

United States
Nuclear Waste Technical Review Board (NWTRB)

Transcript

DOE Research and Development Related to
Disposal of Commercial Spent Nuclear Fuel in
Dual-Purpose Canisters

VIRTUAL PUBLIC MEETING - DAY ONE

Monday

July 27, 2020

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PROCEEDINGS

BAHR: So good morning. We're about to get the meeting started, and so I hope that Paul can get my slides queued up? Great. Thank you.

Hello and welcome to the U.S. Nuclear Waste Technical Review Board's summer meeting. I'm Jean Bahr. I'm the chair of the board. And this meeting will focus on the U.S. Department of Energy research and development activities related to disposal in a geologic repository of commercial spent nuclear fuel in dual-purpose canisters. Those are canisters which are designed for storage and transportation but not good for geologic disposal.

As you may be aware, this meeting was originally scheduled for April 29 and was rescheduled because of the COVID-19 pandemic. Because of the current situation, we are holding this meeting online, in a virtual format. Also, we are holding the meeting in two half-day sessions -- today and tomorrow -- instead of our usual format of holding the meeting for a full day. This will keep both sessions within the working day of the board members, the

presenters, and other attendees on both the East Coast and West Coast of the United States.

Mr. Paul Case, of Precon Events, will serve as the host of the meeting.

So I am going to first introduce the other board members, and then briefly describe the board, outline what we do, and tell you why we are holding this meeting and our agenda for today and tomorrow.

I'll ask that, as I introduce them, the board members raise their hand so the audience can see who they are.

I'll begin. I'm Jean Bahr. I'm the board chair. All the board members serve part-time and we all hold other positions. In my case, I am a professor emerita of hydrogeology in the department of geoscience at the University of Wisconsin, Madison. I think I'm supposed to switch at this point to panel view, but I'm not sure how to do that. Okay. There we go.

Next we have Mr. Allen Croff. And I believe Paul was going to bring him up live. Here he comes. Okay. Allen is a nuclear

engineer and an adjunct professor in the department of civil and environmental engineering at Vanderbilt University.

Next is Dr. Efi Foufoula-Georgiou. I know she was having some issues with the web interface, so she may not show up. But Efi is a distinguished professor in the departments of civil and environmental engineering and the earth system science, and also the Henry Samueli endowed chair in engineering at the University of California, Irvine.

Next we have Dr. Tissa Illangasekare. Tissa is the AMAX endowed chair of civil and environmental engineering and director of the center for the experimental study of subsurface environmental processes at the Colorado School of Mines. Good morning, Tissa.

Then we have Dr. Lee Peddicord. Lee is a professor of nuclear engineering at Texas A&M University.

Okay. Dr. Paul Turinsky is next. And Paul is an emeritus professor of nuclear engineering at North Carolina State University.

Then we have Dr. Mary Lou Zoback. And I

don't know if Mary Lou has been successful in joining us yet, but we expect her soon. Mary Lou is a consulting professor in the geophysics department at Stanford University.

And then last but not least is Dr. Steven Becker. And we know that his camera is not working. Steve is a professor and chair of community and environmental health in the college of health and sciences at Old Dominion University in Virginia.

So I've just introduced seven of the board members, plus myself, not the full complement of eleven. Dr. Susan Brantley, who is a distinguished professor of geosciences at the Penn State University -- Efi, thank you. Welcome. Sue is at Penn State University. She is not able to join us for this meeting. 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 the board members are their own, not necessarily board positions. Our official positions can be found in our reports and letters, which are available on the board's website.

Okay. So now we are going to switch back to the slide view and say goodbye to the board members, except for me, and on to a description of the board and what we do.

As many of you know, the board is an independent federal agency in the executive branch. It is not part of the Department of Energy or any other federal department or agency. 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 Department of Energy activities related to implementing the Nuclear Waste Policy Act.

Okay. The board members are appointed by the president from a list of nominees submitted by the National Academy of Sciences.

We are mandated by statute to report board findings, conclusions, and recommendations to congress and the secretary of energy.

The board also provides objective technical and scientific information on a wide range of issues related to the management and disposal of spent nuclear fuel and high level

radioactive waste that will be useful to policymakers in congress and the administration.

All of this information can be found on the board's website, www.nwtrb.gov, along with the board correspondence, reports, testimony, and meeting materials, including webcasts of recent meetings. So there is our web -- our web address.

And if you would like to know more about the board, a two-page document summarizing the board's mission and presenting a list of board members can be found on this board's website.

And we'll have a public comment period at the end of each day of the meeting. Because of the virtual format of this meeting, we can only accommodate written comments. When you joined this meeting, you will have seen a link for submitting a comment for the record. Comments we receive before the end of each day's break period will be read online in the order received by board staff member Bret Leslie. Time for each comment may be limited depending on the number of comments we receive, but the entirety of the submitted comments will be

included as part of the meeting record.

Comments and any other written materials may also be submitted later by mail or by email to the points of contact noted in the press release for this meeting, and that press release is posted on our website. These 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 will see during the meeting.

The meeting is being recorded and the archived recording will be available after a few days on our website. And to assist those watching this meeting, the meeting agenda and presentations have been posted on the board's website and can be downloaded.

So, why are we holding this particular meeting? In the United States, commercial spent nuclear fuel is stored at over 70 sites, including operating and decommissioned power plants, and is continuing to be generated at a rate of more than 2,000 metric tons of uranium per year. Much of the spent fuel is in dry storage inside canisters that have been designed

to serve for both storage and transportation, and because of those two purposes, they're known as dual-purpose canisters. These canisters are welded closed after the spent fuel has been loaded. And while they have been designed for storage and transportation, design of these did not consider their potential use for geologic disposal. Currently, the dual-purpose canisters in U.S. number more than 3,000, and as the figure in this slide indicates, this number will increase significantly with time. Disposing of spent nuclear fuel in dual-purpose canisters, after loading the canisters into some sort of suitable disposal overpacks, has the potential to avoid the cost and the complexity of cutting the dual-purpose canisters open and repackaging the fuel into smaller canisters. That would also eliminate the need to dispose of the empty canisters as low-level waste, and it would decrease worker dose during handling before eventual disposal in a geologic repository. And for these reasons, over the past several years, the Department of Energy has been investigating the feasibility of disposing of spent nuclear

fuel in dual-purpose canisters in a geologic repository, without first repackaging the fuel into other canisters, and DOE refers to this process as direct disposal of spent nuclear fuel in dual-purpose canisters.

