this afternoon with Dr. Josh Jarrell from Idaho National Lab who is going to update us on what's going on with the development of the DOE standardized canister.

JARRELL: All right. Everyone can hear me OK?

All right. So, I'm Josh Jarrell. I'm the Department Manager in INL in the Used Fuel Management Department. And I've got the opportunity today to talk about what we're doing to the DOD standard canister. And specifically, how it relates to DOD NE and the support they provided.

My colleague, Dr. Mike Connolly, we will be following this up and talking about some of the works the DOD-EM has been funding as well. So, the next slide -- I'm sorry.

So, just a quick overview of the presentation, provide a brief overview. It looks like Bret did a pretty good job of giving a review of the fuels and the canister, but I will still make sure we're all on the same page as far as where we are on fuels and canisters.

And then I'll talk about the work that we've done over the last two years or so looking at the standard canister, looking at different neutron absorbers and poisons, the materials in the canister; looking at how we would load the

canister at the INL facility; and then kind of where we stand going forward.

So, this slide and this picture probably looks familiar. There's a very broad, diverse set of fuels in the DOE complex. Most of which reside -- we have some of most of those things at INL, low-enriched material, high-enriched material, a range of clads and fuels, you know, the standard commercial zirconium UO₂, yes, we have that fuel but we also have quite a bit of other materials.

And with that, we have a range of sizes, and we also have a range of locations that those stored and so -- that's not bright enough. We have wet storage. We have some below grade storage. We have vault-like storage which is the CPP-603 facility which we'll talk about in some more detail.

And so, because we have such a wide range of fuel types, the DOE looked at it and say well, we need to come up with a standard and effective way to manage all these fuel types. And so, they came up with the DOE standard canister.

And the idea with the standard canister is that you would develop the system for storage, transportation, and disposal. So, the idea is you put material on it and you never have to open that canister again. And to do that, you need to really design a robust canister. So, minimize how much you have to rely on actual fuel performance and transition the safety case to the standard canister itself.

And so that canister was and has been designed over the last -- let's call it 20 years. And it was included in a Part 72 license, the Idaho Foster Wheeler storage facility which was licensed at Idaho but actually never made.

And it was also referenced in the Yucca Mountain license application that Bret discussed earlier. And it really was designed to accommodate most of the non-commercial fuels besides the N-Reactor spent fuel that was/is currently loaded in the MCOs at Hanford.

So, just to put us on the same page, this is an ATR fuel element. It will be loaded or multiple elements will be loaded into a standard canister. And the idea is that that

canister would be sealed up, never opened again, and then could be placed into a storage configuration, a transportation configuration, and eventually into a disposal waste package.

So here's a little bit more detail on the standard canister. Bret took my punch line away that the standard canister is actually not just one canister but four. There's two different diameters - an 18-inch and a 24-inch diameter, and they had two different lengths. They had basically a 10-foot length and a 15-foot length. With fuel, they could range somewhere between 5,000 to 10,000 pounds and the most interesting thing about the canister, and it goes back to this concept of being a robust package, is the skirt that they designed.

And so I'll talk about some of the drop tests and the design, the reasons they put the skirt in. But really it was to make it very robust in sort of accident sort of scenarios.

So it was designed for basically the broad range of spent fuel, but specifically, it was designed for ATR, so the Advanced Test Reactor. And this is where it comes back full circle to why DOE-NE is so interested in this canister.

So, ATR is the Advanced Test Reactor at INL. It generates on the order of about a hundred spent fuel elements each year. And the current planning for the material is to move from ATR to the 603 facility. So, this is this dry storage vault.

And it's a, basically, it's a vault so it only has so many slots for canisters and locations. So, this is very similar to a spent-fuel pool they might see in commercial space where you only have so much volume you can load.

And so in, as in what they did with commercial spent fuel, they re-racked those pools. We're doing the same thing when we're reconfiguring our canisters to basically make higher density configurations.

But even with those reconfigurations, there's a potential for the facility to basically fill up and reach capacity. And if that happens, ATR, we don't really have any viable alternatives. And so we think, and NE is looking at this and that's the reason they're funding is this standard canister can provide that alternative for storage to ensure ATR can operate for decades to come.

And the reason we're proposing a standard canister for that option is, well, we want to make sure it's road ready and disposable. All right. And so, that comes back full circle to always, as the Board mentioned, always think about disposal in mind when packaging.

Well, we have a really robust package that's been proven over the years. And we think it's a near term alternative for ATR fuel. So, again, it's looking at what we need now for storage but also making sure we think about can we transport this thing later on.

So we've focused on four main areas over the last couple of years. The canister design itself, including how the

canister performs in disposal environments, I'll get it -- I'll provide some results here in a little bit.

But we're looking at what sort of criticality control that's available. We're looking at the poison materials that have been previously considered, specifically, the borated stainless steel, and then another material which they call the advanced neutron absorber which is, as Bret mentioned, the nickel-chromium-molybdenum-gadolinium as the poison alloy.

And they were also looking at different locations and geometries in the canister. And I'll talk about the different concepts and designs but just in brief. This is the Type 1A basket that is kind of the standard that was included and referenced as part of the Yucca application for ATR fuel. There's other configurations that could be conceived that may perform better and may reduce the number of canisters.

The second piece that we're working on is looking at what it would take to actually load the fuel in that 603 facility.

So, we're evaluating specifically the clearances and tolerances of that facility. And then looking at what sort of upgrades will be needed to be able to load a canister in the facility.

We are working on storage configurations. So, we're talking with vendors to discuss what sort of packages they currently have that could be compatible with the standard canister for storage and eventually for transportation.

Now, we never really haven't had a detailed discussion. We haven't really gotten into the transportation piece, working really hard. But the idea really is to make that system that we load for storage road ready.

And when I say road ready, what I'm really implying is that we have a transportation package with an NRC certificate that has a standard canister with whatever fuel is in that standard canister as approved content. So, our goal is to get it from where it is today into a road ready storage position.

So, before we went down and listed all these activities, I wanted to kind of cover where or what the history of the canister was, so I'll just briefly touch on this. Really in the mid-90s, the National Spent Fuel Program was developed to help with managing DOE spent fuel, and they developed the DOE standard canister. Shortly, thereafter, actually '95, the second bullet there, they developed what they called a co-disposal waste package.

And so, you'll see some images of this because I'll show some criticality analysis of that co-disposal waste package. But that includes a DOE standard canister and then five high-level waste packages is basically around it. And that was the conceived waste package for the standard canister.

Moving on a little bit later, the late '90s, around the 2000 timeframe, a lot of work really went into developing the neutron absorber, and looking at corrosion performance and criticality performance.

In addition, during those same times, the canister was prototyped and actual real drop tests were performed. And

the drop tests were based on the transportation regulations, the hypothetical accident conditions and you can see in Part 71 basically dropping the package from 30 feet.

And even though it was expected that the canister itself would always have an overpack with it, we wanted that canister to be so robust that even if for some reason it didn't have an overpack, it would still survive the transportation accidents and maintain confinement and containment.

And the reason that was important was that it wasn't entirely clear in transportation the way that we would ensure moderator exclusion. So we wanted a really robust package so that we go to the NRC and say, hey, our package is so robust and you have a transportation package that we would like to take credit for the fact that moderator is excluded from that canister. And some of those meetings did actually happened in the 2006 timeframe, although that process was never really completed.

The other one I guess I skipped was in 2001, the NRC did approve the Foster Wheeler storage application to construct and operate a spent fuel facility but again, though it was licensed, it was never constructed. That facility had the standard canister as the basis and included three fuel types in that license, Peach Bottom, Shippingport, and TRIGA.

And then in late 2000, 2008, the standard canister was referenced in the application, and promptly the funding was reduced and then completely suspended shortly after that for the standard canister.

But during that time, a number of really good analyses were done on the standard canister. And really, there was no showstopper, per se, in any of the analyses that were done. The most interesting one were these drop tests, where they actually did -- this is the drop that was actually done out of Sandia. And they did real drops and then they modeled it with finite element analysis to predict what the drops would look like.

And so, they did a really good job matching. You'll see here this is kind of the canister, that deformed skirt. Here was an indentation where the canister was dropped out on an unyielding point. And this is the finite element analysis, they agreed very well.

There are a lot of works done on materials interactions. I won't steal any of Dr. Connolly's thunder but we'll talk about some of the other material interactions that were evaluated. The absorbers were selected and evaluated, and I'll talk about that in a second, how you would actually weld and close this canister was looked at. And then, obviously, the source-term calculations and dose consequences were done using the standard canister.

The last one, and this is one I'm going to spin back up into is the pre-closure and post-closure criticality analysis were performed. And so, what really drives that criticality analysis is the fuel, ATR, which is an HEU sort of fuel, and then the poison that you select.

And the reason that the poisons were selected were, well, actually, I guess they had a lot of reasons. But the idea there was for the poisons, that they will be in the basket of the standard canister so they can maximize the amount of fuel in the canister. And the idea was to reduce the probability of criticality for the relevant period of performance per Part 63 which we talked about was that 10,000-year period.

And for the standard canister, they developed this new alloy which they called advanced neutron absorber. It was nickel-chromium-molybdenum and gadolinium which was the poison of about 2%. Gadolinium is a really good thermal absorber and that's why it was selected. It was also determined to be less soluble than boron. So, if you had corrosion, hopefully, the gadolinium would stay within the package to prevent the criticality.

So, in the early 2000s when this was being evaluated, the initial corrosion test showed that borated stainless steel corroded - didn't have very good performance and would corrode quickly. And so that's why they selected, really

fundamentally that's the reason they selected the advanced neutron absorber for this DOE standard canister.

Later, though, other fabrication techniques were employed to fabricate that borated stainless steel. Basically, it's a powder metallurgy fabrication approach where you had a more homogenous mixture of the boron particulates. And it was shown that that material actually had better performance. And so that borated stainless was selected for the commercial spent fuel for Yucca Mountain in the TAD, which is an image right here, which is the Transportation, Aging and Disposal.

And so, basically, one package selected borated stainless and one package selected advanced neutron absorbers. And so, since then, there have been additional evaluations done both NRC and INL that looked at how borated stainless corroded and how borated stainless corroded compared to this advanced neutron absorber.

The big conclusions there were that the more boron you had, the worse performance you had in borated stainless. So, in

this plot right here, you see 304B4, so that's stainless steel 304 with boron -- B4 is between one and 1.25% boron. So, this analysis that was done by SWRI, which is a contractor for NRC, showed about 80 nanometers per year in water and humid air which after 10,000 years would be about .16 centimeters.

So, if you think about how much .16 centimeter is over 10,000 years, it's actually not that much. However, if you go up to B5, again, the Bs go up by -- and they reflect how much boron's in there which is between 1.25 and 1.5% they have a maximum corrosion rate of 600 nanometers per year, or over 10,000 years, you're talking about over a centimeter, so.

That actually may be significant when you look at what the basket thicknesses and the amount of material you have, so. B4 seemed to do pretty good. I mean, .16 centimeters over 10,000 years is a pretty good corrosion performance. Again, that was in a specific environment but it just shows you that that B4, the 304B4 did pretty good.

Another study compared borated stainless and ANA, and this is actually done in INL and it compared 304B4 which is of 1.17%. Again, the B4 was somewhere between one and 1.25, just you get what you get sometimes with these lots.

And ANA which had just under 2% gadolinium and you can see that these two different tests, if you look at the corrosion rate, this was about 32 nanometers per year. In this one, you got 16,000. And so again, it looks like that borated stainless, you're crediting just the material and kind of ignoring the corrosion products after the fact may be a pretty good alternative.

The other piece there is borated stainless is commercially available. It's been used in cask and cans and pools around the world. ANA really was developed just for the DOE standard canister. It really isn't commercially available.

So, we said all right, there's been some work recently done with borated stainless versus the advanced neutron absorber. Let's see from a criticality perspective how they do. And so, what we did was we analyzed 65 distinct cases, storage

cases, transportation cases, flooded, dry, intact. These cases are the most challenging from the criticality and these are the disposal cases. And at every single case, I'll show the results but in every case, borated stainless perform better from a reactivity perspective than the advanced neutron absorber.

And so, in this scenario, I just -- I bring up three K effectives. This first one is the co-disposal package. I talked about the green is the high-level waste on the outside. There's five of those. And then there is an intact standard canister that has 10 ATR elements that are still intact in the standard canister. And the pink right here is flooded, so there's water in the system.

So if you look at the difference of K effective of that system with ANA, again in that scenario it's actually down about .63, so very sub-critical in this scenario. Intact scenarios really don't challenge criticality if you have intact fuel elements.

But with two different 304B4s, again, this 1.17 is kind of the average. Well, maybe not average but it's what we had previously tested so we knew this number. You get about .59. And then if you have 1% boron which is the minimum B4 that you could get when you buy a lot, you'd be about .5 or about .6, so you went from .6 to .63.

Same thing with a degraded ATR element. So, if these elements degrade out and we make an assumption they degrade into these aluminum oxy-hydroxide materials which actually we'll talk about -- Dr. Connolly will talk about next which is these gibbsite sort of materials and then these uranium mixture which is a schoepite but actually have some hydrogen in them.

You can get increase the reactivity of the system. So, with ANA in the system, it's about .81. If you had borated stainless, you'd be about .78. All right, so. And then those systems, you'll see that the borated stainless does better than the ANA.

Then we say, well, OK, what about scenarios where it's more dry? And the reason you'd look at that is because the gadolinium has a really strong thermal absorption cross-section. So, is there a difference if you have a different spectrum in some of the neutrons and it turns out the answer is not really. And there's a few reasons why, mainly because the degraded elements have enough hydrogen in them to actually thermalize the spectrum pretty well.

But either way, if you have no flooded scenarios, basically, the pink is now white, the reactivity actually goes up a little bit because again, you have enough hydrogen in the degraded fuel elements. But again, you see about .83 with ANA and .8 for the borated stainless, so.

We did the criticality analysis, and in every scenario with the same thickness of material, B4 which was the one that over 10,000 years corroded .16 centimeters, it performed better than ANA from a criticality perspective.

So the next thing we looked at once we had done that basically poison comparison, is we said, well, what other

options do we have for managing these ATR elements? So, if you look at the previous elements, you actually had 10 ATR elements in a given level. And that was the Type 1A basket that was referenced in the Yucca application.

Well, in order to put those 10 elements in the Type 1A basket, you actually individually handle those elements until you have to pull them out of the configuration they're in now and put them into some other basket.

Well, a lot of them are in this configuration now where we actually store them, each of these is an ATR element and they get stored into an ATR4 bucket. So you can pick up the ATR4 bucket and there's four elements in it. And in storage, they get placed together so that you can get 16 ATR elements in a given level and make a nice circle, kind of like this.

And we said, well, OK, they're already stored like this. We have a facility that we're looking at, potentially loading these in at INL. Is there a way that we could continue to handle them like this? And basically increase the

throughput, how fast we can load the canister would go up because throughput is going to be an issue with our current facility. It's a legacy facility. And we could potentially reduce the number of canisters if we can put in a close packed sort of system, so we did.

We started doing evaluations there. What we found was the current Type 1A basket was an 18-inch basket. If you put four of these and you try to fit them into an 18-inch basket, it's really, really, really tight tolerance and there's no locations to put additional poisons in for long-term criticality control.

So, we talked to the operators about it if they could even do it. And they might have been able to do it, but we still had no room for poison. And we said, all right, but we have two standard canisters, two diameters. Let's try the 24-inch.

So, we actually did some design work, actually Orano TN, led a lot of this design work where they came up with a bunch of different options for the 24-inch canister.

In this scenario, basically, you see a cross-plate. Here, you have a flux trap that keeps these ATR4s away. And here are some interesting ones. These are my favorite. These are the star patterns where you could fit five ATR4 buckets in a given level.

And so, again, you can get basically 20 ATR elements in a single level, in a 24-inch can. So, yes, we had to pick a bigger can where you can get 20 versus the Yucca which you remember had 10. So, you could potentially get half the number of canisters with ATR4 or with ATR elements.

And then, of course, we had to do a criticality analysis. And so, what we looked at was locations that we could insert poison plates, bars, rods into this bucket, because again these ATR elements are basically set in the bucket and you do have access to the top of it when you load.

So we looked at putting some inserts in in different locations, then we did the same sort of analysis that I talked about previously, storage, transportation, flooded,

degraded disposal scenarios. And so, here is an example where we actually assumed that there was five standard canisters in a storage configuration that flooded.

And with no absorbers at all, just these buckets, so basically just this concept with five of them flooded, with intact assemblies the K effective was .83. OK. So, basically, what you're seeing here is in storage and transport, you really don't have a reactivity sort of issue even without poisons.

However, again, as a previous example showed, in disposal environments with degraded scenarios where you have a lot of hydrogen in the fuel, you potentially have a reactivity issue. And so, in this scenario, this is a co-disposal package. And what you'll notice missing is there's nothing in the middle, because we had to go up from an 18-inch to 24-inch we only had five locations because these are high-level waste, all high-level waste before where in this case we have four high-level waste and this one 24-inch.

And in this scenario, with degraded cases, with no absorber, you can get above one for reactivity. However, if we put these inserts in, we were able to drive the reactivity below .93 which was the criticality limit for Yucca. And, frankly, this is by far the worst case we could come up with. How realistic it is, we can argue about. But, again, we were below .93, so we think this approach for ATR is a very viable approach for a basket design.

So, these were the kind of the two activities that we looked at as far as canister design, poison, reactivity, that sort of thing. The other thing we looked at was could we actually load one of these things in the 603 facility?

And so, we saw some presentations earlier today about the crane upgrades at the 603 facility. That comes into play in this evaluation because we can actually load a large cask that could handle multiple standard canisters.

But we have looked at this 603 facility, and I kind of pointed out earlier sort of like a very yellowy picture that was just a picture of a vault. If you're looking down,

here's the vault and here is the fuel handling cave. The think of this as like a giant hot cell, so anything that goes into the vault or out of the vault has to go through this handling cave.

And we said, all right, this is a really good location to potentially weld up, and load and then weld up a standard canister. So, the activities around this is, one, we're trying to get very tight tolerances, so we're doing some LIDAR activities to get, you know, the dimensions and tolerances of this facility down to half an inch or less.

And then we went through and evaluated all the steps that we thought it would take to load fuel from the storage facility, bring it into the handling cave, bring a standard canister into the handling cave, put the fuel into the canister, dry it, weld it, make sure the welds were good with NDE, potentially have to repair a weld, backfill it, and then you'd have to decontaminate the system and then move it out.

And also, you had to move a bunch of different materials in, welding equipment, NDE equipment, all these sort of things. So we have this whole process that's laid out. We've identified what's new steps and old steps, and what will require facilities upgrades or what would require new technology development.

But looking back over all of it, the real answer is, yes, there's a few things that we would have to upgrade and technology we'd have to develop but there's no showstoppers. And, in fact, we're trying to right now discuss, for example, the welding techniques with a couple of contractors and actually what it would take to get there.

So, really, no showstoppers. We think we can load this material in the 603 facility. We think we have viable canister concepts for it and we are in the process now of trying to evaluate what the next step would be, which is the storage options. And once we have a loaded canister, kind of what we do.

That was what I really wanted to talk about. Just, you know, to conclude we think this DOE standard canister is a near-term storage option for the ATR, basically, to make sure that we have capacity for ATR fuel storage in the future, whether that's actually putting ATR elements in the canisters or potentially putting a different fuel in the canisters to then give room for ATR fuel to go into the storage array right now.

The canister as was discussed has always been designed with transportation and disposal in mind. It's a very robust package. It was previously referenced in disposal and storage license applications.

And we've done drop testing to basically ensure that this package could maintain confinement in fairly significant sort of scenarios regardless if it's overpacked or not, which is really a remarkable benefit of allowing these skirts to dissipate most of the energy in the drop events.

We've done the basket design work with ATR elements. We think that we have viable alternatives for those basket

designs. And finally we think the 603 facility does appear suitable to load canisters in.

And we think we can, really no showstoppers with a few facility upgrades and technology development pieces, I think we can get that pretty quickly. So, that's really all I had to say. So with that, thanks for your time and I'll take any questions.

BAHR: Hey, thanks very much, Josh. Bahr from the Board, a couple of questions. When you talk about the corrosion rates over 10,000 years, is that assuming that the surface is perfectly smooth and that's -- or what happens if you have defects, scratches into the surface?

JARRELL: There's a couple of things. So, one thing, I mean the pitting corrosion question is not included in these corrosion rates, so they're basically perfectly smooth.

Now, we do have other studies related looking at pitting in cavities, crevice corrosion, and specifically looking at over how those would impact it. So, yes, those rates really

were in only certain environments, you know, sort of water, humid environments.

If you had a repository in like a reducing environment you'd have different sort of corrosion. And so, actually, we started to think about actually what it would take, what activities we could do looking at different environments and the corrosion performance of different materials in different environments because again this really -- a lot of this work was focused more on, you know, the Yucca Mountain sort of repository.

And so, while we think that at most cases the oxidizing sort of corrosion is more limiting than the reducing sort of these materials, we really would like to explore that in more detail in the future.

BAHR: OK. Thanks for that clarification. Then looking at the picture of the damaged canister from the drop test...

JARRELL: Yes.

BAHR: I guess my question is that what you've demonstrated is short-term confinement, but would you send something like that on to a repository? Or would the material need to be repackaged eventually after that?

JARRELL: So, I think with any -- if we ever had a real accident with fuel, I think we would do all stop and reassess. I will say that those skirts were designed to be basically cut off and the package itself could be used in a waste package with those skirts taking all the energy.

In reality, if we drop one of these things I think we would have some significant different questions. Everybody would stop, we'd reassess and think about those questions. But, you know, as part of that...

BAHR: It's showing the side damage, too, so you couldn't cut that off.

JARRELL: Right. Yes, right. So, you'd have to figure out what you want to do. Again, this is making sure that it maintains confinement or containment in the worst sort of

scenarios, if you have a really, really bad day and you have one of these events, I think you'd be very happy that the canister held and then you'd have that discussion, OK, how do we recover.

BAHR: OK. Thanks. Questions from the Board, Paul?

TURINSKY: Turinsky, Board. Josh, what do you have to do between now and being able to actually load the ATR fuel into these in regard to experiments, testing, licensing, et cetera?

JARRELL: Yes.

TURINSKY: And then also, the next step, transportation?

JARRELL: Right. So, Mike will talk about some of the ATR, aluminum clad questions. So, I'll be honest if I ever going to load a canister tomorrow, I wouldn't pick ATR fuel. And it has to do with the performance of aluminum.

We think we're pretty -- we're on our path, the path, to making sure we're confident on the way it performs but I have in that 603 facility lots of other fuel that's much more robust and has a better history.

So if I was going to load a canister today to support ATR, I'd probably pick Peach Bottom or Fort Saint Vrain or something that I know that has a reactivity issues that ATR might have and would still free up space in the 603 facility for ATR while I finalize, you know, or the EM work finalizes related to how it performed over time and some of the corrosion questions.

And, honestly, the poison are still an outstanding kind of question. Yes, we've done some initial criticality but one of the things is without knowing the repository environment, you know, if I pick the most reactive fuel and put it into a sealed system, am I going to potentially jeopardize it. So, again, I think I would pick the easier ones to start with.

TURINSKY: OK. But having picked something else, what -- let's say you've picked an easier one. What do you have to do?

JARRELL: Oh, yes, the steps. Yes. Yes, sure. So, you know, this fuel is at INL, basically in DOE space. We could basically evaluate in DOE space, basically. You don't have to go through a 72 NRC license, for example. You just do evaluation based on the safety basis at our site.

And you would do the evaluation. You finalize the design. You go through the safety calcs. And, hopefully, you'd find out, yes, there's no issues here. Then you go out to a vendor and say, hey, I want you to build this. Go build it.

Go out to a different vendor potentially and say, hey, I want you to design the storage cask for our system. Here is the performance spec. We'd like it to look a lot like your other systems, maybe one that has a Part 71 cert so that I can transport it later on, and I can get into that space relatively easily.

And that would be kind of a step wise process that you'd want to do. We'd also have to do some technology development to finalize, again, the weld technology, the NDE. Again, if you're on a hot cell, if you're going to do this remotely, then how do, you know the NDE welds? Yes. I guess that's probably the big one, big steps. I don't know if that quite answered your question.

TURINSKY: It's really, other than the weld issue, we have no outstanding issues with the canister or basket that require some physical testing?

JARRELL: I don't think for -- so, I don't think so. I mean we've done a lot of work on this system. You know, we'd have to do the structural analysis. Everything that we've seen on the structural side has really been, you know shown that our models really agreed well with how the canister performed when we previously dropped it.

Again, I would have to, you know, go to our -- whoever ends up certifying the package to confirm that. But we've -- this is a fairly robust package that's gone through quite a

bit of analyses. I really think that at least where we picked the low reactivity sort of system, I think we'd be in pretty good shape.

TURINSKY: What's preventing you from moving ahead?

JARRELL: Funding? I mean, you know, I think we have, I mean all of this were near to be done before we said we're ready to pull the trigger.

And I think with some of the work that NE has provided funding for, that EM has provided funding for over the last couple of years, we've got to the point now where I think we have a pretty straightforward path to loading a package, for example, if we decide you know we have funding to load it. I really think it would be a pretty, for like tactical effective would be some small things but no showstopper by any means.

BAHR: Bahr from the Board. Just to follow up on that. If you have the funding in hand, how long would it take to complete those steps?

JARRELL: If you gave me money tomorrow and I will have to let a contract, you know, my personal goal, right. If I had all the money in the world, I'd say you could load this by, in the next three years maybe.

BAHR: Three years?

JARRELL: Yes. I mean the thing is you need to finalize the design, go through the certs, work with the industry and the vendors to come up with the concept. But, again, a lot of this stuff we've done with canisters is not groundbreaking.

We've had experience loading these sort of canisters. For example, West Valley has high-level waste cans that are 24-inch cans, NAC did a system where they loaded the cans, put it on a pad. I mean it looks -- I stole a picture from the West Valley here.

I meant there's concepts that have already been done out there. So, I really, you know, aggressively three years if

you gave me the money tomorrow, maybe five years to hedge my bets a little bit.

BAHR: OK. Thanks. Dr. Peddicord?

PEDDICORD: Peddicord from Board. So, other things on that horizon out there, so coming down the road we hope there's a virtual test reactor and things like that. Are you kind of at the table or taken a peek of what they're thinking about and how their concepts in terms of fuel match up with the standardized canister?

JARRELL: Yes. We really haven't worked on that too much. I mean we're involved in the kind of the, let's call this the CD-1 sort of level. As far as detailed evaluation on how it would merge with the standard canister, we have not done those analyses yet.

PEDDICORD: But hopefully, have a good look so they don't end up with something...

JARRELL: Absolutely. I mean I will say that, you know, at INL we're hoping that we're going to deploy a number of different reactors. And so, with any of those reactors, we're considering the backend when we're starting, so VTR is one of those options that we're having those discussions about.

BAHR: Other questions from Board members? Staff? Nigel?

MOTE: Nigel Mote, Board staff. You focused on criticality.

JARRELL: Yes.

MOTE: In the commercial world, the reason are both economics, the technical reason that the canister vendors have stayed away from borated stainless steel is because you need more of it and the thermal conductivity is lower.

JARRELL: That's right.

MOTE: So, what? Are you anywhere close to a thermal limit on...?

JARRELL: These things are freezing cold compared to commercial, so.

MOTE: Even the ATR fuel?

JARRELL: The ATR fuel, the hottest one we can come up with that would ever show up with this facility would be 100 watts per element. So, if you had 10, you know, you're a -- the package itself could maybe be three kilowatts on a really, really, really hot day.

MOTE: Yes, OK.

JARRELL: Which is one and a half elements from a commercial space. So, you're way, way different thermal.

MOTE: OK. Kind of have a follow up. You showed a diagram of the concept for disposal at Yucca Mountain which was a standard canister in the center, with five waste packages around the outside.

Then you showed with the increase to 24 inch diameter, you need to place a standardized canister in one of the outer ring which means that you're now displacing one position out of six, which means that you're multiplying the number of waste packages total. Have you looked the impact of that on a program?

JARRELL: We are in the process of developing that, doing that analysis, and we'll have a paper at Waste Management that will talk about the impacts. We haven't -- I don't have the results now.

We looked at, I mean not every waste has a spent fuel can in the middle so there's a tradeoff. You don't actually need all those holes, those slots. But we are looking at the analysis and we'll have that in March I guess at Waste Management.

MOTE: OK. Thank you.

BAHR: Dan Ogg?

OGG: Board staff. Josh, on the standardized canister, you mentioned some of the operations that would happen at CPP-603 and you've listed drying up there but you didn't talk very much about that. And given that we've been talking a lot about it here today, are there any special considerations for drying a standardized canister? Or are there any special design features that you can incorporate to sort of facilitate more complete drying during the drying process?

JARRELL: So, I will say in the 603 facility we have a conditioning or a drying station before it goes into the storage rack, so it's dried once already.

With ATR fuel and aluminum clad especially that picks up that hydrogen, we -- EM is funding work on that which Mike is going to talk about shortly. And so, we are looking at what it is going to take.

We are hoping that we pick some other fuel forms that don't have some of those hydrogen uptake issues that potentially that our conditioning station would be enough. But that's

one of those technology, we probably do small demonstrations of the different technologies over the next year, kind of small things to prepare for the full blown one whenever we get the funds.

BAHR: Are there questions from the staff? Bret?

LESLIE: Bret Leslie, Board staff. How much time is going to be needed to package this stuff at Idaho already? And, you know, Ned is not here to talk about the high burn-up demonstration cask. So, once you start your process, the CPP-603 is going to be used full time. How is DOE as a larger entity? Have you guys thought about that?

JARRELL: Well, I'm sure some at the DOE has. But, you know, as the nuclear engineer for INL, how the different throughputs and processes are going to play out? You know, it's hard for me to tell.

You know what? I will just say we realize that 603 is a legacy facility that has other missions, and that's one of the reasons we looked at that ATR4 basket design to maximize

throughput. But as far as kind of how they fall out over the coming years, that's kind of outside my pay grade.

BAHR: Any other questions, Bret?

LESLIE: It's a follow up to Paul's question and your response which was the finalizing the NDE and the welds. How difficult of a task is that, because you're doing it in the confines of that facility? And you just said something about doing small scale stuff, so can you give us a little more...

JARRELL: Yes. For the welding. So, remote welding in this facility, I do not think it's going to be that challenging. We did some work at INL in the early 2000s where we did, we actually did a lot of these remote welding sort of thing and grinding out. And we did in the late 2000s a lot of waste package closure stuff with basically remote welding capabilities.

So, again, the welding I don't think is going to be all that challenging. Remote NDE is maybe a little bit more

challenging. It's really hard to PT something with a robot arm. And so, we just need to basically finalize the NDE approach that we would take. Again, that's why we would kind of to start small sort of thing to see what we can and can't do with, in that remote environment.