At the board public meeting held in Albuquerque, New Mexico, in October 2018, representatives from DOE and the national laboratories described the results of preliminary studies on the technical feasibility of disposal of spent nuclear fuel in dual-purpose canisters. Since that meeting, DOE has made progress in its research and development efforts on this topic and, today and tomorrow, we'll hear presentations on the most recent results.

So today's session will start with an opening statement by Dr. Bill Boyle of the Department of Energy Office of Nuclear Energy. We'll then have a presentation on past studies on the technical feasibility of disposal of spent nuclear fuel in dual-purpose canisters. After that presentation, we will take a break and resume at 2:30 p.m. Eastern time. We'll

then hear a report on the technical bases for the engineering feasibility and thermal management of disposing of spent nuclear fuel in these canisters. That will be followed by a presentation on one of DOE's ongoing research and development activities, which is reactivity analysis of dual-purpose canisters. Then, as I mentioned earlier, we'll have a public comment period during which staff member Dr. Bret Leslie will read the public comments we have received. And we'll adjourn today's session at about 5:00 p.m. Eastern time.

Tomorrow we'll resume the meeting at 12:30 p.m. Eastern time with additional presentations on ongoing Department of Energy research and development activities, and I'll introduce those in more detail tomorrow morning.

Okay. So now we're going to switch to the camera view just briefly. I'm going to queue up the slides for -- I guess there are no slides for our first speaker.

A lot of effort went into planning this meeting and arranging the presentations, and I want to thank our speakers for making

presentations at the meeting today and especially those who participated in a board fact-finding meeting that was held at Oak Ridge National Laboratory back in March, on March 6. I would also thank the board members Allen Croff, Lee Peddicord, and Paul Turinsky, who acted as the board leads and who coordinated with the board's staff to put this meeting together.

So our first presentation. It's my pleasure to turn the meeting over to Dr. William Boyle, who will get the meeting started. So I will get rid of myself, and there is Dr. Boyle.

BOYLE: Okay. Thank you for the introduction and this opportunity.

Can everybody hear me and see me okay?

Seeing no objections, or seeing no chat, I assume you can.

I think what I'm about to say, the board and the staff know, but to inform the public, I was not originally going to be the presenter this morning. I'm very happy to do it.

Originally it was going to be the assistant secretary for nuclear energy, Dr. Rita

Baranwal, but she got another offer she couldn't refuse.

People may not realize, when NASA sends missions into deep space, they have a choice of how to generate electricity. Some of their missions they use solar panels.

Others the sun is not good enough for them, so they use radio isotope thermal generators, where it's decay heat from radioactive decay of isotopes can be converted over to electricity. I'm not an electrical engineer so I can't explain it.

But the Office of Nuclear Energy has for years supplied these generators to NASA and this week NASA's launching Rover to Mars. And so NASA invited Dr. Baranwal to come for the launch this week for the Perseverance Rover. So she is on her way to Cape Canaveral. And I will be presenting her remarks, which to show you that she really was going to do this, it's written in the first person, which I will convert to the third person as I read through her talking points.

And it's an overview of everything that

the Office of Nuclear Energy does.

So thank you again for this invitation to speak today.

Rita views nuclear energy as crucial to ensuring the sustainability of our environment now and into the future.

Nuclear energy is the nation's largest source of clean, reliable and resilient electricity generating about 20 percent of the electricity in the U.S. and over 55 percent of the nation's clean energy.

In 2019, electricity generated by nuclear in the U.S. avoided the release of over 476 million metric tons of carbon dioxide in the atmosphere. That's like removing 100 million cars off the road.

Many countries see nuclear energy as a means to meeting their energy demand in growth, supporting their clean energy goals and providing energy, diversity and security, just as we do.

I am confident that U.S. nuclear energy technologies can and will play a major role in providing the U.S. and the world with clean,

reliable energy for days to come.

Nuclear energy is revolutionary beyond electricity generation.

Nuclear energy can provide low emission energy for water desalination to achieve worldwide water secure.

Nuclear energy can decarbonize the industrial sector with processing.

Nuclear energy can decarbonize transportation with hydrogen and electrification.

There is a current funding opportunity announcement open for a pilot program for these purposes at the Davis-Besse Power Plant.

And nuclear energy helps the betterment of humankind by way of medical applications and space exploration.

Rita believes the United States has the most innovative technology offerings in the advanced reactor technology space.

The U.S. is developing a diverse catalog of technology options from microreactors for small grids, remote or islanded communities, small modular reactors to large reactors to meet

large baseload generation needs. We have the right reactor for the application.

New advanced nuclear reactors have the potential to solve the diverse challenges across our nation as well as across the globe.

At DOE we are focusing our efforts around four priorities: Sustaining the existing fleet of operating nuclear reactors, mainly through our work on accident tolerant fuels and the light water reactor sustainability program.

The second priority is getting advanced reactor technologies over the finish line.

The third priority is establishing and maintaining critical fuel cycle infrastructure.

And the fourth priority is enhancing global competitiveness.

We are already seeing the fruits of the labors in the past of the Office of Nuclear Energy. One small modular reactor concept is undergoing license review by the nuclear regulatory commission, and the first nonlight water advanced reactor entered the nuclear regulatory commission license review process.

In April, the president's nuclear fuel

working group released its report restoring America's competitive nuclear energy advantage, which lays out policy options to restore American's leadership in nuclear energy and technology. The report recommends continued support for the demonstration of U.S. advanced nuclear technologies.

The Office of Nuclear Energy took action on that by launching the advanced reactor demonstration program, or ADRP.

This program focuses DOE and nonfederal resources on the actual construction of advanced demonstration reactors that are affordable to build and operate.

The window to apply to participate is currently open and will close on Wednesday, August the 12th.

Ultimately, the goal is to make awards by the end of this calendar year.

The Office of Nuclear Energy is also strongly supporting the National Reactor Innovation Center, known as NRIC, to enable these demonstrations.

In 2018, the president signed the

Nuclear Energy Innovation Capabilities Act which created the National Reactor Innovation Center.

The center, which is led by Idaho National Laboratory, accelerates the demonstration of advanced nuclear energy technologies by harvesting world-class capabilities of the DOE national laboratory system.

It does this by enabling the testing and demonstration of reactor concepts proposed and partially funded by the private sector in partnership with our national laboratories.

This center enhances these private/public partnerships by focusing on executing specific activities at the national laboratories in partnership with industry to achieve demonstration and ultimately deployment of advanced technologies.

The president's nuclear fuels working group report also highlights the vital importance of the versatile test reactor known as the VTR.