LESLIE: Thank you.

BAHR: OK. Yes. I think we're just about at time, so, thank you very much, Josh. And we'll move on to Mike Connolly, also from Idaho National Lab from the EM side to talk more specifically about the aluminum clad fuel and the -- and research on its dry storage.

CONNOLLY: Good afternoon and thanks for the opportunity to present to the Board on this DOE-EM sponsored research. I'm looking at how does aluminum fuel behave in dry storage?

So, it's a program actually that's been underway now for three and a half years or so, so I'll kind of walk through the activities. And I do need to stress that the results that I show are preliminary results, so I don't think we

want to cry wolf or claim success based on what we're going to show. But at least, start to show that we're starting to understand what some of the issues and problems are, and how to look at it in a graded and systematic focus kind of approach, so moving on here.

So, what I'm going to do is I'm going to run through a quick description even though I know Bret talked a little bit about it, but there are some other nuances I think that's important to understand with primarily what we're looking at which we believe are the worst actors which is research test reactor fuel.

I'll walk through why we think that's the case and why we use the ATR right now as kind of a benchmark the same way that the repository did. I'll talk a little bit about what we've done to identify knowledge and technical gaps associated with these items, how they maybe are similar to what the Board presented.

And Bret captured that a little bit earlier. I'll talk a little bit about what we're doing in the EM funded activity

world and this is -- we have, we're actually in our third year in this project, so we've had three years. Well, hopefully, we'll receive FY20 funding and we'll have our third year of funding. Then I'll talk about where we're going, what we need to do in the future.

Before we get going with this, I want to make sure everybody understands that we've put together a fairly strong group to look at this problem. So, Idaho National Lab, Savannah River, those are the two sites that actually have fuel remaining aluminum fuel that's in either wet and or dry storage, so there's been a lot of -- there's a lot of subject matter expertise that resides to both of those sites associated with those materials.

The University of South Carolina, the reason we have the University of South Carolina on our team is they were previously funded through the NE program through an IRP. You heard what IRPs are earlier today, specifically to look at fuel drying of commercial fuel.

We had HOLTEC on our team because HOLTEC owns intellectual property on one of the drying technologies, forced gas dehydration, which we want to evaluate, so we got them on the team. And then, Fluor Idaho is our support contractor on the ICP on the EM side at the Idaho site. So, all of those facilities and where we have our materials are stored in their facilities.

We do get a lot of support from both the Environmental Management and NE. They're not subject matter experts but working on the program, but they provide a lot of support and that type of stuff. And a lot of what we're doing in our program is developing information to support EM and NE decision-making.

So, at the end of the day, that's really important to understand. It doesn't mean that we're going to move forward with dry storage. What it means is we're evaluating is it a viable option. And how does that weigh against treating it at H-Canyon or treating it in some other process, right? So, it's really designed, first and

foremost, to be about decision-making. And then, hopefully, we move on from there.

And then we have a lot of the individual contributors, so I'm kind of the program, I'm the program lead now, I'm kind of the mouthpiece sometimes. I'm certainly not the subject matter expert, so if you started asking me details about how we did modeling and discretization, all those types of things, well, I'll cry uncle and we'll defer those types of questions off to somebody else.

So, what are we talking about here? A lot of the -- a lot of the fuel was, as Bret pointed out, is highly enriched, the ATR reactor it's 93% enriched. What we end up with is we have these types of fuels. They're typically plate fuels, right, as opposed to like you saw with the SPR, a cylindrical fuel type.

Majority of what we're talking about are plate fuels and that brings up a couple of things that are fundamentally different. If you compare the surface area of these, say, think the ATR fuel, put it in a standard canister. These

are one eighth basket, so we have 30 elements, that has about 125 square centimeters of surface area compared to an MCL that has four square centimeters of surface area.

So, just the surface area in itself is a huge, is a huge difference. And then when you get into how things behave in the reactor, that's also quite a bit different, too. And I'll talk a little bit about that in a second.

You heard a little bit about these surface hydroxides and oxyhydroxides. There are aluminum plates, right. So, we had the hydroxides which are the gibbsite and the bayerite. We have the oxyhydroxide which is boehmite. Collectively, I'm going to continue to refer these things as a hydrated oxide layer, right. And some mishmash of stuff and we'll go through that a little bit as we're going through.

So what do we have? We have water, right. How much water do we have there? Well, we have some free water, physisorbed water, chemisorbed water, I'll come back and talk about those. And then we have to worry about

radiolytic gas generation; not only hydrogen but other species.

If, for example, you're in an environment that's not sealed storage but like the 603 facility where it's air storage, what other types of radiolysis chemistry do you have and what are they generating inside that canister? Does that create a problem for structural integrity to the fuel element? So, we'll come back and talk about that.

These are just kind of physical characteristics. The susceptibility to corrosion is really the important one. The other important one is the lower melting temperature, right, 500, 530 degrees thereabouts is the melting temperature.

But the alloy itself goes through a bunch of phase changes when you start to get around 250 degrees. So while we're looking at trying to figure out how to drive these things, we have to be cognizant of what happens with the alloy and what happens with the structural integrity as you start to heat these elements up too high.

So, I talked a little bit about cladding surface area. The cladding, these things have extremely thin cladding. The cladding on the ATR element which is over here and here is about .38 millimeters. But what they're trying to do is maximize neutron density, right, neutron production.

Go to really thin cladding and you put it in to a plate configuration like the ATR. So, here's an end-box on the ATR, here's the element. Again, down here is the cross-section. So, we have 19 plates - they have lots of channels.

We have lots of potential for things to happen inside those channels, inside the reactor that sets up an initial state condition for something you're not going to move into a water storage. They then move from water storage into dry storage.

So, it's a coupled problem we're trying to understand, but the first thing you need to understand is what's the initial

state condition? How is that -- what it's look like when it comes out of the reactor? And how do we know?

And then we have the extreme behavior inside the reactor, conditions that sees high temperatures on the surface, an erosion-corrosion phenomena, a bunch of things that can takes place.

So what are the issues? The first thing we had to look at is in-reactor effects on cladding. I just threw up here over here. This is neutron flux density as a position of axial -- it's a function of axial positioning on one of the elements or plates inside the ATR reactor.

You can see there is a significant difference in flux which also drives a significant difference in temperature, which will drives a significant difference in temperature profile across those thin films. And those thin films have to do things.

We pre-treat the ATR reactor fuel. Most of the reactor fuel that goes into the research test reactors as pre-treated.

You put down a few microns of boehmite, so now you got an oxide surface - it's very stable. Well, things happened to that oxide surface and we have a really good idea what happens.

So there's HFIR. There's been studies on for decades on how these fuels behave, how do we make the fuels better. So, we have a really good understanding of what's going on but that creates kind of initial state. We take it from there and now we get into water storage so this is the 666 space at Idaho, very well-controlled water chemistry. And you heard water chemistry is a big issue with this.

It's not K-basin, OK. You don't have soil sludge. You don't have iron oxides. You don't have all the types of things in there. It's very clean, right. We control that chemistry very well. And what you end up is you end up with this layer down here. This is what we're calling the hydrated layer.

So, it could be some combination. Maybe you have pseudo-boehmite, maybe you have boehmite, maybe you have gibbsite,

maybe have bayerite. You have some combination. How was thing going to behave both radiolytically, from the radiolysis perspective, and from the chemical perspective? What's the thermodynamics and kinetics of that layer? How it's going to behave? How do we affect it by drying?

So, while we're talking about affecting stuff, over here this is the classic phase diagram or phase changes found from the Alcoa report. So we're looking at boehmite, bayerite, gibbsite. And somewhere in here, we get some phase transformation up to about 200 degrees, maybe 250.

This is the kind of the temperature limit that we think we're going to be looking at. So, this just gives you some of the ideas. So, what we're going to do and trying to do is understand what's all the chemistry that's taking place over here? How does it affect storage?

So we started -- this all started back in April of 2016 when the department, the Office of Nuclear Engineering at Idaho recognized that there was potential shortage of storage space in the 603 facility. Once we moved everything that

was in wet storage, the existing wet storage at the time, the 603 facility was going to be full.

They went to -- they went to the Office of Naval Reactors and said, "Hey, how about we do joint dry fuel, dry fuel storage at the NRF?" They said that's a great idea. Just answer these questions for me. Well, Lance received those questions and he came to me and said, "Can you answer these questions?" And I said, "probably not."

And that started putting -- that led to the DOE spent nuclear fuel work group putting together a subgroup to go off and study this issue. So what did they do? We evaluated the existing and planned storage system. So what are those existing and planned storage systems? The 603 facility Josh talked about. It is an air storage facility. These are vented canisters, right.

The MCO. The DOE standardized canister. Those are the three things that we looked at. And we also looked at the advanced technology program at Savannah River because that

was their program that they were using to look at how it's going to behave.

We evaluated these technical engineering studies that started, went back to 1950s. So people have been looking at how do these things behave especially in the reactor. But you see, you see the scare stories all the time. Oh, my god, look at this piece. Look at this piece of aluminum fuel.

You know, Bret was kind enough to show us one that didn't look very good. He didn't show us when that looked really nice. OK. So, I'll point that out. There's a lot of these scare things that are out there but there's also a lot of fuel that looks really good. And we'll come back and we'll show you some of the stuff we looked at.

So what are those -- so what did the department do? So they issued this report, June of 2017, so it took about a year to do this study. We put a team together that was Oak Ridge, INL, Savannah River, other players but primarily dominated by them.

They identified these five areas. I mentioned this before, chemistry and behavior of hydrated oxide layer. What's the thermodynamics and kinetics of this layer? How those transformations take place? How does it dehydrate? What's all the types of stuff that happened? Do you form pseudo-boehmite and then it converts. And now I'll come back to this and some of the modeling stuff that you'll see what we're going to talk about.

Radiolytic gas generation data, there's all kinds of gas generation. Not all kinds but there's gas generation data out there for both powders, and Savannah River has looked at that bulk powders before. But we're not talking about bulk powder. We're talking about a thin film. We're talking about microns of some things sitting on aluminum substrate. So what's the radiolytic properties of those things? And how does it differ? How do we understand that?

And this is tied specifically to the 603 facility. How does this breathing thing? All right. So, if you look at temperatures or functions of time, you know, the days or

years or months, all that type of stuff the facilities breathes. And you bring humidity in, you get some freezing, and all these types happen. So how do you couple that in?

And then, how is this stuff actually performing? How will we go get some of this stuff and look at it? We've had fuel in dry storage in Idaho for 22 years. How about we go get some and take a look at it, that had never actually been done.

You know we have lots of fuel at the Savannah River between the two places. We have about 10-metric tons. There is three to seven or eight thereabouts in Savannah River and about two or two and a half or something like that in Idaho. And we're generating about 100 kgs a year, that's a 100 element thing.

And then centered to the whole thing is what happens when you try to dry in higher temperatures, greater than 100C? Why do we choose 100C? Josh mentioned the fuel conditioning station that we have right now as part of 603 facility. We

currently dry fuel before it goes into that facility at 100C.

The MCOs dried it cold. So we already had two benchmarks. So we don't really need to look at that, we want to go higher. We know from thermodynamic studies and those changes and those phases that we need to be above 100. So that's what we're going to go look at.

The report, the DOE Report, the 1575 Report recommended going off and doing a little bit of an action plan. Basically, here's the problems. Now, how do we go about resolving? Put together a different team. Now the team is more subject matter experts, material science, chemist people, radiation chemist types and all that type of stuff.

OK. Guys, take this stuff and go back with a recommendation. The recommendation that came back was a multi-year program based on laboratory studies coupled with modeling and simulation. If we're going to predict the behavior, how do these things happen, we need to have a

model. OK. We need to inform that model with our laboratory studies and other things.

So, the action plan identified six tasks. These are the six tasks. So, the first one is what is the thermodynamics and kinetics of these, of transformations that take place in this layer as it dehydrates, as it transforms from, let's say, bayerite to gibbsite or bayerite to boehmite.

What happens in that? What temperature you need to get to? How long do you need to hold it? That type of stuff if you're going to do drying in higher temperature, you need to be able to inform that drying at higher temperature.

We need to understand the radiolytic behavior, gas generation behavior of the films as opposed to the bulk material. We have to come up, we have to develop a model for both sealed and vented systems. With the 603 facility, the question is different, right. It's not about are we going to build up pressure. We're not, it's vented.

The question becomes around am I going to impact structural integrity of the fuel? Is there some corrosive gas that I'm going to build up that's going to continue to eat away at the aluminum, or is the aluminum going to continue to corrode over the next 50 years, so now I go to pick it up and do something with it in the future, put it in our standard canister and have a handling issue. So it's more looking at that question. And then the response to drying, and then the surrogate sample preparation.

So all of these experiments are being done for the most part with cold surrogate materials. We simply cannot afford to do these things on real fuel, so we have to make sure that our surrogate, the way we develop these surrogates are really representative of what you see with this coupled problem. It's not going in the reactors, it's not going to see those extreme environments, it's not going to have the erosion, corrosion thing happening in the reactor.

And as Bret pointed out, we actually have funding from the EM Office of Technology Development to support this and we're in our third year of funding to the program.

This is just a notional chart to show what do we need to do to get to what -- what do we think we need to do to get the road ready dry storage. I don't want to spend a whole lot of time on this, but basically step one, identify problem, we've done it. That's pretty straightforward, but it took a year to do it.

Step two is let's put some laboratory studies in place, surrogate studies, PIE to validate the surrogates. Let's look at some real samples on how does it compare back what we've made with our surrogate materials, develop a model, start some drying studies. We have advanced somewhat into stage three in that we've been developing an instrumented lid that we could then put on to a DOE standardized canister.

So if we're going to go to the point where we're going to do an instrumented canister demo, we need to have a lid so we can actually do the experiments. Similar to, you heard the problem with the MCO, after they collected four or five samples they couldn't collect any more, so we've already

started that part of the step. And then Josh is looking through his program of how would we actually go about loading the DOE standardized canister using the existing infrastructure in Idaho.

So we're coupling these things together. So we have about \$10 million so far on the multi-year funding to address these issues.

First, I want to touch on is the chemistry and reactivity of hydrated oxide. Again, these are a combination of modeling and experiments looking at thermodynamics and kinetics. So some advanced thermodynamics modeling, updating some of the old diagrams that were done, phase diagrams, I'm not going to throw a bunch phase diagrams up here, higher temperature studies to support fuel drying.

If you look at this work over here and this is the result of some Savannah River Laboratory directed research and development work this year working in conjunction with Professor Travis Knight at USC.

If you look at this basically -- so they created this thin film on a metal surface and they subject it to drying 5 degree C per minute and right in here, you see in this temperature range between 220 degrees and 260 degrees, you see the greatest amount of mass loss. There's a fairly rapid amount of mass loss when you get into this temperature range.

This is something that we really need to understand because when we go to design these drying experiments that I'll talk about in a minute, we need to understand how do we do this? What temperature do we need to go and how long do we need to hold it, all that type of stuff. So understanding this stuff on a lab scale is going to help us inform the larger scale experiments.

So the weight loss is due to dehydration and this is an important piece and we'll come back to it in the modeling that I'll show you that. Radiolytic gas generation characterization, so what we tried to do is to do pre-filmed substrates.

We're doing radiations with cobalt irradiator, so we have irradiators at Savannah River, we have irradiators at Idaho. We have irradiators in University of Notre Dame. So we're doing irradiations in three different places depending upon what we're trying to accomplish. We do heated ones in one place and higher dose rate ones at another place, all that type of stuff.

And now, I want to point this out too, because this is something that if you look at the MCOs at Hanford, not only do they assume that their corrosion layer has a combination of stuff, it's iron oxide, it's these aluminum oxides and it's also uranium oxides. In our particular case, we're focused strictly on aluminum oxides.

We don't have the iron, we don't have the sludge in the basins, we don't have uranium metal fuels, we don't have highly breached fuel, all those things run down the list and says, yes, we really only have to worry about this aluminum.

They also look at, we only considered gamma radiation. We don't consider beta or alpha. In their particular case, the

way they distribute the alpha -- or I'm sorry the gamma is different than what we do and they also consider contributions from beta which we do not do. So what do we know? Well, they promote the formation of hydrogen, I'll talk about that in a second and the G-values appear to be dependent upon gas composition. I'll talk about that too.

So over here, these are just generation curves for hydrogen gas as a function of absorbed dose. To give you an example, an average loaded standard canister is about 1,500 kilograys per year. So our dose rates out here are getting to about 1,000. So that's kind of the dose rates that we're using. You take this nice information, so we can see there's a significant difference between nitrogen and argon and there's also a slight dependence upon humidity.

So if you look them over here in the table, you can see the argon maximum value is at 1.9, the nitrogen ones are about 0.8, so it's about a factor of 2 difference. And these, we average all these -- we average these numbers together, in our modeling work we're using an average G-value of 1.6, in the MCOs, they use a G-value of 0.2.

Modeling and simulation, I'm not a modeler OK, so bear with me on as I try to explain this thing. So it's a CFD based model but it incorporates reactive chemistry. Not only it incorporates chemistry from the gas phase and also chemistry from the solid phase with the radiolysis of the thin films.

So we have thermal convection and mass transport inside a canister. We have gas production kinetics of aluminum oxyhydroxide, the hydrated oxide layer. We have bulk phase, gas phase radiolysis reactions and then we have these heat exchanges and this is really on the 603 facility.

We started with the Wittman and Hanson model for radiolysis that, PNNL did it and they published it in 2015. So we take that complete reaction set which is this spaghetti pile over here and we reduce that down through some sensitivity studies using another program called Cantera. So all this work is done, the STAR CCM and then we coupled it with Cantera to do chemical reaction modeling and then use radiolysis models from PNNL, couple it all together. And so you have these two different reaction sets.

So we're going from 40 species, 115 reactions down to 8 species and 22. And then we have 5 thermal zones inside the DOE standardized canister that we do chemistry in. So it's a fairly complex model. It runs on 720 processors, so when we run this model then the time steps out to 50 years.

So it started out with basically a fuel scale model that scaled up to a canister scale model. And in the case of the 603 facility, then goes to the facility model. I'm not going to talk, I'm not going to show results of modeling on the 603 facility. I'm strictly going to stick with the canister because that wasn't really the focus of what we want to do.

What does a model look like? Josh showed us a little bit. So our sealed canister which is the DOE-standard canister. It's a Type 1a basket, so 10 elements from a symmetry perspective, you only have to worry about looking at half and this is the 603 has more elements in it and we could have 24 elements in a 603 canister. So the center line temperature is a little bit different than what you would

get in here. And this kind of shows center line temperatures.

So low wattage, Josh touched on this, so we can move elements out of the ATR canal over to the 603 dry storage facility when they reach less than 100 watts. That's because it's a transportation cask limit. So we ran four levels, 6 watts, 18 watts, 42 watts and 67 watts. The 67 watts would be you have 30 elements in a standardized canister, so that's 2,000 watts.

The average of what we typically do our stuff on is 18 watts. It takes about, for an ATR element, eight or nine years on average to get to 18 watts. Most of the stuff we have in the 603 facility is very old, so it's going to be fairly cool stuff.

Bottom line here is the center line temperature, this temperature right here in the fuel element in the center, maximum gets up to about 100 degree C, average case is about 45, it's pretty cold as Josh was indicating. These are velocities, I'm not going to get into the velocity piece.

So what are we seeing for preliminary results? In all cases, even low heat, we see 4% hydrogen. That's what these graphs are showing and I'll come back and talk about these in some detail, but we exceed 4%.

It also gets very small amounts of nitric acid, especially when we consider a case of 1% residual air left in the canister, because that drives some of those radiolysis reactions. So if you look at this, these are little complicated over here, but basically looking at a range of things where we have thickness of the film, water content and heat load, so that's what these parameters are standing for, so low key was heat load, low thickness is the film.

The standard case that we're on 18 watts, 10 microns film thickness and I'll come back and talk about that in a second and 1% relative humidity. That's our base case, so that's what we're looking at here and these are just showing different -- so this is showing hydrogen concentration, so it gets up to about 40% in worst case, pressure 3.5 microns.

If you jump over here, this is showing pressure in the canister as a function of the thickness of that hydrated aluminum oxide layer, OK, 32 microns is the biggest case. We don't think we'll ever see things at 32 microns and I'll show you why. But if you look at 10 or something like that, you're down to about 3 atmospheres. You see this, there's a pressure spike right here. That's assuming thermal dehydration of pseudo boehmite.

If we go through a drying program and we convert that pseudo boehmite to something else, we're going to get rid of that, of that pressure spike which means all these things would drop down.

This is just looking at nitric acid. This is the hydrogen concentration, it's a function of layer thickness. So when we do these G-values, we're actually correcting the G-value so that we're correcting it for absorption into that thin film. So once you have that correction done, now it's a linear scaling with film thickness, it's going to become very straight forward.

Next piece, characterization of stored aluminum fuel. So we wanted to investigate how is this stuff behaving, what do we actually know and how does it help us inform to some of the other parts of the experiments that we're coupling. What's the real thickness of these layers, what's the composition of the layers look like, that type of stuff.

So we started out with end-boxes, right, had a picture of an end-box earlier, so this is an ATR end-box. We cut those off before they go into dry storage and then they look like this when they go to dry storage, cut the end-boxes off simply for height, so we can get two elevations into the 603 canister.

And this is plate 19, so the ATR elements are 48 inches long, thereabouts, 49.5, that's plate 19. So we took this ATR end-box, we took some pieces of it, we cut these off in the ATR canal and there's a collection of them in the canal so we got some. We cut them into little pieces and we did SEM and XRD.

On this one, we actually built a scraping device and we scraped the layers off including a small amount of the aluminum and then even we collected the scrapings, so there is the end-box piece. And then at Savannah River, the Uruguay RU-1 reactor, these were in dry storage for some number of years, like close to 40. The Mark-16b, universal sleeve housing and the MURR, these are all structural components, but they've all been inside the reactor. So we have samples of these things all analyzed except for this one. That's what's on the next page.

So RU-1, 30 years in dry storage, in the reactor 70 degrees, gives all this, what did we find out? Well, we have some gibbsite on top of maybe some boehmite, film thickness nanometers to about 25 microns. So it's that layered structure again, boehmite with some tri-hydroxide.

Missouri University Research Reactor, 18 years wet storage, what do we have? Bayerite, boehmite 5 to 10 microns thick. Universal sleeve housing, 40 years wet storage. What do we have? Boehmite, bayerite, hard to pick out how thick the

film is, so therefore it's pretty thin. Mark-16b, 40 years wet storage, bayerite, boehmite and possibly some gibbsite.

It's back again to what I showed in that early-on picture. So base on chemistry that we thought should happen is actually happening and the layers are really not that bad. That's why I said the 32 microns is the upper limit and the way they come up with 32 microns is kind of complex. It has to do with ATR, but that's where the 32 microns comes from.

So what do we get so in the end-boxes? Same type of thing, 2 to 5 microns boehmite and we don't have the data back yet for the scraping. The scrapings is going to be probably one of the center pieces because it's actually a fuel element as opposed to a structural component of a fuel element. It's just we don't have the analysis back yet.

All right, so now we're going to move on to where we're at with planning for the hydrated oxide drying stuff. This has been deliberately delayed till the end because we needed to inform this engineering scale experiment, in this particular

case we're taking a one-third height standard canister to one elevation.

We're making surrogate. We're making these mock surrogate elements that are going in this, we'll have 10 of these elements in there. We needed to inform this with our modeling, so now we have a CFD based model that's been developed by the University of South Carolina for how to design this experiment, how we think this experiment is going to work.

They actually are looking at some other thermal models to describe the dehydration that's taking place. I showed you the results from the Savannah River LDRD in collaboration with Savannah River, so they're developing that model which is going to help inform us how we do our drying, what temperature we need to go and how long do we hold it, that type of stuff.

And now we've come up with a way based on what we've been doing to develop these laboratory surrogates, how to make these on a larger scale. So this is a single plate inside

of this element, so we have 20 of these things. These are about 12 inches. Each one of these is 12 inches divided by space, 12 inches divided by space, right?

So we will have three of these oxide plates per element and we'll have 4 elements per 10 in here that have the chemistry. The rest are for about flow and temperature measurements and all that type of stuff that we need to do. We have a CFD based model that is actually helping us design these. And then we have our chamber with a bunch of ports and other things for observation.

These experiments are just currently being designed, so we're in the middle of making these, we're fabricating this, we're fabricating these elements. So that's kind of our approach to doing our drying experiment, but it's fully informed by everything we've done with all the other steps.

So what have we done? Well, we've identified some knowledge and technical gaps. We put a very focused and collaborative program in place, a multi-year program to address them.

We're starting to collect some preliminary information that shows what we're seeing is what we expect to see.

We thought we'd see this kind of bilayer type stuff or trilayer type stuff. That's what we're seeing. The thicknesses are about what you predict to see based on modeling and all these -- the backup stuff is the reports that we're putting out, so you can look at the back-up size and we'll get these little slides.

The critical piece here is that we've got to have this multi-physics model. The only way we get to predict 50 years, 100 years is by the model. The model has to be accurate, the model needs to be informed.

We have some follow-on studies we need to do. We have some hydrated oxide radiolysis experiments we need to do. We need to go understand is it something with our sample preparation or is there actually a difference between argon, nitrogen and helium because we have backfill with helium, so now we're going to go look at helium and we're going to try to understand what's going on within that reaction set.

We're also going to take some sample, probably the RU-1 sample. I'll speak for Savannah River, but we may be taking the RU-1 sample, cut a piece of it off and put it into a gamma irradiator and see how it performs.

And then once we do the drying studies, we'll have some of those large scale samples and we'll take some of those samples, cut them up and put them into the irradiator. OK, so we're doing that. We got some additional experiments that we want to do on the thermodynamics and kinetics of these layers. We need to complete the characterization of the ATR SNF stuff, the scrapings.

We need to complete our drying studies. And then based on all that, that all gets fed back into updating and refining the model. The model has been primarily used to address and look at ATR. We're going to start modeling other configurations. You showed, Josh showed the other configurations.

We're doing 10. Now, maybe we need to do 20. We have to look at what's that center line temperature, how does that drive chemistry, is it a good thing or a bad thing. We need to look at some Savannah River specific configurations on fuel, how they would package it and what the fuel elements look like, what this stuff look like, OK, anyway.

Questions?

BAHR: Thanks. Bahr, from the Board. So if I understand correctly you're using mock ATR elements in your drying experiments, not actual fuel elements, is that correct?

CONNOLLY: Yes. We looked at using dummy elements, dummy ATR elements and there's a couple of reasons we backed away from them. Cost, number one, they're very expensive. And number two, it's really hard to get all of the, I'll say the temperature measurement systems and everything else that we need inside that element as they come from the vendor. Because the way we design these is so that you can actually thermocouples in when you need thermocouples in and make flow measurements, we're going to make flow measurements.

BAHR: So if a large part of the water is chemisorbed or physisorbed but you're not using the actual materials, how, are you confident that your results are going to actually reflect the response of the water in real fuel elements when you're using surrogates?

CONNOLLY: I honestly don't think it's going to really make any difference. What's important is that we need to get certain temperatures and center line at different locations within the element itself. So the way Professor Knight and others have designed this experiment and the surrogate elements is so that you can make temperature measurements at the place that CFD model was showing we need to make temperature measurements. So we'll make some temperature...

BAHR: So you're just making temperature measurements, you're not actually looking at how much water remains at the end of this?

CONNOLLY: We're going to analyze if I go back, so we will be able to take these plates, these plates right here and we'll be able to post analysis on these layers to make sure

that if we got them to 200 degrees, do they look like what we think they should look like going to 200 degrees. So we'll be able to have like temperature measurements in these locations and then we'll be able to go back and look at do the destructive analysis, the XRD and the SEM on those levels.

BAHR: But they're not the same material that would be in the actual fuel elements.

CONNOLLY: No, they'll be surrogates, but what we've tried to do through our program is to demonstrate that the surrogates are an accurate representation of the actual fuel, because you're never going to do these experiments with fuel. For us to do on destructive analysis on an ATR fuel arm is about \$3 million to \$4 million to do one and we have -- right now, we have 2,800 of them.

BAHR: OK. Questions from other Board members, Lee Peddicord?

PEDDICORD: Lee Peddicord from the Board. So back to slide seven and eight in your presentation, and let's pick one, so here you talked about -- as I understood, you brought together a group to kind of do a bit of a deep dive on the various technical subjects and then from that emerged this program that started a year ago on January. And I think that was a timeline you were laying out in the next slide.

CONNOLLY: Yes, right. So we started till this -- I'm sorry, yes, this report. This report that we put out, our action plan, was November of '17 and we actually initiated the experiments in January of 2018.

PEDDICORD: So first of all, how long do you expect that project to last? I recall you're telling us a number of months and years.

CONNOLLY: Yes. So to finish, if I go to the last slide, if we go back to the last slide, we project having the engineering drying studies done, these experiments performed and initial report written by the end of this fiscal -- by the end September of 2020, OK? Now, that will tell us what

we need to do to update our model and all those types of things and maybe it will say, "Hey, we got some other experiments we need to do."

So all I can tell you right now is that we have funding for FY'19 and FY'20 we believe, and that should get us through the engineering scale drying studies and then hopefully we'll convince the department if we have additional experiments that we need to do in our modeling that we continue our funding to do that.

PEDDICORD: So you also anticipate bringing your group together and kind of revisiting your six task they identify and see if there's some mid-course correction?

CONNOLLY: So yes, there's always a lot of detail. We actually have biweekly conference calls with the whole team. We have been having biweekly conference calls since we started the project. And then we have -- we probably try to get together two, three times a year as a group, so we'll have the continuous feedback.

So for example on the radiolysis studies, so we're doing work in Notre Dame, we're doing work at Idaho, we're doing work at Savannah River, that sub-team talks all the time. All of the team members talk at least biweekly.

PEDDICORD: OK. Then you talked about some of the materials and fuels that you're looking at. I believe the oldest fuel you showed us was your Uruguayan, fuel 30 years old, some components 40 years old, do those -- does that represent the oldest fuel in the inventory? You must have some stuff that goes way back, some of the samples...

CONNOLLY: Well some of the wet storage stuff is 40 years. We started dried storage in Idaho in 1997, we started moving fuel in the dry storage. So our oldest stuff which are the elements we went after, so we did three elements when we did the scraping on plate 19 and those have been in dry storage for about 22 years.

PEDDICORD: And in that inventory, do you have any failed fuel?

CONNOLLY: We have -- currently, we have one what we consider to be breached fuel element in the 603 facility, that was identified as a leaker in the ATR reactor. We have another one that was identified as a leaker in the ATR reactor that's been in the ATR canal for 20 years now. It is moving into dry storage before Christmas.

PEDDICORD: OK.

CONNOLLY: So, we'll only have two what we identified as leakers. So when I said we don't have breached fuel, Idaho's fuel is actually in very good condition in terms of not being breached in that type of stuff. Pinhole and breaching are two completely different things, right?