The United States has identified the construction of the VTR as a cornerstone in

reviving and expanding our nuclear sector and is one of the highest priorities for the Department of Energy.

Once completed in 2026, the virtual test reactor will support the development of advanced reactor technology and the continued operation of the existing fleet through accelerated testing of new fuels and materials and development of advanced instruments and sensors.

In 2019, the DOE formally established the mission need for the virtual test reactor.

Further support is shown through the president's fiscal year 2021 budget request which asked for \$295 million to support the design and construction of the facility.

Additionally, many of these concepts will require high-assay low-enriched uranium, which people call HALEU, and we are pursuing multiple pathways for HALEU.

As an aside, probably many people outside of the nuclear business, commercial power plants use fuel that's about five percent enriched in uranium 235. This high-assay low-enriched uranium is still low-enriched, but

it's about 20 percent enriched in uranium 235.

That's what differentiates high-assay low-enriched uranium from what's currently used today in power plants.

The report also recognizes the importance in having a healthy operating fleet of nuclear reactors in the market challenges they are facing currently.

The department is investigating alternate sources of revenue for the existing fleet including through the production of hydrogen.

Also, in support of the front end of the nuclear fuel cycle, the fiscal year '21 budget request includes \$150 million to establish a uranium reserve in order to support uranium mining and conversion capabilities in the United States, as well as provide a backstop for the uranium in the event of a market disruption.

Finally, we need to make sure that the world has access to civilian U.S. nuclear energy technology.

We want the world to adopt and utilize U.S. technology because it comes with the

highest regard for safety and security, standards that some competitors do not have or require.

Regaining our global leadership through the export of our U.S. nuclear energy technology will ensure that our proliferation security and safety standards are adopted and maintained globally.

We are moving forward to ensure the U.S. regains its nuclear energy leadership building upon the United States leadership in innovation and advanced technologies, but this will not be easy and will require a lot of work. In particular, we want to achieve these aggressive goals by 2030.

Thank you for letting me make this presentation. With that, I turn control back to Chairperson Bahr.

BAHR: Okay. Thank you, Dr. Boyle.

And we have about 20 minutes for questions. So are there questions from the -- from the board members for Dr. Boyle?

I see Dr. Turinsky with his hand up. I'm bringing him up. There we go. And are

you -- you're muted. Unmute yourself. Okay.
Good.

TURINSKY: Can you hear me now? Okay.
In your program that we'll be talking about
later today, you have this option 2, which is
basically to work with utilities to put in their
current canisters either special control rods,
curtains or actually how they load it to address
the criticality issue that we're going to be
talking about at length later on that.

Mine is a nontechnical question. And
that is, other than budget to go out and work
with utilities and their vendors and give them
perhaps some financial incentive to do that, is
there special legislation required? Is there
anything in the current legislation that
prevents you from having conversations with the
utilities in moving forward?

This seems like just sort of a fairly
inexpensive thing to do. It may never be used,
depending on the path forward, but it's so
inexpensive relative to some of the other
options that we're looking at, that you're
looking at, the department is looking at.

It would seem almost prudent to start thinking about perhaps having those conversations, and having utilities as they move forward, not with their current canisters there are already sitting out on the site, but in future canisters, exercising that option, too.

BOYLE: I think, if I heard you correctly, you started off with a question about whether the law permitted it. And we've certainly looked at the technical aspects. And offhand, maybe Tim has a different knowledge. I'm not aware of anyone ever bringing up a statutory problem with working with the utilities to do this.

I think it would certainly require the cooperation of the utilities, and even as you mentioned in your question perhaps consideration for them.

But my -- as far as I know, it could all be handled through the standard contract, if need be. I'm not aware of any statutory issues.

TURINSKY: Okay. Thank you.

BAHR: We have a question from Dr. Peddicord.

PEDDICORD: Yes. Thank you.

So first of all, this is always a very interesting presentation of the scope of the work going on in the Office of Nuclear Energy, and certainly a lot of key initiatives.

And you mentioned both as the -- as part of the fuel cycle work and the fuels work with the HALEU activities, which I think are going to be quite key in terms of the new technology, SMRs, the microreactors and so on.

My question -- and we're talking today about the dual-purpose canisters, but have you started looking ahead towards the implications of the HALEU shields towards the back end of the fuel cycle and disposing and so on? And one of the questions that comes to mind, with enrichments up to almost 20 percent, some of the designs out there for SMRs and so on, and microreactors, as well, suggest some quite high burnups that these might reach, well beyond anything LWRs achieve.

So I'm wondering if you get a chance to start at least going through thought processes of the implications of these new directions and

fuel enrichments, fuel designs and so on on the infrastructure and the technology and even things like the canisters that you're looking at now?

Thank you.

BOYLE: Yes. Sure. Historically, this has been looked at. A few years ago in the Office of Nuclear Energy -- I had always associated the work with a colleague, B.P. Singh -- did a study that looked look at alternative fuel cycles from beginning to end, you know, different power generators, accelerators, fast reactors. And the storage and disposal aspect was considered for all of those.

Also, in this year's appropriation, the United States Congress has directed the Office of Nuclear Energy to contract with the National Academy of Sciences to look at different fuel cycles, including the disposal impacts.

I will point out that in the U.S. inventory for things to be disposed of today, there's things with varying enrichments.

The commercial enrichments have only

gone up through the years. They were lower than 5 percent. Now they're up around 5 percent.

But the things in the government's possession, for defense reasons or research reasons, have higher enrichments and different isotopic compositions as a result, which is what high burnup would produce as well.

It's all a question of detail. But I think the fact that the U.S. already has things in its possession that are different from what the bulk of what is produced today, yet it demonstrated it could be disposed of.

I personally believe as long as people pay attention and don't accidentally or deliberately do something foolish, any waste stream coming out of the different fuel cycles should be able to be handled appropriately.

PEDDICORD: And this seems like a good opportunity to draw on the work that the labs have done at multiple locations, but particularly Idaho, on the DOE inventory of spent fuels and look at the implications for these new designs, new applications, some of which are really quite intriguing in terms of

the innovative approaches, as well. So this is really a chance, in my mind, to blend a lot of this together, integrate across a variety of DOE programs. So thank you.

BOYLE: I will say in the near term we do actively cooperate with our colleagues and any that are working on the accident tolerant fuel. Because it is -- it's typically different in its cladding, which leads to different weights, you know, which -- it's just different.

So we are aware of those differences and we do work with them to make sure that we stay aware of the changes that may be coming.