PEDDICORD: Yes.

CONNOLLY: That's why we say we don't have to worry about uranium chemistry, that type of stuff. I think the estimate from Savannah River is they have about 7%, Bob, of the fuel might be...

SINDELAR: Bob Sindelar, Savannah River National Laboratory. In the mid-'90s, late '90s, 2000, we did an evaluation, me and somebody from our spent fuel project engineering organization, evaluated the foreign research reactor fuel that we're bringing back to Savannah River.

And in contrast to ATR, you've just heard Mike say we had two leakers. We estimated based on visual some test, information, about 7% of, at that time there was like 1,500 assemblies that were on site visit trips and 7% of those were declared to be - likely to be have through clad penetrations, again, pitting.

So it's a finite exposure of fuel core meat. And, we can go on a tangent there with what the contrast of that - with its metallurgical connection the claddings was really not that significant other than it will slowly release cesium from that configuration. But so, yes, 7% through clad from pitting.

PEDDICORD: Also, Peddicord from the Board. But is there any motivation - recognizing the cost, you talked about

working with actual fuel of trying to look at some of those that have failed in - there's lots of different failure mechanisms I assume, the degree of failure, of looking in more depth at some of those and see if there are implications from the failures that relate then to the long-term storage mission?

SINDELAR: We have under separate programs, again, back in the late 1990s took uranium aluminum alloy fuel and exposed it - this is sort of our - in our vapor corrosion testing program. So we have a lot of laboratory data, not PIE of this failed fuel. We didn't bring it to a hot cell and cut it up.

But we took DU aluminum alloy. Prototypic and metallurgical form of, I call it sort of dispersoid, you have uranium aluminide in aluminum, is the fuel core material and under corrosion conditions, it is typically a ceramic metallic structure dispersoids and you have your aluminum corrosion starts first, your dispersoids, your aluminides slowly degrade with time.

So that's sort of phenomenologically we have an understanding of how this material would corrode or it would behave in a breached configuration. So I think, on the fly here, don't know if you can follow my blathering.

But I can put together a phenomenological description, I think it's pretty accurate of how this breached - a breached core fuel would behave. And this is in water. You put it in dry. And so what would happen, I'll maybe put words in your mouth, Lee, that do we have a different hydrated oxides or oxide systems from that breached area.

Very small and I'll say insignificant. Again, it will be aluminum corrodes first. You'll have that system. Sure. You'll have, finally, your uranium oxides. But this is breach fuel. It's a very small finite and from an engineering standpoint, its impact, I'll make a statement now and I'll defend it later. It will be insignificant to affect its performance in a dry storage system.

PEDDICORD: OK. Thank you.

CONNOLLY: Yes.

PEDDICORD: If I may, Madam Chair? On slide 11 then, you're talking about as you're moving, I think into the modeling. And here, to kind of simplify the exercise, you downsized from 40 species to 8 and 150 reactions to 22.

CONNOLLY: Correct.

PEDDICORD: So, were some of those kind of bundling similar species reactions together or eliminating some or both?

CONNOLLY: No.

PEDDICORD: What was the process?

CONNOLLY: Yes. So, the lead model and what the lead modeler did in this case was to do a sensitivity study. Look at all the reactions and then keeping the ones that were actually sensitive to any change.

PEDDICORD: The dominant ones...

CONNOLLY: The dominant ones, yes.

PEDDICORD: Yes. OK. And then finally in slide 14, I'm guessing or I wondered if the wiggles are the annual variations and ambient temperatures or something there?

CONNOLLY: No. This particular case it's all on sealed - the sealed canisters.

PEDDICORD: And the ones over on the right and all.

CONNOLLY: These ones over here. Yes. What this is doing, these are variations based on a film thickness. So once we determine those G values and how we partition and how we partition the energy between the layer and the aluminum substrate, then it becomes basically just a linear function, so you can - you can scale fairly easily between 5 microns and 32 microns.

PEDDICORD: Yes. So why small line wiggle. I still don't understand.

CONNOLLY: The wiggles?

PEDDICORD: Yes.

CONNOLLY: Well, I don't know. I'd to have to ask the modeler.

PEDDICORD: Because...

CONNOLLY: Because I remember I pleaded ignorance at the beginning.

PEDDICORD: Well, they're all nice and uniform. Yes, so...

CONNOLLY: And I said, the thing that's really important to know here is this is thermal - it assumes thermal dehydration, right? So if your drying is effective at getting 75% of your - the drying - so your product is 75% then this big initial spike and pressure, you're not going to see.

PEDDICORD: That's right.

CONNOLLY: OK.

PEDDICORD: But the wiggle.

CONNOLLY: Yes. And so all these things will drop down and we will find out where the wiggle comes from. I honestly don't know.

PEDDICORD: Thank you.

CONNOLLY: I had an unsteady hand over the weekend.

PEDDICORD: Yes.

CONNOLLY: Any additional questions?

BAHR: Are there questions from the Board? Questions from the staff, Dan?

OGG: Yes. Dan Ogg, with the Board staff, wanted to explore a little bit more of your surrogate testing because I think the discussion maybe wasn't clear before.

CONNOLLY: Yes.

OGG: You've examined a number of aluminum materials that have been in the reactor and in storage. And you examined those and determined what kind of layers have built up on those materials.

CONNOLLY: That's correct.

OGG: So the oxide layers and hydroxide layers. And in designing and building your surrogate materials, are you then replicating those layers on the surrogate materials?

CONNOLLY: Yes. So if you go - yes, we are. So we can grow - we can grow a bayerite when we need to grow bayerite. So we can grow a layered structure if we need to grow a layered structure.

OGG: So then the surrogate materials that are going into your drying test very closely replicate the actual materials that you've pulled out of reactors and out of storage that have conditions very much similar to those actual...

CONNOLLY: Yes. As best we can, yes.

OGG: OK.

CONNOLLY: Yes.

OGG: Right. I just wanted to make sure that was clear.

CONNOLLY: Yes. Yes, because this is critical. If we're going to do everything based on laboratory studies, we need to make sure whatever surrogate materials we're using are representative, right? And we just - we'd love to do the other experiment when we take ATR fuel element and put all these sorts of things on it, but the Department is not willing to fund that.

BAHR: Sue Brantley.

BRANTLEY: Brantley, Board. Thank you for the talk. I tried very hard to follow the trajectory and I mean I think I understand what you're trying to do. And it's extremely ambitious to go from essentially chemical reactions on a hydrated surface that are related to aging and chemical aluminum oxide, water reactions.

CONNOLLY: Correct.

BRANTLEY: And then you're scaling it all the way up. And then at the end you have a multi-scale model or multi-physics model.

CONNOLLY: Right.

BRANTLEY: It's kind of a miracle happened along the process because I couldn't quite figure out how you put it all together. Did you show us anywhere in there where you compared model to data?

CONNOLLY: So I didn't show you but we actually do have, in the technical reports that are in the backup slides, we do actually have some benchmarking on the model for hydrogen generation yes.

BRANTLEY: Because everywhere along that path, you have to be comparing your model to data at every scale. And then as you scale up and you get rid of some variables, you have to convince us again.

CONNOLLY: Right. And that's why - that's why...

BRANTLEY: But there was never a single slide that showed us anything that built that kind of confidence.

CONNOLLY: Yes. I didn't - there are only so many slides I could show in 30 minutes.

BRANTLEY: You showed quite a few.

CONNOLLY: I did show quite a few. But I did not show the ones of benchmarking against hydride and generation but yes

we do have those. And the point I was trying to make - the point I was trying to make with this last slide is we would - ideally, if you go back to the notional chart, notional timeline chart that's at the beginning, where we really want to end up is out here, where we've actually loaded the canister.

And then we use a model to predict how well it's going to do. So we're going to update the model based on all - completing all experiments including the drying experiments and then we would use that model against this over here.

So we're already developing the instrumental lid, hopefully Josh would be able to go forward with receiving funding to do a demonstration of how to load a canister, and then we'll address all the issues associated with loading aluminum in a canister. And then we'll instrument it and we'll compare it against our model. OK.

BRANTLEY: Well, in my experience, doing this kind of thing, not that I've ever done it for this exact system, I mean it's extremely difficult and you have to be able to...

CONNOLLY: Don't disagree. The other thing - right.

BRANTLEY: You have to be able to show every step of the way how you're...

CONNOLLY: Right.

BRANTLEY: How you're making the scaling up.

CONNOLLY: Right. And we have that in our technical repots. I don't necessarily have it in this presentation because that wasn't - the intent was not to show validation of the model. That was not the intent of the presentation.

The intent was to show that we have a model and that we are validating it through other means. I just didn't discuss it in here. But one of those experiments that we want to be able to do and I mentioned is to take the RU - the Uruguay-RU1 plate, take a piece of it, irradiate it and see what we get for results. Now, we can then use that to help us with our model. OK.

So we're trying to do everything we can do without actually going to the point of taking a full intact fuel element because the Department is not going to fund us doing that kind of experiment. We've asked repeatedly. So we're trying to figure out ways of validating these models that we have by doing certain types of experiments and as we learn more, we build upon it.

BAHR: OK. Tissa?

ILLANGASEKARE: Yes. Tissa Illangasekare, Board. So this maybe a detailed question but you mentioned in a multiphysics simulator, you basically mentioned that - my experience in multiphysics simulators they are very unstable when you try to do many things at the same time.

But you also mentioned they are very inefficient, but you mentioned you have 700 processors, is that correct? You mentioned like 700 processors.

CONNOLLY: Seven hundred twenty.

ILLANGASEKARE: Yes. So with that processors, how much time it takes to do a reasonably long simulation?

CONNOLLY: I don't know. Josh, do you know that answer? Off the top of my head I don't know the answer how long it takes to run a 50-year simulation. I think it's on the order of a half a day. So, it's not that long.

ILLANGASEKARE: OK.

BAHR: Other questions? OK. Thanks, Mike.

So, we now have a break until 3 PM when we'll hear from Dr. Paul Standring from Sellafield.

(BREAK)

BAHR: OK. Welcome back for the final talk of this afternoon. And just as a reminder, that will be followed by a panel discussion.

And our final speaker is Dr. Paul Standring from Sellafield in the U.K. As I mentioned at the beginning of the day, the Board has found it very useful over the years that we've been together to get perspectives from outside of the Department of Energy, and in particular from outside the U.S. on programs that are doing related work.

And so, we're very pleased that Paul was able to cross the Atlantic to be with us today and I hope that he's not too jet lagged. So thanks, Paul.

STANDRING: Thank you. First of all, I'd just like to thank the NWRBTB for inviting us to come along and speak to the Board meeting today.

This is a joint presentation with the parent company, which is the NDA. So, just for your information, Sellafield Limited here works for the - is a subsidiary of the parent company, which is the Nuclear Decommissioning Authority of the annual spend - well, I'll make a point here of the annual spend of 4 billion, Sellafield accounts for more than half of that expenditure.

OK. So, to business. I'm going to give you a little bit more than just aluminum clad fuels today. I'm going to give you a bit more general stuff. So, a general overview something what aluminum clad fuels we have; U.K. experience on dry storage; specific one on Magnox contingency; current developments, and then we'll end up with what we're doing with our aluminum fuels.

So just for background because we don't have standard fuels like everybody else, we have those peculiar fuels to the U.K. So, this is the first generation reactor we have. Gas reactor. It's uranium metal fuel with a magnesium alloy clad, so that's magnesium 0.8% aluminum clad.

No more operating reactors now. There's no more fuel in any of the reactors now. The last fuel came out of reactor and shipped to Sellafield in October this year, so all reactors are cleared, all the fuel is now at Sellafield.

Second generation, yet again, yet another gas reactor. This is a UO₂ version, so it's uranium dioxide and the fuel

cladding this time is stainless steel, and that gives that fuel some specific unique properties as well.

And the third generation - we actually went to the market and bought one off the market this time, which is a standard LWR. Sellafield does not manage the fuel from this reactor. It's all managed by Electricite de France at Sizewell B, but we do have LWR fuel from reprocessing contracts.

OK. Along the way to that third generation reactor, we have a number of power reactors like the steam generating heavy water reactor. These are all either completely decommissioned and gone, or they're still there and either the fuel has been totally removed or is in the process of.

The two fast reactors are Dounreay and then the Windscale AGR at Sellafield. The thing I will say about this and the thing that the U.S. also experienced is that during the development of these reactors, these power reactors, we created all sorts of crazy fuel. Everything you can think of, we've got glass-coated pins, everything. Everything was tried in these reactors.

So to the aluminum clad fuels, so what about aluminum clad fuels? I mentioned aluminum to date, but as you know, the first reactors weren't power reactors, they were there for weapons production, so the first two were there, BEPO. The British Experimental Pile zero energy reactor.

Was a forerunner to the Windscale piles. They're both aluminum clad fuel, uranium metal, and then the latter aluminum clad fuel reactors which have been in operation have been MTR Consort and the training reactor Jason.

Those are aluminum clad aluminum uranium fuel matrix, the previous lot were all uranium metal. What you will see there is a set of storage conditions. And that represents three different facilities. The fuel at the bottom is stored in nice good conditions. We routinely inspect the fuel and we know what it is and we know it's not degrading. The other two storage facilities as you can see there, aluminum clad fuel and sodium hydroxide does not go together.

OK. Any simple chemist can tell you that. I can tell you why it's in sodium hydroxide. That's really explained probably by the next slide. So in terms of storage of fuel at Sellafield going forward into the what will be remaining at Sellafield prior to repository coming available, it is dominated by oxide fuels.

And those oxide fuels are those advanced gas reactor fuels. And the storage regime for that fuel is wet storage. I could explain why it's wet storage. But that's not the purpose today to do that. The next big blip on there is called all the legacy fuels. And legacy fuels is sort of what's happened with history at Sellafield over the time but most - majority of those legacy fuels are made up of Magnox fuel and it's severely degraded Magnox fuel.

The previous slides mentioned something like sodium hydroxide. And, to store Magnox fuel in better conditions, you store it in sodium hydroxide. And the aluminum clad fuel which you can't see - even see on this diagram is alongside it, then unfortunately it's sacrificial. We do the majority not the less. And the other thing about that slide

is that what is going forward in terms of expenditure with dealing with the legacy fuels as a bracket, there's a whole lot.

So, aluminum in the first place would have to fit in there. So whatever we're doing will have to fit in. So in terms of experience, well, the U.K. is still the only country which has ever had a reactor - a power reactor with an all dry fuel route and that was the big Magnox at Wylfa.

It stored its fuel initially - forced CO₂, dry vault store and then when it cooled down it was changed into an air cooled vault store. And the thing to bear in mind here is that air cooled vault store is vented. It's not a sealed system. It's a vented system.

OK? In terms of dry storage going forward, well, at Sizewell B, Electricite de France has developed - adopted the Holtec system but it's not a normal Holtec system. It's being modified to the standards required by the British regulator.

In terms of projects, the major project which is being done on dry storage was associated with advanced gas reactor fuel. And that was storing stainless steel clad fuel. And the thing to note here is the water carry over assumption here is nothing, so they had a target of 50 VPM, which is basically no water. And that's on the fuel performance in a dry storage system.

And that project was cancelled in the '90s when the parent company at that time, Scottish Nuclear Limited, signed a contract with Sellafield which is Sellafield Limited now to reprocess the fuel and first to manage the lifetime arisings. So, that project is not going forward but there was about 50 million pounds worth of research done on it.

The one I'm going to talk to you in more detail is a contingency one for Magnox fuel. And here, we're looking at water carryovers between 0.73 and 2.6 liters of water, is quite high, it's quite high. And then the last one is the project which will go forward in the future which is a legacy fuels and there you've got an assumption of water

carryover at 60 liters. These are large volumes of water, OK?