PEDDICORD: Thank you.

BAHR: Okay. We have a question from Paul, who is coming up live. There we go.

TURINSKY: I got my camera centered also this time.

What we're going to hear about you folks have been doing is all on canisters.

Has any work been done on cask systems? That is the bolted systems. I know the (inaudible), but has anyone done an exercise on how they would differ the issues you're

investing for the canisters?

BOYLE: Well, I'm pretty sure that this work started off with a basic question of could we dispose of what exists today, which is largely the welded stainless steel canisters, but there are bolted systems out there.

So Tim or Ernie may have -- and Kaushik or others may have more information, but it's always been my belief that, yes, we did look at bolted as well because they exist today.

TURINSKY: Okay. So if the other speakers when they're talking about canisters, if they could also mention what they know work they've done on cask, that would be useful.

BOYLE: Yeah, okay.

BAHR: Sorry, my mic was off.

I was asking if we had any questions from staff members.

I don't see any more hands raised from the board members.

I see Bret Leslie.

LESLIE: Thank you, Jean.

Today we're going to hear about the ongoing studies on technical feasibility of

direct disposal.

I know you proposed in your next fiscal year to completing an evaluation. And what more would be done? Or is this a question for Tim a little bit later?

BOYLE: Well, Tim can always address it, too, but from my point of view, we do -- the bulk of our work is done by scientists and engineers at national labs, and I've learned from experience that there's always yet another technical question.

We're not really at a stage where we're working on a firm fixed price contract, if you will, where we have to get something done by a certain due date with exact specifications.

We're doing research and development, so we're mainly in the data gathering, data production phase.

Somebody -- when the country makes up its mind what it wants to do with respect to storage disposal, or even something else, then we will have generated a lot of the data that will inform such a decision.

LESLIE: Okay. Thank you, Bill.

BAHR: Other staff members?

Okay. I am not seeing any more questions for Dr. Boyle --

BOYLE: One more remark.

I think Tim shows a slide where he goes through some of the history of looking at the direct disposal of the storage systems that exist today. And you'll see that this work goes back quite a ways, at least to the 1990s.

But I would say it got a bit of a rebirth due to some strong encouragement from a member of the Nuclear Waste Technical Review Board. It was Andy Kadak, after 2010, who encouraged as long as we -- we, nuclear energy -- were going to look at multipurpose systems that could store, transport and dispose -- as long as we were going to look at the little ones, like that maybe had a capacity of four pressurized water reactor fuel assemblies, why didn't we look at turning the existing dual-purpose canisters into disposal systems as well.

So I did want to acknowledge that a lot of this work came at the original suggestion, at

least more recently -- like I said, Tim will show history that others had the idea long before. But it was one of the board members that led to a lot of this work. So I'd like to acknowledge it.

BAHR: Thank you. Thank you for acknowledging that.

Okay. We're a little bit ahead of time. I want to try to keep us pretty much to the publicized agenda since we are online and there may be people joining just for part of this.

I did want to acknowledge that Mary Lou Zoback has joined us now. So maybe I'll bring Mary Lou on, if you're willing to be -- okay. So that's Mary Lou Zoback. I'm sorry that she had a little trouble getting on. So I think now everyone has seen all of the board members.

Anything else? Are there any housekeeping issues from the staff that we need to remind people of?

Again, if you have -- if members of the public who are watching have questions, there is a way to submit those online, and we'll need to have those submitted before our break, which is

scheduled to take place at 2:00 p.m. Eastern time.

So if you have any trouble doing that, I think there may be an email. Maybe I'll ask one of our facilitators here to come on and -- Paul Case, can I make you live -- or Jason -- in case there are issues that people watching out in online land might have?

CASE: Yeah. We haven't had any yet, but as you stated, there is a form on the website for them to submit questions.

If anybody is having a problem with the stream, they can refresh their browser or there are backup streams available on the website.

BAHR: Okay. Thank you, Paul.

We'll take a brief minute to queue up the next speaker, who is Timothy Gunter from the Department of Energy, Office of Nuclear Energy.

We have Bret Leslie.

LESLIE: Yeah. So the form that you mentioned for submitting public comments is working fine. I've got a number of people who have already tested the waters to make sure it works. So we're getting them.

BAHR: Okay. Excellent. Good to know.
Thanks, Brett.

So we are queuing up Tim Gunter and his presentation. And Tim is going to provide us with the historical review and also update on how studies of technical feasibility of dual-purpose canister direct disposal.

And I will take myself off for the moment and turn it over to Tim.

Thank you.

GUNTER: Okay. Thank you, Dr. Bahr, for the introduction.

And good morning or good afternoon to everyone, depending on where you're located.

I'm Tim Gunter. I manage the disposal research program for the office of spent fuel and waste science and technology within the Office of Nuclear Energy.

I'm going to talk today a little bit about the history and overview of the past studies that we've been doing related to the direct disposal dual-purpose canisters.

Once I figure out how to advance the slide. Here we go.

So you'll see on each of the presentations today the first slide will be a disclaimer. I'm going to spend just a few seconds on it and then the others won't necessarily have to go through it.

It somewhat relates back to Dr. Turinsky's question on working with the nuclear industry. And that is, we want to make clear that the work we're doing is research and development.

We're looking at the technical issues and the feasibility for direct disposal of DPCs, and that doesn't necessarily recognize that there are standard contracts in place with the industry that describe how and what types of spent fuel will be disposable.

So to the extent that the work we're doing is not 100 percent aligned with the standard contracts, just recognize that the standard contracts would take precedence and that any future decisions on implementing it would have to be considered. There's not only policy but legal issues related to the standard contract that would have to be addressed.

Just a brief outline of what I'm going to talk about, a little bit of background, a lot of which actually Dr. Bahr presented in her opening comment, so I will speed through some of that.

A couple examples of DPCs in service, projected inventory of DPCs.

And then talk about the history of the storage-transportation-disposal canister investigations.

And then what is our current campaign work going on related to that and then a quick summary.

And before I forget, the other question about bolted canisters, I'm going to somewhat defer that to either Ernie or Kaushik. But just in general, when we started this back in 2012, 2013, one of the things that the lab did was to review the existing work that had been done to date, and I'm going to say that that included the bolted canisters, but I'll ask Ernie or Kaushik if you could remember to address that in further detail when your presentation comes up.

Okay. This is the background. Like I

said, you've seen some of this already.

But just to go through it quickly, dual-purpose canisters, we call them DPCs for short, they were designed, licensed and loaded for storage and transportation of spent nuclear fuel, but not with consideration for ultimate geologic disposal.

So what are some of the things that could be problematic with disposing in a repository DPC?

So I have a few of them listed here as subbullets.

One is the fuel baskets. They were designed to control criticality for short-term operations, such as during fuel pools and also for transportation accidents.

The longevity of some of those materials are not that robust, so after disposal, some packages, in geologic time, could eventually breach and allow water to infiltrate the packages.

Because water is a moderator which can increase the reactivity of the spent fuel, it becomes an issue to criticality.

And I mentioned the neutron absorbing materials that are in the DPCs.

Most of them are aluminum-based so they don't have long-term resistance to groundwater.

And there's about currently more than 3000 DPCs across the U.S. at a number of different locations containing spent fuel.

Typically, a DPC would hold 32 PWR assemblies or 68 BWR assemblies. That's typical, but some hold less, some hold more.

And I'll show you a couple of examples coming up.

So why would we want to directly dispose of DPCs?

Well, the biggest reason is repackaging of spent fuel into specifically designed disposal canisters, given the number of DPCs that we already have in existence, would be financially and operationally costly.

Also, it would have radiological operations, safety and management risks because the repackaging process would, of course, give you additional radiation exposure to workers.

You have more operations just from

repackaging, so there's additional risk. And the more activities you do, the more risks there are in something happening.

And we looked at, you know, potential cost avoidance if we were able to directly dispose of DPCs.

And this is a rough order magnitude estimate, but we did some estimates in the past where we used available industry data and DOE data that estimates repackaging costs.

And we believe, like I said, rough order magnitude, the avoidance could be up to \$20 billion savings if we could directly dispose of DPCs, about half the repackaging specifically designed and built disposal packages.

So what makes up this savings? What are the different things that could result in this?

Well, the third bullet there, the significant contributions to cost avoidance, first off, you eliminate procurement cost of the disposal canisters.

So right off the bat you're eliminating -- like I said, we've got 3000 DPCs today. That number continues to rise.

So it's a large number of disposal canisters that you would have to procure.

Reduction in the number of disposal overpacks, which the canister would go in for disposal.

I think the biggest -- probably the biggest one is the third subbullet, elimination of repackaging operations.

You know, it's not a -- not a simple thing to remove fuel from one canister and put it in another canister, because it has to be done remotely, typically in fuel pools. So there's a large amount of cost there that would be required.

And then the last item is just elimination of disposal of the DPC hulls and baskets as low-level waste.

So you take the fuel out of the DPCs and you put it in a specifically designed disposal canister, then you have the leftover DPCs that are no longer needed and you have to somehow get rid of those.

So just to show a couple of examples. I think most people on the -- on this conference

probably knows what a DPC is, but in case you don't, here's one example of a NUHOMS horizontal DPC.

Most disposal canisters are the same general design. They're a metal cylinder with some type of internal basket structure that allows the fuel assemblies to be inserted into the canister.

The basket design varies based on whether it's PWR, pressurized water reactor, or boiling water reactor assemblies.

The actual materials of construction typically are stainless steel, but the internal materials can vary based on design and continued use.

This particular design is about one third of the current fleet.

On slide 7, this is just another example. This is Magnastor DPC by NAC International.

The previous one, like I said, was a horizontal design. It was intended to go horizontally into concrete storage.

This is a vertical design. It goes into

also a concrete overpack, but typically they're in a vertical orientation and then they sit on a concrete pad.

Okay. Moving on to slide 8. Dr. Bahr showed a graph similar to this, although hers I think was a number of canisters. This one's in metric tons heavy metal.

But shows roughly the same results, and that is, as you go out in time, the amount of spent fuel in spent fuel pools is decreasing as more and more fuel is placed into dry storage systems.

So you see the green line going up and the blue -- which is the dry storage inventory, and the blue line going down, which is the spent fuel pool inventory, and then the red line is the total inventory.

And when this graph was created, they put in a couple of key points.

So 2008, which was about the time of the license application for Yucca Mountain, and then the recent date of 2017 that they had the data to generate this.

But you see about in the year 2022 or so

where those lines cross? You have the same amount in the pools and dry storage, and then the amount in dry storage continues up until pretty much 100 percent of the spent fuel is in dry storage.

And this -- this chart was based on a few assumptions. They are listed there. One is it assumes no new reactors, and also it assumes license renewals for up to 60 years for the current fleet unless they've been announced for an earlier closure. This comes from a Sandia report that's listed there.

Okay. On to a bit of history. I think Bill mentioned this has been -- or at least the concept of directly disposing dual-purpose canisters has been around for quite a while, going back to the early 1990s.

In fact, the disposability was recognized as an issue for storage canisters by both DOE and the Nuclear Waste Technical Review Board as early as 1992. And there's a reference there to a presentation that was made to NWTRB back in January 1993.

Large waste package capacity was

established by the MPC conceptual design report and later modified by Westinghouse design study. Again, recognizing the need for a multipurpose-type canister system.

And not only in the U.S. has this been something that's been investigated, but also internationally.

International programs have demonstrated subcriticality using burnup credit without neutron absorbers for small waste packages. And that's up to like a 4-PWR or 12-BWR.

Of course, our concept is larger than that, even though we did look at those smaller packages at one point in the program, but one of the issues to that is, you know, obviously, if you have small packages you're going to have a lot more canisters to handle and dispose of, and the fact that that would also require some type of repackaging for the smaller package design. And it makes reference to the Swedish concept.

So again, just some of the history of investigations in this.

The 2008 license application, it recognized what was called a transport aging

disposal canister, or TAD. It was a multipurpose canister for -- it was also disposable. And it was purposely designed. The intent was things would be repackaged, most likely at a repository site.

What made the TAD suitable for disposal, like I said, it was purposely designed. It had 11 millimeter thick basket plates of borated stainless steel, which was a neutron absorber. It would reduce criticality probability.

Corrosion resistance of the borated stainless steel was evaluated and validated experimentally.

It was also included in regulatory safety reviews conducted by the NRC.

Direct disposal of commercial spent fuel in DPCs, turned out it was not implemented, even though it was considered.

There were a couple other reports that are listed as footnotes. BSC, Bechtel SAIC, looked at this issue. Also EPRI, Electric Power Research Institute, looked at this issue also.

They pretty much identified post emplacement criticality as the most important

technical issue to resolve, and suggested that fuel burnup data from reactor operations should be used to perform the criticality analysis and take into account as-loaded configurations.