And in addition, there's three other projects, there's another one for AGR fuel, there's a contingency in the future to recover it for disposal. So, there's a couple of PHDs on drying in that area going on at the moment. And then this is some work we just sort of - just a study which is being looked on the aluminum-clad, aluminum uranium fuel. And we currently have something looking at fast reactor fuel as well.

So, the Magnox contingency, so why did we look at dry storage for Magnox fuel? Well, basically, it's a contingency option to mitigate the failure of the reprocessing plant. And when I say contingency, it's not the first contingency. The first contingency is to fix the plant.

In fact, the second contingency is to fix the plant and the third contingency is to go to dry store of the fuel. So,

this is a last resort type of thing. We don't really want to do it but we need to have a contingency on the table.

Why? Well, the plant is 55 years old and keeping an active reprocessing plant going 55 years is no easy task. We're talking about 1950s technology which was built in 1964 and keeping that going is not easy. And to put that into context, in its peak day, it had about 1,600 tons a year throughput and now we're down to 400, OK?

Requirement, safe storage of fuel and that's a mixture of either intact fuel and at that time we were looking at this contingency, we had an inventory of degraded Magnox fuel. So, the bounding case is for degraded fuel not for the intact, although for the system we're looking at, intact can be the bounding case and not degraded.

So, the concept - so, we stole the concept, so we came up - we looked at the American experience on the Hanford multi-canister overpack and that was used for metallic fuel. The difference is it wasn't used for magnesium fuel, that is

mainly Zircaloy-clad fuel. It was uranium metal but with different, these different challenges.

So, Magnox is more challenging. Fuel vacuum drying was the - yes, so fuel vacuum drying and the potential for this canister being pressurized, and it was developed to a point whereby it's on the shelf and if the plant falls over, we can take it forward, OK?

So, the main issue here is that canister we're going to put the fuel in, it's a sealed system, so that's very important. So, it's a sealed system, design criteria, it's got to be corrosion attack from the inside, attack from the outside, the assumptions we worked to 150-year storage, that comes from the regulator, OK, 150 years assumption for the repository will be made available by this time.

So, what's important here is that this is putting the reliance on the strength of that canister and that it is a pressure system. So, we're talking about the canister here being able to cope with 30 bar pressure. And we did a drop test - no, we did a burst test on this canister, a full size

canister and it managed to survive about 120 bar pressure. Corrosion resistance, they decided to jump to duplex stainless steel 2205. Downside of that is it's expensive and you don't want to get it too hot either.

Technical issues, we've heard this already today, same technical issues, removal of free water, removal of physically absorbed water and we've got chemically bound water to the magnesium hydroxide on that degraded fuel.

So, apart from the engineering side, what we did here was we developed a chemistry model. The chemistry model wasn't developed by Sellafield Limited. It was developed by our National Nuclear Laboratory who were one of the subcontractors on this project. So, they did all the modeling work for us.

It's very pessimistic, I've heard today about how people have been doing modeling to get exact results and everything. This modeling is a bounding model. We're trying to see whether we're approaching that 30 bar pressure or not. That's the context of the modeling, OK?

If we thought we were going to approach that 30 bar, then we would have to do sophisticated modeling. So, that's what you have to bear in mind. There's information on this, it's published, it's in an International Atomic Energy Agency document, the number is there and we looked at the behavior both intact and degraded fuel.

So, the other side is the fuel drying, full scale piece of equipment there. Process copied the Hanford. What it didn't copy off the Hanford is that this is cold - this is cold vacuum drying. I think Hanford in the end did a bit of the heated stuff up in the end, but this is the original cold. Drying trials were conducted with 24 intact elements. These are real elements without the uranium metal inside but the actual Magnox cans, they dipped the cans in magnesium zirconate to try and simulate the magnesium hydroxide layer on it.

And then they also modeled degraded fuel and the water trapped behind the fuel clad. So they put a - got them wet

and they've put this stuff on and then we've dunked it all in water and then they've tried to dry it.

So, that just shows you a bit more. OK. So, the fuel was weighed before and then it was weighed after. Weighing it before is not a state of art experiment. You got something this size which is wet and you stick it on the balance and you try and put it off the balance as fast as you can and do that way -- that's the way this is being done.

Conclusions on the drying side, well, it's capable of removing free water, but it didn't remove any of the chemically bound water, then again, we expect that. So, we know what the performance of the drying system would be in this situation.

And some other data which tells you drying times, depends on how much water is there - surprise, surprise. If you increase the heat then it would dry better, yes, of course, of course, there's nothing, no rocket science there.

So, a little bit more interesting side is the canister chemistry model. So, magnesium-clad fuel readily reacts with water to form the hydroxide and hydrogen and this is so readily - does it react that we can measure it. That's why we don't store the fuel in normal de-min water, we actually store it in caustic-dosed water to stop this from happening so fast.

But if you put in a pure water environment, it will react very nicely. Why is it different from aluminum-clad fuel? Well, we had a nice chemistry lesson in the previous speaker, but what I will say is the clue is in the name, magnesium is non-oxidizing.

So, whereas aluminum-clad fuel in principle will have a nice oxide layer on it to protect it which doesn't make it very easy for this hydroxide layer and all these hydrated layers to form and thick hydrated layers to form, the magnesium-clad fuel doesn't and it will readily form and, therefore, on those grounds I would suggest to you that Magnox is bounding for aluminum fuel we have, OK?

So, the rest of the reactions are to do with uranium metal. So, how the uranium metal will corrode in the sealed system when there's water there, when it's oxic, when it's anoxic.

We can see we get many different type layer, sort of forms of uranium oxide, formed in the system. And then the one which we prefer to avoid is when we've used up this oxygen, it starts reacting with the hydrogen in the system to give us uranium hydride and this is where the safety issue starts to arise for us.

A number of uranium hydride reactions, these are all modeled in the chemistry model and then the radiolysis reaction. That is a summary of radiolysis reactions. We can write pages of radical reactions here. So, a one-liner like that does no justice to radiolysis so, it's just there.

So, what happens? So, this is the impact on pressure for intact fuel at 75 degrees C. And I probably didn't need to model this because it's telling me what exactly what I expect it is, that I put water with like a radiolysis occurring in a sealed system so the more water I got there,

then the bigger the pressure I'm going to create from this reaction.

So, we've got pressure variation with time. We've got the various, what happens between intact and bare uranium bars. As you can see, bare uranium bars are very good in this system. So, maybe you could suggest taking the cladding off if you were going to put it in there, which is one option which was considered, OK, because the bare uranium metal will take things out nicely.

And this just shows you that in comparison the internal can pressure that the intact is far worse from a pressure point of view compared to a degraded fuel, OK? More graphs and see the effect of temperature, maximum pressure, time, that will stabilize with time.

So, results, so radiolysis so, there's a minimum impact on canister pressure, as radiolytic gas generation is small with respect to corrosion and that's corrosion of the fuel, OK? So, whilst we got this nice radiolysis going on there,

it's the actual reaction with the uranium fuel which is causing the hydrogen to generate so - oops.

So, insufficient radiolytic O₂ to inhibit the uranium hydride reaction. So, once we've used up that O₂ from the radiolysis then we're going to get hydride formed. Fission product gas, so we've got no volatile fission products released. Insufficient quantities to affect the canister pressure so that's not going to impact the pressure.

Helium production by decay is negligible. There's not plutonium fuel here, there's nothing to worry about.

Hydrogen migration through the canister wall to bring the pressure down, no, it's not working.

What is a concern to us is with the various atmospheres which could be in the system, is we have a worst case scenario where we could end up with 23 kilos of uranium hydride per canister and that's bad news. It's really bad news and it's not something - it's not somewhere you want to go because that's a real problem to deal with. So, that is a worst case scenario.

Despite that and even with 23 kilos of uranium hydride, we could develop a safety case, OK? Safety cases around it being a sealed system, about the system being able to take the pressure. Where it does leave us with a problem with is release the pressure at the end of life which is not such a big issue because the oil industry does this on a regular basis.

The uranium hydride fault scenario is not something we really want to go there; we don't really want to get into that ground of that potential. So, we retain this option but we retain it only for intact fuel not for degraded fuel.

A number of other issues, it's very high cost, very high cost implications, the downside, the uranium hydride. So, the way forward on this is not to seal the system, is to have a vented system. And is there precedence for this? Well, if we go back to the Wylfa side of things, that's a vented storage system. The difference is it's vented for intact fuel which was never wetted in the first place.

If we look a bit further afield, we can go to Idaho National Lab and they have TMI-2 fuel which is in a vented system which is degraded. So, it's been done before.

So, where are we going with the latest developments? So, currently, they're working on something called the self-shielded box and it originally started off as a mechanism for guessing when a cold ion exchange skips out of one of the old facilities. Now, what I need to tell you about a lot of the programs at Sellafield is that based on hazard reduction and normal rules don't necessarily quite apply.

So, if you can remove it and whilst there may be a short term increase in risk, in the longer term if it goes down, then maybe you want to go in that direction, OK? So, you're trying to remove the problem and make the situation better in the longer term. So, they've been looking at ways of doing this.

This self-shielded box is effectively a lighter version of a Magnox transport cask. So, a transport cask but it's a vented transport cask. So, what they're doing is they're

taking these ion exchange skips which look exactly like a fuel skip effectively, they're putting it inside this box which would have been a transport cask but it's not. It's now vented, it's slightly different. And then they're going to put it into a store.

So, minimum handling, so it's lighter construction. It's vented, minimum handling, technical issues, avoiding buildup of flammable gas from radiolysis, airborne aerosols, vented system so we need to try and prevent those aerosols and the critical technology element there for this system is the filter system, OK, because that's going to stop everything.

So, we thought up the idea for one thing so you then think maybe I can apply it for something else. So, in this case, we think we're going to apply it to legacy fuels as well, similar idea, minimum handling, take the fuel skip out of the pond, you put it in the box and you let it dry itself within the box. It's a vented system, OK?

So, as I said it's about hazard reduction. It's not about an ideal storage system, it's about hazard reduction. This

is an interim step, it's not the final solution. The interim step is to get it out of the existing facility, make it safe and manage that hazard. So, the fuel skip is simply washed, it's drained, maybe a little bit of sorting going on but they're minimizing the handling and as the fuel warms up, it dries itself out. It may take a long time to do that, OK?

A number of technical issues, technical issues here is internal corrosion of the system. And so, that internal corrosion, potential for the filters to block, potential for a thermal excursion to happen in that system. Radiolysis, still got to assess against uranium hydride formation, airborne aerosols again.

So, there's been a whole raft of models developed for this. I won't show you any results because they're still being worked on. The information has not been released yet. I think one American company has actually been involved with, doing quite a bit of modeling in this.

Base case at the moment is something called - base case is degraded Magnox fuel self-draining. That basically means it hasn't really got a any cladding on it, OK? So, internal corrosion impacts the shielding of the box so more corrosion, less shielding you've got, you got to assess that over time, filter performance, may corrode the filters and you got to change the filters and it then may actually in the long term prevent you from retrieving that fuel which is inside the box because you can't retrieve the skip it's in, OK?

Potentials for the filters to block from material dry out, well, modeling has shown that we actually need less than one filter to maintain the conditions in the box which we need. So, two engineering design, I think we have eight so we designed with eight and that will maintain oxidic conditions.

Potential for thermal excursion, that's basically a function of how the fuel is packed inside the box. A potential for cesium and mobile particles release, you got to get it quite hot to get cesium to release and it's not really going to go there but it is something which is assessed.

Radiolysis, what we tend to find with radiolysis is when you put it in, the modeling says here it goes up in one day and then drops down to nothing so - uranium hydride formation, those filters are working properly, they're passive since it allows air ingress, it maintains those oxidic conditions.

And effectively, by allowing oxygen to go in there, you're taking chemical energy out of the system because you're reacting that uranium metal to the oxide. It's slow, it's a slow reaction and it - it will evolve over a period of time. But it is changing the form. And airborne aerosols again. So, these are the issues which we're currently dealing with and it's still in progress, is that project, OK.

So you've had the two sites, the sealed system and a totally vented system. Aluminum clad, uranium metal fuel dry storage position, well, we look at the Magnox contingency and basically we've got the same problem, uranium hydride, so it's a no go. It's currently being looked at in terms of self-shielded box option, gas - gap analysis have been undertaken to compare to the cell, to the reference case

fuel. And, OK, there's some differences in the material types, and the packing, some additional bottling will be required, but basically it's bounded by the self-draining fuel.

A much easier fuel is the aluminum clad aluminum uranium fuel which is in quite good condition. Management options, well, they looked at basically reprocessing this at one time.

I think they were assessing it to go to France, but they haven't decided to take that option, so they're being looking at the dry options instead. So continued wet storage, we can't go with that going forward in the future because all our facilities will be sodium hydroxide dosed and that's for the fuels which are being stored in them. So there will be no de-min water facilities and therefore this will have to be pulled out and put into dry storage.

It was considered against the Magnox contingency, it probably will be OK in the Magnox contingency, but it's not going to be put into that contingency type of system unless

it is built for one of the other fuels. The amount of fuel here is so small, we cannot justify the cost to down that route. So we possibly will look at it in terms of any other dry storage system which is out there at the moment, it's still being considered. So self-shielded boxes are currently on the table and therefore it will be considered against that.

Apologies, very quick, very - if I got muddled up at some stage, I'm sure you'll have noticed and you'll correct me. Hopefully, I've given you an overview of what's happening in the UK, what's happened in the past, what some of the issues are, how we've looked at it in terms of both the sealed system and now looking at it in terms of a vented system. So thank you very much.

BAHR: Thank you Paul. Cheer for people when they come across the ocean. Bahr, Board. What's the timeframe at which you need to remove the aluminum clad fuel because you're adding the sodium hydroxide to the pools?

STANDRING: The timeframe is still open for question because it currently sits in a facility which will be on a timeline to be decommissioned, OK? So I can't give you an exact date at the moment.

It's not tomorrow, it's probably not in 10-year time, but it's still - it will take time to include it in any project. So it's still open for discussion, that one. But it's in a facility, the facility is OK, it's not degrading, but the facility is on a timeline to be decommissioned, OK? Because it's being defueled effectively.

BAHR: And in these vented systems, then the filters would capture other radionuclides, do they capture iodine - what other things are escaping?

STANDRING: It's going to capture the particulates.

BAHR: OK.

STANDRING: OK?

BAHR: And so there are...

STANDRING: If there's any - if there's any gaseous, then it's going to get out of the system, OK?

BAHR: And what's the backend of the filters? Do they have to be removed and exchanged periodically or do you wait until the end and what's the disposition of those?

STANDRING: Right. If you're an operator like me, then you prefer to do nothing, OK? So it's still being assessed on whether those filters will have to be periodically changed or not. And they probably will find out some of the information and when the system actually gets into operation. Let's go back to it's hazard reduction. It's making it better, they have a capability to change those filters, but whether they will do will be established as part of a lead and learn, OK?

BAHR: OK. Do we have questions from other Board members in his presentation? Yes, Steve Becker?

BECKER: Becker, Board. Have we moderated the sound? Thank you. So what is the current status of the self-shielded box option? And if this were fully exercised, how many such boxes would be needed?

STANDRING: Right. The current status is they're being manufactured, OK? So there are - they're already - there's already a contract out there for the ion exchange work, and there's already a store built to put those boxes in for ion exchange material, OK?

The fuel would be the next phase. The big issue is they have to get the safety case and the operating, the license to operate through the regulator and they're currently working on that at the present time. I had hoped to have it by now, but I - there's still some issues which they have to iron out, OK?