The EPRI report basically looked at both thermal and criticality and found that in their view there was no technical impediment to the direct disposal and conditions of volcanic tuff, which was the proposed disposal geologic media at that time.

So that brings us up to what we're doing in DOE under the spent fuel and waste science and technology.

So we want to continue the research for availability of technical solutions for safe, timely, cost effective disposition of commercial spent fuel in dual-purpose canisters.

There's a number of different strategies that could be employed.

The three that we're kind of focused in on are direct disposal without modification. So basically, we don't want to repackage. We want to directly dispose. And to do that one of the biggest technical issues is criticality during

postclosure. And we have to address either the probability or consequences of that.

The other way we could get at this, number two, is modification of already-loaded DPCs with injectable filler material.

So what we need to do is avoid infiltration of water, and if we can find an acceptable method of filling the canister with some type of filler material that would keep water out, if it ever breached in the repository, that would prevent the moderator, the water, from coming in and enhancing the probability of the criticality.

And then the third item there is modification of DPCs to be loaded in the future. Either that or the fuel they contain, by changing loading maps, adding disposal criticality control features, or basket redesigns. And we'll talk a little more about the details of that.

So slide 12 is kind of a timeline of our work in the campaign going back to 2013 -- actually, 2012, fiscal 2013, I think. But where we did a feasibility study and we tasked Sandia

and our other labs to take the lead on that.

The core components of the study are those first four items from 2013 to '14.

So safety, engineering, thermal management, postclosure criticality.

The first thing they did -- or one of the things the lab did for this is they reviewed a lot of information that was existing, such as the historical data on the previous two slides.

As I said, criticality is the one that keeps coming up as probably the one that's one of the most important, but there are other issues, too.

So the safety basically encompasses two major aspects. It's safety of the workers that are -- that would be doing the -- you know, handling the DPCs, and then safety of the public and the environment in terms of how would this perform in a repository, can we ensure that your probability of criticality is low or if you have a criticality that it would be -- would have no impact on the environment.

There are a number of engineering aspects that were looked at. DPCs are large and

heavy components, so we had to look at, first off, can you -- even though they handle those in the industry at the sites, we had to look at how would they be handled at a potential repository site. Could they be put underground? And that somewhat depended on, you know, specific site designs. Are you using a design that employs a ramp to get your waste packages underground, or are you using a shaft, which is typical in salt repositories.

There's also thermal management issues that we had to look at because DPCs, like I said, are large, they contain a lot of fuel. You have heat -- increased heat loads that have to be evaluated. What impacts might they have on repository performance.

Can that be -- one of the ways that can be addressed is surface aging to allow the heat to decay over time so that when you put it underground you don't have as much heat that you have to consider.

It also can have an impact on actual repository designs on, like drift spacing, how much distance you have to have between adjacent

waste packages to avoid exceeding any limits on the repository -- or on the spent fuel itself.

And then as I mentioned, one of the big ones we're looking at is postclosure criticality. And that centers around either preventing or limiting criticality in the underground postclosure, which could have an impact on the repository performance because if you have criticality you're changing your isotopic composition in the canister. It also could have an impact on the performance of the waste package and the engineered barrier systems.

So that's what we spent the first couple years looking at. You'll hear a lot more on those topics today from Dr. Hardin. He follows me. Particularly on the thermal management and engineering criticality will be addressed also when he talks.

As we move out in time beginning in late 2014, 2015, we looked at other specific issues that were actually in some way related to the first four.

But salinity calculations had to do with

the salinity of the water that could potentially leak or infiltrate the disposal packages, to the point there being that if you have higher salinity water, the chlorine in the water could reduce the probability of criticality.

Overpack reliability, again, on how well does the overpack prevent infiltration of water.

And then we issued a -- it's called a final report. That might be the title. It's actually kind of an interim report of where we stood at the time and made recommendations on, you know, what needed to be continued or what other topics we should look at going forward.

So beginning then based on the final report and there was some other things that came up, particularly the filler investigations, which I mentioned, where you can potentially fill the canister through drain or vent ports. You wouldn't have to cut it open. Fill it with some type of material that would take up the void spaces and reduce or prevent any water from leaking in in the future.

Continue our criticality calculations.

And then about 2018 we started another

issue which was criticality consequence analysis.

This was -- this also has to do with the performance in the repository, but the direction it takes is if you can't demonstrate low probability, can you live with the consequences of criticality in the repository? What would -- what would that look like and what would it do to performance?

And then the last item there is the fuel basket modification. So are there things that we can do for future canisters, the basket designs, the canister designs that can be implemented relatively easily.

Also even the fuel, while it's in the spent fuel pool, are there things there that could be done that would improve the criticality in terms of decreasing probability.

And all these -- all these items will feed into our next report.

Basically, we issue -- or at least typically we issue our annual update on our reports for what we've been doing for the past year and what -- any conclusions we have. So

all those topics and the timeline continue to feed into our updated reports.

And then someone mentioned -- maybe it was Bret -- the 2021 final report. So those would all feed into that, also. And I think Bill mentioned this, too.

It's called the final report because we would like pretty much a path forward on which way we should go and what potentially out there still could be an issue. But there are things certainly that we know won't be completed. For example, criticality analysis. Particularly like the as-loaded criticality analysis. That's something that would take a long time for all the canisters out there. But the report would be to continue doing those analysis.

And I will touch on -- not to take too much of Ernie's talk, but just the feasibility studies results that we've done over the past few years, as far as the -- particularly the safety and engineering, even somewhat thermal management, I feel like there's no major implementation barriers to those issues.

There's still a little bit of work to be

done maybe, but particularly for like repository designs, that's going to be specific to your actual repository design, you know, whatever -- in other words, it's going to be different whether you have -- eventually have a design in salt or in granite or in shale.

So a lot of that work we've done about as much as we can do and we would need site-specific data for an actual proposed repository site in order to do a whole lot more on the -- on those issues. But as I said, we don't believe there's any -- any major problems with resolving that. A lot of it is design concept, particularly on the canister handling, we think that can be overcome. It's just a point of getting -- getting there.

So on page 13, I wanted to mention that in the R&D program we have what we call an R&D roadmap, which kind of lays out our current priorities on R&D. That was done originally back in, I think, 2012, 2013.

But we recently did -- fiscal '19 we did an update to that where we went back and reviewed all our R&D and just checked to see if

there's things that needed changed in terms of priority.

We did that by somewhat of an expert elicitation type of activity, but it was really mostly the lab and some other folks that came together and evaluated the research in terms of, you know, how much do we know, how much do we still need to know. You know, the level of maturity, the impacts of every search on the potential performance assessment.

So included among the highest priority R&D activities that came out of that -- came out of that review, there is four that are listed there that are specifically applicable to the direct disposal of DPCs.

So again, postclosure criticality consequence analysis which are, like I said, a more recent initiative.

The DPC filler and neutron absorber degradation testing and analysis. And the neutron -- I talked about the fillers, but the neutron absorbers, you know, would be looking at did you replace, you know, some of the less robust neutron absorbers that were part of the

original DPC or canister with something that has a better longevity in the underground.

Also, multi-physics simulation of DPC postclosure. So it looked at interaction between chemical, mechanical and thermal-hydraulic processes, not only within the waste package, but what impact could those have on items external to the waste package, such as the engineered barrier systems, the actual geologic media that you're using to dispose of.

And then source term development with and without criticality, which the source term is certainly key to, you know, the performance.

First, if you have a criticality, then you change the source term and then you have a new set of radioisotopes that you have to consider in your performance assessment.

So our current program started with the work we did earlier in the 2013, 2015 time frame, determining whether we needed to do additional investigation on those topics.

It considered the R&D roadmap update that was done and added in canister fillers, fuel basket modifications -- fuel and basket

modifications. And then the criticality consequence investigations.

So that's our current R&D focus: DPC fillers for criticality control, potential future DPC modifications, postclosure criticality consequence analysis, and then as-loaded DPC criticality modeling.

So I think one other point I wanted to make is that we believe that most DPCs, with just a few exceptions, could probably be disposed of directly in a repository and meet performance assessment requirements. But we got a little more work to do before we can say that definitively.

And it also comes down to being able to implement some of these items. You know, some of the things that we're doing are investigating -- they seem like, you know, they have merit, but that doesn't -- we're not far enough along to come to that conclusion that that would be something that would be successful.

For example, the filler materials, I mean, there's promising work being done there,

but that, along with any of these, really, we also have regulatory issues that we would have to deal with to make sure that it would be approved.

So I think almost the last slide here.

It's kind of a pictorial summary of our current R&D. It was meant to be a nice one-page summary, and it turns out it takes a little explaining, I think, to come across. But it is, I think, a pretty good representation of what we've got going on.

The circle and the quadrants or subquadrants are the major R&D activities that we're looking at -- or potentially not looking at in terms of the lower left quadrant there which is -- one idea was to do drop particle fillers, so instead of using some kind of pumpable filler, one of the original thoughts was you could cut the lids off and fill it up with some kind of dry particle, which was actually looked at in the past, also, but not with cutting the lids off.

But we decided if you're cutting the lids off you're not really going to be avoiding

that much anyway as opposed to repackaging. And that's the other half of that quadrant, is repackaging.

So those things are grayed out because we're not actively looking at those. In fact, repackaging is what we're trying to avoid with the other R&D activities.

So the top left quadrant is our work on fuel modification and basket redesigns.

So some of those -- just start at the top and go counterclockwise.

So control rods for PWRs, there's potential for inserting disposal control rods into some of the existing spaces that would be some kind of neutron absorbing material.

In BWRs there's rechanneling where could you have another opportunity to insert neutron absorbing materials.

And then zone loading, looking at the way this would be in the future, looking at the way DPCs canisters are loaded in terms of optimizing them for lower probability or criticality.

And then similar to the fuel

modifications, the basket redesigns are a couple of items Chevron inserts which are in there that you could -- not in there, but you could slide in Chevron inserts that would again be a neutron-absorbing material.

And then the existing absorber plates that I mentioned that were not that durable.

Those could be replaced with a more durable material that's also a neutron absorber.

Moving to the top right quadrant, reactivity margin. It's broken down into BWR and PWR. Kaushik is going to talk a lot about the reactivity coming up, so I'll just say on this that we're looking at both BWR and PWR.

DPCs loaded with BWR are generally less reactive than PWR. So we think that we have a lot of room there, particularly if we could take credit for burnup. That would give us -- or reduce reactivity in those calculations.

And then the bottom right quadrant is our consequence analyses and the fillers.

So once again, the consequence analysis is that you approach where you recognize that you will have some -- could potentially have

some criticality, but the consequences are such that you demonstrate there would be no impact to the performance in a repository.

And then the last two there are the injectable fillers. Two things being considered are some type of cement and some type of molten material, molten metal or other material.

And then one last thing on this is just the concentric grains. Coming out from the center of the first ring is meant to represent the current DPC inventory, as of now 2020. The next ring is 2030 where one half of the projected spent fuel is loaded in DPCs. And then the outermost circumference of the circle is all the spent fuel ejected is loaded.

And I think -- so I've got -- there's a number of references sprinkled throughout the presentation, but here's one more reference. They did some of the cost analysis.

And with that, I'm done, so ready to take any questions.

BAHR: Okay. Thanks, Tim.

One question that comes to mind to me, it wasn't clear to me why for the PWRs there's

no possibility to do the criticality calculations for the remainder of the inventory, that white -- maybe we can go to the slide.

GUNTER: Slide 15?

BAHR: Yeah. So there's a white area --

GUNTER: Right here?

BAHR: -- right there?

GUNTER: Yeah. Actually, I thought about that when I looked at these earlier. And I'm not sure I have the best answer for that. I may ask to defer that to Kaushik.

But I think -- I think the PWR analyses are further along than the BWR.

But if we could just hold that question for Kaushik to address. I'll make a note and help remind him.

BAHR: Okay. I see there was a hand up, Efi Foufoula. So let's bring her on. Okay.

Efi, do you want to unmute yourself?
There you go.

FOUFOULA-GEORGI OU: Criticality analysis you talked about the trade-offs between low probability and consequences to the humans and the environment.

Can you give me a sense of what probabilities we're talking about to be still in space for consequences, what probabilities are we considering?

GUNTER: Okay. So the probability of having a criticality in the underground, based on the reactivity of the spent fuel and as -- if you go out in geologic time, the scenarios are that you potentially could have a breach of the waste package in the canister, you have an influx of groundwater, which is a moderator for criticality, which increases the probability.

And they have to -- analyses are done to determine, you know, what is your probability of actually have a criticality underground.

FOUFOULA-GEORGI OU: Yeah. What I was referring to is a little more quantitative. Like, are we talking about six probabilities? What kind of probabilistic values are we talking about? I know and you talked about the probabilistic criticality consequence analysis, you basically consider the space of probability and consequence. But we're talking about probabilities one in 10,000 years or one in a

thousand years? What are the failure for which they start the consequences? Can you give me a number?