So they are being built, these things are being drop tested, they're being made, they're currently - there's currently production going on to provide them, and there's a store for them to go in there. For the ion exchange, I think there's

250 boxes, maybe, or the ion exchange alone. For the fuel, I suspect there will be at least another 250, so it's - so we're talking sort of order of magnitude of these boxes.

There - what are they, about 30 tons a piece. So this isn't some little can we're talking about, it's a - it's a big beast. It - did I answer your question? Did I help you with that? OK.

BAHR: Other questions from the Board and staff? Nigel?

MOTE: Nigel Mote, Board staff. Thanks Paul. So, I got the story about the self-shielded box, I'm not sure what comes afterwards. I don't know whether that's intended to be a disposal unit, but maybe I can ask you one question that...

STANDRING: No, no, no. No, that's - what comes afterwards, right. What comes after the self-shielded the box is - again, if you were an operator, you would like to do nothing else. So, once it's in that box they would like then to send that box to a repository and do absolutely nothing to it.

And they've written to the repository, future repository operators, for them to give a considered view on that approach and they've given them a letter of advice saying what they think.

And so that's going on in that respect. But also there are a number of evaluated alternatives and those are from a level of do nothing, condition the material inside the box, and you process the material inside the box, in not an existing plant, so - whilst we have two reprocessing plans, one currently being under post operational clear out at the moment and one that's still operational, but 55 years old.

That's not considered suitable for this material and the reprocessing element would be a small scale or a series of small scale dissolver units to manage things like criticality, et cetera. Additionally, other options are being looked at for putting it, just encapsulating it in grout, which is possibly, it's been done, they've looked at it. Further option at looking potential option is to look at an opportunity, there's a lot of work going on at

Sellafield at the moment about looking for a potential opportunity for thermally treating waste in the future.

So they may be able to do thermal treatment. It could be nice to simply just oxidize uranium metal fuel and take the chemical engineering out of it completely. Maybe the thermal process will do that. But we're looking at thermal processes for other wastes at the moment, OK? So this is a thermal process, like the one At Savannah River.

MOTE: So, can I have a quick follow-up Jean?

BAHR: Sure.

MOTE: I find the concept of disposing of a box that is a vented system in a repository to be novel and other countries are looking at a container which itself is - it's the engineered barrier which is part of the performance requirement for the repository. How did the - I don't recall how you - I'm going to say the regulator, you didn't say that, but how did the regulator receive the concept of having a vented unit to be disposed of in a repository?

STANDRING: It's nowhere near. It's just an option. This is - this is more or less a do nothing option. I didn't say it was right. I didn't say it was the way forward.

MOTE: You did say you'd asked them about it.

STANDRING: But they have asked them for advice on whether doing such a thing could be accommodated in their design of repository.

MOTE: OK. Thank you.

STANDRING: I mean, to be honest, I'll come back and say, "No, you need to put some containment." Yes.

BAHR: Dan?

OGG: Yes, Dan Ogg, Board staff. Paul, thanks for the presentation, very informative. The Magnox fuel, the baseline right now is to continue to process that material in the Magnox processing facility.

STANDRING: Yes.

OGG: Does that include a hundred percent - I mean, the baseline plan includes a hundred percent of all the Magnox fuel or is there some problematic Magnox fuel that wouldn't go to the reprocessing plant?

STANDRING: There is always some residues which will not go to - through the reprocessing plant or would be too difficult to put through the reprocessing plant. This is the same with oxide fuel as well, OK? So you always get some residues left which will have to be managed. And currently, yes, there is an assumption on the quantity of fuel there. And that ideally would be treated the same way as the degraded fuel which is a much bigger problem, OK?

It's a bit of noise in the background. It was different seven years ago, if I had several thousand tons of the stuff, that's a different issue. And that's where we were, but now we don't have anything like that. There's not much left to do, so.

OGG: And regarding the aluminum clad spent nuclear fuel, when you listed as one of the options there, reprocessing as well, is that something that would have to be a new facility or would you be able to use an existing facility?

STANDRING: No. It - this is in the literature, it's - it was an option which was considered by the owner of that fuel. And they went to Orano in France to see if they would reprocess it. They have decided not to go down that route as well as I understand at the present time. OK.

But it's - you'll understand in the UK it's up to the owner of the fuel, what happens to their fuel. The NDA happens to own a lot of fuel, some of it is very severely corroded and they manage that position. That particular aluminum clad fuel is not owned by the NDA, OK?

OGG: Excellent. Thank you.

BAHR: Are there questions from staff? Bret?

LESLIE: Bret Leslie, Board staff. Thanks for the presentation. One quick question, you had mentioned that you did inspections of the aluminum fuel, can you explain a little bit more?

STANDRING: Yes. They're CCTV inspections, visual inspections of repeated inspections of some of the modules. They've been benchmarked and several years later they've looked at them again to see where there's any signs of corrosion on them and then periodically, they get recovered and looked at. There's no obvious signs of any degradation going on there, so.

LESLIE: OK. Thank you.

STANDRING: OK.

BAHR: Anything else? OK. Well we - our last event for the afternoon will be a panel discussion and we'll need a few minutes to set that up. So we can take a break until about 4:00, that gives us about seven or eight minutes.

(BREAK)

BAHR: I'm going to turn things over to Bret Leslie who is going to moderate the panel discussion.

LESLIE: OK. I'd like to get started. We have 45 minutes and we'll see how we do, and kind of the ground rules. And what I want to start off with is I want to give you guys the opportunity and I will start with Paul to ask questions of both Josh and Mike, but if you've got - also just let the discussion go because Paul's come over from a long distance and I want you to maximize the ability to learn and that's one of the things the Board values in bringing the international folks in.

We have provided the panelists a couple of questions and we'll go to those in a little bit. I will be turning to the Board members if they've got questions. I know one Board member does.

And then I'll also turn to the staff, and I'm going to try to stay out of the conversation even though I made a

presentation earlier. I want this to be more of a discussion for you guys. So, Paul and I will remind folks, pick up your mic and make sure it's close to your mouth and then go ahead and ask your question.

STANDRING: OK, thank you. I've got a question and I think it's probably for Josh, sorry, Josh. It's related to - when I ask people to put fuel in a can and then got to put it into storage, they usually ask for the can, the criteria behind the can going into storage, that I am looking for something which will last 150 years.

And what I am interested in, and as I said before, the 150 years comes from my regulator. But what I am interested in is the leak tightness of that can. While you normally throw at people, is the ASTM leak tightness criteria. More often than not I get thrown back at me, we can't meet it.

So I am interested in this can that you've designed here, and the sealing system, on how you are going to meet that criteria. I've heard about the corrosion properties of the

metal and everything. But the basic requirement on leak tightness, maybe you can say a few words on this?

LESLIE: And it might be either Mike or Josh, and we'll let them confer and try to figure out who the right person is. OK. Let's have this conversation on the record.

JARRELL: So we are discussing how to respond to Paul's question. So in the design of the canister, it was developed to meet the ASTM standard. And so, I am a little hesitant to speak too far off the cuff because I don't know for sure.

With commercial spent fuel and the canister design, traditionally you do volumetric testing of everything but the final closure weld. And then you'll do the final closure weld and PT that to ensure leak tightness. That's how it's done. But as far as the specifics on this can, I really don't know how to answer you, Paul.

LESLIE: And maybe I will ask a different question because I jotted it down. The UK looked at 150 years. Mike, in your,

the working group looked at 50 years. Would there be different issues for a longer period of time? And would the work you are doing now give you a lot of confidence in projecting for a longer period?

CONNOLLY: Yes, I think it's important to remember that the working group, so the MCOs have a design basis of 40 years. The original DOE standardized canister, the materials and the actual report that was put out associated with that. That's a part of the license application that was based on 50 years.

So when we started our study we used them as underpinnings. So we are looking at what we call extended or long-term dry storage which is greater than 50 years. So by default we are already actually looking at things greater than 50 years because we have to work to the assumption that the MCO was a 40-year basis, and the standard canister already had a 50-years basis based on the analysis that they performed.

Now we demonstrated in our analyses and I didn't bring this up, that the materials in our action report which is a

report that our national spent nuclear fuel program put out back in 2007 or '04 or whatever the year is for it, it projected that you would build I think somewhere - at that time they weren't able to couple all of the reactions together.

So they looked at pressure build-up due to free water, and with the pressure build-up due to radiolysis, and the pressure build-up due to dehydration. And then they had all of those things together and they were showing numbers of 11 PSI total, 50 PSI total.

Now that we are capable of being, and now that we know more and we have a way of modeling what we can bring back reactions and everything else into play, we are showing that it's only a few atmospheres which is nowhere near the design life of the canister which is 537 pounds, right.

So we are talking three to five atmospheres is what we are projecting building at 50 years. And at 50 years you see in those curves what's the driving those, the number after you

get beyond the thermal dehydration that I talked about, the spike at the beginning, it's all based on radiolysis.

At some point in time you've depleted that substrate material and you only have a few microns of it. So that radiolysis reaction rolls over. So at some point, yes, and when you get to beyond 50 years those numbers are actually pretty flat. OK. I'm not sure if I answered the question that you wanted me to answer...

LESLIE: No problem. Go ahead, Mike.

STANDRING: OK. I mean...

LESLIE: Or Paul?

STANDRING: Yes. It's interesting to hear the answers. I mean the question is really, it is actually, the question is thrown out in respect of, if you go to the supply chain and ask them to guarantee something for that length of time, the answer will be no. They won't do it. But yet we seem to be able to do internal projects which say maybe we can.

It's really meant in that sort of context. You are asking for a guarantee from somebody and you are not going to get it.

LESLIE: OK, I'm not sure how to handle that I think. Maybe, Mike, you indicated what they've designed it for, so maybe you could..

CONNOLLY: So I was talking about what's building up inside the can, so you are talking about is the structural integrity of the canister and the associated welds that go with the canister.

And so, what we are trying to demonstrate through, to at least our analysis and other analyses that have been done is that you are building up any corrosive gases inside, you talked about hydrogen and you talked about hydrogen embrittlement and hydrogen diffusion through the canister. All those things are, in a 100-year lifetime, probably a non-player.

Now when you get to way beyond 100 year lifetimes, you know, if we meet the requirements of NRC in terms of leak tightness and closure, then you are looking at simply the integrity of the system. So what's challenging the integrity of the system? Is it excess pressure, is it corrosive gases or is it something else? I think that's the way I would look at it.

LESLIE: OK. I'm going to ask a follow-up question. I mean, in terms of, and Paul talked about how they are looking at and trying to keep things and manage the aging of their infrastructure. Again, we don't know how long the DOE standardized canister might be in use. And, you know the NRC has licensed this cask and for a certain period of time, now it's up to 40 years with a renewal out to another 40 years.

Have DOE thought about what aging management requirements might be needed if the DOE standard canister is employed and used for much longer than the initial 40 or 50 years that you've thought about, or is that something that can be

thought about, not right now, or when does it need to be thought about?

CONNOLLY: So DOE is looking at aging management, right? I mean the L-Basin has an aging management program. We have our programs for the 603 facility. Their draft strategic plan recognizes aging management as an issue that we need to look at.

Have they specifically started looking at aging management associated with the DOE, those standard canister? I would say the answer is no because we don't have anything in the standard canister.

LESLIE: So do you think your demonstration could help inform?

CONNOLLY: Yes, and I will go back to the answer I gave you just a minute ago and that's looking at the structural integrity and what affects structural integrity, it's pressure, it's corrosive gases and there's other types of things like that. So if you can demonstrate you don't have

those then that helps make an argument of what the aging management program needs to be.

LESLIE: OK.

CONNOLLY: That's the same thing we do with our existing facilities, we have corrosion coupons in the 603 facility. We have canisters that are mimicked, that are simulants of fuel canisters with coupons inside of them, on trees, so we do all have that stuff. What we need to figure out is what do we need to be worried about and then start to monitor forward as part of an aging management program.

LESLIE: Go ahead, Josh.

JARRELL: Yes, I'll just add one other thing. So we are looking at options for storage of standard canisters, right now. And one of those discussions that we've been having with the vendors is do we need to - so the standard canisters, what Mike is talking about here is challenging the canister from the inside out.

So do we need to look at how you manage it from the outside in? So when you store these canisters, this sealed systems, it doesn't make sense to seal them in another sort of inerted environment to help prevent stress corrosion, chlorine-induced stress corrosion cracking for example, and those sorts of things. So we are having those discussion right now.

I'm not sure where the point of kind of deciding the right way to handle it but again but again I think when you go into these aging management, at least for a sealed canister the two options are inside out, or outside in and you have to consider both from an aging management perspective.

STANDRING: OK. In terms of this aspect, condition monitoring and inspection is a very important area for us at the moment. And I don't mean it's just in terms of fuel but I mean it in terms of generically all waste packages of everything we own on site.

And we have a dedicated innovations team looking at this particular area and lots of different things going on at the

moment. And they do have a vision of trying to create what is called a Smart Package.

So a package which will tell you how it's behaving. Now that's a vision, isn't it? That would be great if we had something like that. And I wish them good luck in doing that.

They work with all the various universities to try and get the ideas off these guys to come up with these answers. But it is a very active area at the moment and a very important area as well, especially if we wish to go into these very long time scales of actually of being out to what do we actually monitor and things like that. But I don't have the answer, sorry.

JARRELL: Understand one of the things that we are actively looking at, at INL for the 603 facility, is actually developing a technology that could be deployed basically in the canisters in 603 to monitor humidities, temperatures, those sorts of things that we are working with, with

Westinghouse and others, looking at sensor arrays and other sorts of technologies that could be used for that.

And again, really for us our immediate need is making sure that we can model our systems but long-term we would want to use that data.

LESLIE: OK. Do you either, Mike or Josh have questions for Paul? Otherwise I will turn to, or Paul, do you have more questions? OK.

So we provided a couple of questions to the panelists ahead of time, and let me just ask Mike and then Josh, and then maybe Paul kind of what were the two most important things you think that are important to understand and control to ensure the dry storage of your respective fuels, understanding, Paul, we are not necessarily talking about your aluminum fuel but you're dealing with similar things in terms of worrying about long-term storage and what's the appropriate approach to take. So, Josh, do you mind starting?

JARRELL: Sure, I mean, I think for me the big two with aluminum fuel at least is understanding hydrogen generation and generalizing, we think it's going to be from oxy-hydroxide layers.

And then the other piece is, especially for our vented systems, where we know we are going to have to move this material at some point down the road, we need to make sure that we understand structurally how the material performs, again, because we are going to have to move it later and we don't want that handling sort of issues. So those are the two I would say.

LESLIE: And Mike?

CONNOLLY: Yes, and mine kind of support about that, I think it goes back to, if we are going to put this stuff in the canister we know that the design basis for the canister and we need to ensure that we stay within design basis for the canister. Our approach to date is to try and understand that that chemistry of the layer, that's really was going to drive this.

And there's a thermal dehydration chemistry and it's the radiolytic chemistry. And that means that we need - and the so, the experiments, I put in the path forward are those things that we really need to do, we need to understand what's happening with thermal dehydration and that's probably going to come from the studies we are going to do at the engineering scale drying experiments, coupled together with doing some additional radiolysis studies where we are really trying to look at radiolysis of post dried materials, that we also want to look at the radiolysis of actual fuel samples themselves. So those in my mind, those are a couple of areas that we really need to look at.

LESLIE: OK. Paul?

STANDRING: OK. I am going to answer this question as a bit more generic way rather than specifically on aluminum fuel. I mean basically what we tend to be interested in is how the fuel, any particular fuel will evolve in the system we are going to put it into. And that comes down to being able to

understand a particular fuel over various mechanisms that were going on there.

In some cases we don't have a thorough yet, enough understanding of how something will behave for some of these very unusual fuels. And therefore we have to approach it from a different point of view sometimes.

And that different point of view is that you may have to accept that if you put it into a system that it will fail in the system. That you can't maintain the initial primary containment system of the fuel and that it will fail at some point in that system.

Then you get into a philosophical question of is it better, for example, if it's UO₂ fuel, that if you know that at some point in time you are not going to get a transition to those higher oxidation states which would cause the cladding to potential expand and crack, would you then put it into the system when it's gone past that date, or when it's cool enough that it won't actually do that transition.

So sometimes we don't know enough about something, then we have to work to the other safety side of things, which is like I don't want to see it transition and we end up with debris in the bottom of a can or something like that. So if I can engineer a situation where I don't end up like that because I've left it long enough in another system so it would cool enough and it won't there.

Those are the types of things which I do feel are very important, because one thing I have learned is that I know how something is going to behave to the best of my knowledge at a particular point in time. But what I don't necessarily know is how, is the gap. I could have a gap in my knowledge and it's happened to me once. So it can't happen again.

LESLIE: All right, OK.

STANDRING: I don't know what I don't know.

LESLIE: Yes. So and I will use that as a segue. I mean the DOE process, the working group basically for the DOE standardized canister or I should say for the aluminum-based

fuel. You guys went through that gap analysis. And can you - can you explain a little bit more how broadly you looked?

I mean because if you - if you have a small team, you don't know what you don't know, but as you broaden your team in terms of evaluation, I know you talked a little bit about it in your presentation, but, Mike, could you kind of add a little bit more to kind of address Paul's comment about trying to make sure that you've captured everything?

CONNOLLY: Yes. So what we did in that process is we tried to bring together folks from Oak Ridge, Savannah River, Idaho National Lab folks, contractor folks and review as broadly-based as we could the literature that was out there that supported development of research test reactor fuels or how they behave in the reactors.

Those are studies that have been going on for decades. Decades and decades. Now, as part of that, we reached out to fuel people to ask those - to ask additional questions, for example, in a - in the reduced enrichment research test

reactor program, right, the idea of trying to convert reactors from high-enriched to low-enriched.

They're doing a tremendous amount of studies on how does aluminum behave. So we reached out and engaged those folks in those conversations as we looked through their reports.

So even though we had a core team, we reached out to other people whether they were fuels development people, whether they were materials people, whatever it may be, as we started to look from that literature starting back in '58, '59 I think was when we first found some of the early studies on the aluminum fuel, all the way up through all the studies that support the safety analysis report, for example, for the 603 facility, assumptions that they made about hazards identification and whether it was hazards they needed to worry about.

Maybe they didn't need to worry about it in the 25-year lifetime or the 30-year lifetime for the facility, but now that you go 75 years lifetime on the facility, things that they - that dispense with, for example, some of the

corrosion mechanisms in the facility, now you have to consider those. And so we reached out to those folks that did those analyses and asked them those questions.

So it was fairly - I mean even though I talk about a core team, the team did a lot of reach out to other people to try to look at what do we know and what don't we know. And was that - that may have been a valid assumption in 1972 but here we here in 2016, that's really not a valid assumption anymore. So we try to look at all the underlying assumptions that they had with their engineering analyses and everything else and challenge those. It was the approach that we took to try to identify the gaps.

LESLIE: So did you try to bring any international experts or is mainly the expertise here in the U.S., because in some cases you have common problems and common approaches so...

CONNOLLY: We did - I mean we looked - some of the folks that were engaged in this had been engaged in IAEA activities when the IAEA put out their report in 2009. So we went back to the 2009 report. Did we directly bring in

any international folks? No. Did we tried to look at what was done an international basis and reach out to those folks within the complex, the National Lab Complex, that were engaged in those processes.

LESLIE: Sure. Sure. Yes. Because the Board likes to hear that you're looking internationally, that interaction can take a number of different forms and that was one of the things I thought we should bring out in that discussion.

STANDRING: I would just like to add that from my perspective, I would look to the work that these guys are doing on aluminum clad fuel rather than me doing specific work on aluminum clad fuel.

And yes, currently I will use the IAEA's reference documents on aluminum clad fuel, 2009 document. Not sure whether I was actually involved with that. And I know the guys who worked on that and a lot of respect and I think the state of the science sits here at the moment.

LESLIE: OK. Thanks. And I'll turn to the Board to see if there are any questions right now.

TURINSKY: This is sort of a naïve question. Who in the world has aluminum clad fuel? What countries have it? UK has some, we have some, Canada has some. If we look over the Soviet bloc, do they have some and what's the quantities they have and - you know...are there opportunities elsewhere for cooperation?

LESLIE: Go ahead.

STANDRING: Should I answer this question? Well, similar to the U.S., the Russian Federation did a take-back program, which collected all the aluminum clad fuel which was from Russian design and manufactured. So they have quite a large quantity as well.

TURINSKY: So is there communications with them on...

STANDRING: I...

TURINSKY: ...or are they going to reprocess everything?

STANDRING: I can't answer that question, but if you want to know what they're doing and everything else, then the intermediary here is the IAEA, because they know exactly what's going on. I know all the quantities and I know where it all is. I don't know who's doing what and who's not doing what, so that's your vehicle if you want to reach out to international community I think.

CONNOLLY: Yes. Paul is correct. I mean the two largest inventories are what we have in the U.S. and what exists in Russian and the Norwegians may have a few sticks here or there, there's a few sticks here and there, but when you're talking metric tons and a significant problem unfortunately the U.S. has that - wins the prize.

LESLIE: And maybe, Mike, you can talk about the research reactors that are foreign. I mean basically if Bob Sindelar was here from Savannah River, I'd say, "Hey, Bob, tell us how many countries you've brought -- repatriated?"

CONNOLLY: Right. We know. I mean we have a restriction. I mean we are part of the FRR/DRR program at Idaho along with Savannah River. Our receipts got shutdown a few years back, but there's still a few - there's still a few sites out there, Finland.

There's a couple other places that they're looking that want to bring fuel back to Idaho. If Bob was here, he could comment on the Savannah River take-back program. I just don't know which countries they're working with.

TURINSKY: So how is Russia addressing the problem? Are they reprocessing or...

CONNOLLY: I have no idea.

TURINSKY: Communications is still that limited?

STANDRING: I should know the answer to this, but unfortunately I cannot give you the answer, but I should know the answer. I mean I'm trying to remember whether Mayak has a capability to put the research reactor fuel

through, I think it probably can do if it wishes to. It's very flexible in that area. Whether it's actually doing that, you need to consult with somebody who knows the real situation.

CONNOLLY: There are reprocessing options. H Canyon is a reprocessing option, right? The original 1995 programmatic EIS for management of spent fuel for the Department of Energy, they had a regionalization concept. Hanford, you take care of your fuel, they put it in MCOs. Savannah River, Idaho we're going to do a swap. We're going to take all the aluminum fuels, ship it to Savannah River, they're going to process at H Canyon.

We're going to take all the non-aluminum fuel, ship it to Idaho, we're going to package it. So there's treatment options. The La Hague facility, you know, the French are bringing on, I forget what they call it, TI - TC - TC something or other, anyway, it's going to be a line that'll have capabilities for processing research test reactor fuel on the order of a few tons per year.

So there's reprocessing options, but what we're looking at is the dry storage, issues associated with dry storage options as I said earlier to inform DOE decision-making. Maybe we show that you really can't do dry storage and H Canyon becomes a mandatory option for all aluminum fuel or reprocessing of some other type.

Idaho's looking at an advanced processing technique, which is a high temperature chlorination process called Zirc-X. It's capable of working on zirconium clad materials, aluminum clad materials. They're going to be running a demonstration using aluminum clad materials.

So we're looking at other options to address the problem. What we're trying to do with our program is to collect information that supports the Department of Energy and their decision-making process of which direction do I go. If I go on dry storage direction, is it going to be safe? OK.

STANDRING: Just to add on that. La Hague did reprocess the fuel from ANSTO some time ago as well.

CONNOLLY: Yes, they did.

STANDRING: It went through the normal process. So the new process is a special head end that they're putting on so they can take more unusual fuels from what they've done in the past, but they have done some, yes.

LESLIE: So let me ask a question that Mike just brought up and it was the decision-making in DOE. But - so the taskforce, the DOE taskforce that was put together was aluminum-based fuel and what you're - what Josh is working on is really being driven by advanced test reactor and kind of those two things.

How is DOE taking in those, and is DOE taking in those two different kind of projects into figuring out, Mike, you need to have your lid done six months from now because Josh needs it for ATR? And I - if you don't have the answer, that's fine, too, but it...

CONNOLLY: So I'll start off by saying you keep putting us in a position where lab guys are speaking for the

department, but I'll take a swing at it and if I don't do it right, Lance can answer it. So the DOE spent nuclear fuel workgroup, which is - it's co-chaired by the Office of Environmental Management and the Office of Nuclear Energy. Those are some of the issues that they key up and they discuss at their semi-annual meetings.

So there is a lot - and I showed it on my slide - one of my introductory slides with the team is that we are trying to work collaboratively together with both those offices so that the - so that the benefits of research on one side support the benefits of research on the other side.

LESLIE: OK. Josh, you want to add any?

JARRELL: Yes. I mean the only thing I would say is we are working very - like Mike said, very hard to work, you know, to integrate both programs.

The work that we've been doing for NE for ATR fuel, we think that the timing of that potentially we could package non-aluminum fuel which would go through the process and test a

lot of the regulatory basis, safety calcs, all those sort of engineering things that need to be done to support future ATR or aluminum clad loading in the dry storage and the timing actually works out pretty well.

LESLIE: So did you have that idea before you started these calculations or was that kind of an outgrowth of as you get into the process of, "Oh, we've got to deal with this issue, oh, this makes a lot of sense." I don't know if you know the answer to that, but it certainly - this is kind of new information in terms of, "Yes, we're working on advanced test reactor fuel, but hey, maybe it makes more sense to do this stuff over here?"

JARRELL: I mean I think when we started all of this work, I think we had some inclination that you might start with the easier approach rather than go dive in directly to this aluminum clad that we had just identified this whole list of gaps of knowledge. Having said that, though, we had not made the decision, but I think we had that inclination that it may make sense to go after maybe some of these straightforward -

LESLIE: Low-hanging fruit.

JARRELL: Right.

LESLIE: OK.

CONNOLLY: We knew from all the analyses that were done in support of Yucca Mountain that ATR fuel, which is what we've been using as our example, is one of the bounding cases for a whole a bunch of reasons. Criticality, you're going down the list, it's the bounding one for a lot of cases. That's probably not the one you want to start first with.

LESLIE: OK. That's fair. Other questions from the Board or staff? Nigel?

MOTE: Nigel Mote, Board staff. So we're talking about corrosion both for the fuel and the canisters. So this is really a question for Josh. I heard Paul say that the concern about internal corrosion of self-shielding box meant

that there was trepidation about recovery. I guess even more so about reopening.

I heard Mike say that the design lifetime for the standard canister is intended to be 50 years. Now, design typically means you've got good margin on top of that. To what extent are you designing -- the DOE standard canister to foresee that there might be a time in the future that you have to repackage the fuel that's inside it?

LESLIE: So I'll...

UNIDENTIFIED MALE: Sorry, Nigel.

LESLIE: It is a little bit hard to hear up here, but basically Nigel was talking about how Paul has this contingency plan and has to think something else will have to be done. Mike, you talked about a 50-year design life. Yes, you have margin, but to what extent has the work on the DOE standard canister ever considered that it might have to be repackaged or what would drive, you know, again...

JARRELL: Well, I mean the whole idea for the standard canister was to store, transport, and dispose of without ever opening.

So as far as what detailed analysis was done about opening it at some point in the future, I don't know. I mean in general it's a stainless steel half-inch can that you could cut open and get access to the material if you had to. The whole point of that can was the opposite, which was to put it in a condition that you never had to touch again.

CONNOLLY: Let me comment on one thing just because it's - I did not try to infer or say that the standard canister has a 50-year design lifetime.

What I said was in the national spent nuclear fuel program, RFP104 report, materials and action report, is when they looked at the complex chemistry associated with these aluminum oxyhydroxide films on top that they felt comfortable with saying that for 50 years, without knowing more about these films and materials that you're probably

fine. It doesn't mean that the canister has a 50-year design life.

STANDRING: Can I just clarify something here please?

LESLIE: Absolutely, Paul.

STANDRING: So when we talked about corrosion of the skip, you need to put that in context with what that skip is made from, OK. So it is not nice stainless steel. This is historical storage equipment which is - was designed for Magnox fuel. The stainless steel and Magnox fuel is not necessarily compatible in some people's eyes. So this is mild steel painted. So it's context with the...

LESLIE: OK.

STANDRING: ...mild steel painted skip and the corrosion properties over the period. That is why it may not survive.

LESLIE: All right.

STANDRING: So can I - I just wanted to give the context.

LESLIE: Oh, no, no, that's fine and I don't know if Josh or Mike knows the ASTM standard, but I think that was also looking at the corrosion over a 50-year time period as well. If Bob was here, he would know the answer.

UNIDENTIFIED MALE: Bob would know.

LESLIE: Yes. So part of that is with the DOE standardized canister by relying on ASTM, it looks at those process - as Paul points out, it's a really different type of metal for storage. Yes.

MOTE: So maybe I should ask Paul. Why did you use mild steel? But that's not a question we need to face here.

LESLIE: OK. Jean, do you have anything? Otherwise, I'll - I'm not going to extend this, if there aren't any questions you guys have. Do you have any further questions for each other? No. I'll...

CONNOLLY: Let me just address one thing you had on your question list -

LESLIE: Sure.

CONNOLLY: And this is - so the initial - the preliminary modeling simulations that we're showing which are, like I say, are I believe more representative than what was in that materials and action report, is that there is no oxygen in these systems after 50 years. Yes, we may have 35% hydrogen, we may have three or four percent - or I'm sorry, three to five atmospheres pressure, but there is no oxygen.

LESLIE: Right.

CONNOLLY: Right. That's not a flammable situation.

LESLIE: Right. However, putting on a hat for the Nuclear Regulatory Commission because we identified it in our - in our report was actually NRC doesn't care if there's no oxygen in terms of their transportation guidance, in terms

of reviewing for transportation, they have a 4% hydrogen limit. And so one of the points that...

UNIDENTIFIED MALE: Four percent in air.

LESLIE: It says within the canister. So anyway, it's just something that I would encourage you to explore potentially with the Nuclear Regulatory Commission to really clearly understand what their expectations were and I think - now I'm putting my hat not as a moderate but as a Board representative, I mean that was part of the reasons for the recommendation to engage the regulator soon before you start so that you really understand what their words really mean. So anyway. Jean, do you have any final comments or do you just...

BAHR: Well, I guess this is a final comment. Again, I really appreciate all of the speakers taking their time and I appreciate the candid exchange among the panelists. I think that's really helpful. And I think this has been a really interesting day. And we're pleased to see work that we recommended and things that we recommended being followed

up on by the Department of Energy, so thank you for that.

Any final comments or thoughts from anyone on the Board?

OK. Our final time period, we do have available for comments from the public if we have anyone signed up for that. Dan is going to check. We don't. OK. Is there anyone in the room that didn't sign up that wanted to make a final statement? OK. Then we're done well ahead of our 5:00 PM time. I wish you all a pleasant evening and thanks for coming to our meeting.

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