GUNTER: Well, I mean, it would basically depend on the regulation you're meeting. But in the past we excluded criticality based on probability in the 2008 license application. And that's in -- I forget the exact number. But one in ten thousand over 10,000 years or something like that. And you have to have that analysis done to show that you won't have a criticality during that time frame.

FOUFOULA-GEORGI OU: Okay. Second question is, does technical feasibility include the potential need to obtain an NRC license?

GUNTER: No. Technical feasibility is just technical issues, and as I mentioned there's -- we recognize that there's other -- you know, there's not only regulatory issues, there's policy issues with disposing DPCs and those would all have to be addressed once we have the technical recommendations on whether we think we would be successful on this from a technical standpoint. Then we would have to

look at the policy and regulatory issues. So anything that we did, even if it was implemented, it would have to be a part of a license application and then you go regulatory review and acceptance.

FOUFOULA-GEORGI OU: Okay.

BAHR: Thanks, Efi. We have a question from Lee Peddicord.

PEDDICORD: Yes. A couple questions, as well.

As you look at some of these options, the fillers, reconfiguring baskets and so on, did you get as far as looking at cost implications, or can you optimize over some of those, as well, too?

GUNTER: You mean as far as costs between different options?

PEDDICORD: Yeah.

GUNTER: Well, that's certainly something we could do, but we haven't done that yet.

I mean, we looked at some kind of rough ideas on how much certain options would cost, but we haven't got down to comparing different

options.

I think once we have the suite of things that we -- that are available to us that we would recommend going forward with that would be a good thing to put in the mix.

PEDDICORD: The other question, too, is of course you're looking at excluding water or taking into account water ingress and so on in infiltration. What kind of -- what kind of ranges do you put on the types of water? They're going to -- it's going to be pretty dependent on the site and so on.

GUNTER: Right.

PEDDICORD: Some of the water that might infiltrate might have opposite effects, so not increasing criticality probability but, in fact, decreasing it depending on the composition.

So the question I have is kind of what is the extent of the bounds or ranges of the water characteristics, composition and so on that you look at for your criticality analysis? And maybe this will come up later in the presentations.

GUNTER: It probably will come up later.

But we looked at -- so what you said is exactly true. I mean, you'll have different compositions of water depending -- it will be site specific and geology specific.

So we did look at a few different examples. We looked at -- in terms of doing an analysis for these. We did salt and clay and we also did, I think, a sedimentary.

But we did -- they did an analysis on what type of water would be expected. I assume there's some type of range.

But to your point of you would have different impacts of the water depending on what type of repository you were in.

And just believe that in a salt repository if you had any water infiltration that the chloride concentration in that water could actually be to your advantage in reducing criticality.

PEDDICORD: Maybe this is a step not worth taking. But could the type of water in a particular location become one of the criteria for selecting a repository site over another one, if it would help guarantee that even the

water infiltration diminishes or eliminates the possibility for criticality in the length of time you've got to demonstrate this?

GUNTER: That could be one consideration that would be -- I'll just say I'd love to be in a position to be able to select between different repository sites based on, you know, which ones might have the best performance in certain areas. But I think past experience in siting a repository shows we'll be lucky to get one site to move ahead with.

PEDDICORD: Thank you.

BAHR: Thanks, Lee.

We're a little bit beyond our time, but we do have a couple more questions.

I wanted to mention that Geoff Freeze provided an answer to Efi's question. In the regulation 10-CFR-63 it says that one chance in 10,000 over 10,000 years was the cutoff for the probability below which you didn't need to do a consequence analysis. So that was I think what Tim said, basically.

We do have a question from -- we have Nigel Mote, Paul Turinsky, Steve Becker. So

we'll take those three questions and then we're due for a break.

So let's start with Nigel. Thank you.

MOTE: Thanks, Tim. Interesting update.

On slide 5 you have repeated an assumption that I've seen many times before and I've seen it in DOE reports. It's the third bullet and the fourth subbullets. Assuming that hulls and baskets would be disposed of as low-level waste. Is that an assumption or is there a basis for that?

Has anybody looked at the activity and the requirement to dispose of that as low-level waste, or is it possible that the materials can be decontaminated and recycled? Because that would be a significant cost change in the analysis.

GUNTER: Right. So that assumption came out of the investigation reports that Sandia Labs conducted.

I would say that certainly it's something that could be looked at. I don't know that it's a foregone conclusion that these would have to be disposed of as low-level waste. I

think that was kind of the standard operating assumption.

MOTE: It seems reasonable. It's just I've never seen an analysis or a foundation for that. Like I said, it seems like it would go that way, but there are some materials that come from plant decommissioning that are now able to be recycled, but initially the expectation was they would not be able to be recycled, and like I said there is a significant cost difference in the assumption.

GUNTER: Right. That's something we could go back to check on to see what kind of basis there was for that.

BAHR: Okay. Thanks.

Paul Turinsky.

TURINSKY: Two questions. One is a follow-up to Lee's question.

Had people looked at the sort of the combined probabilities, and that is the probability of canister basically admitting water and then the probability of that water being admitted causing criticality?

What I'm thinking is those things that,

may be bad for the canister with corrosion may not be bad for criticality and vice versa on that. Have people look at those combo effects?

GUNTER: Well, we certainly looked at -- you know, as part of the performance assessments, looked at, you know, what impact the water has on the canister, how long would it potentially take to corrode it and provide a pathway for entering into the canister. And then, you know, we looked at the water in terms of moderating and what potential impacts it would do to the reactivity of the fuel.

Now one of the things that I know we're talking about was the kind of coupled effects type of thing, which it's been more in a different view, but that's another, I'll call it, coupled effect.

And I want to say that we looked at that as part of these analysis in the performance assessment work we've done for the criticality.

PEDDICORD: Do things align or not align? In other words, things that accelerate corrosion are also bad for criticality?

GUNTER: That I don't -- I couldn't

answer specifically for everything, but I think it's probably a mix -- kind of a mix bag of things.

I go back to chlorine and salt brine, probably bad for corrosion, but maybe not so bad for criticality.

And it would be specific again to the geology and what your specific water composition is. We probably haven't looked at all those different scenarios.

PEDDICORD: Will that be done in the coming fiscal year?

GUNTER: I mean, it's something that we would consider going forward.

I mean, if we got to the point of, you know, making a recommendation to implement certain things, we would have to have that interaction as part of the -- part of the evaluation.

So I can't say specifically it will be done in the coming year, but it certainly would need to be done.

PEDDICORD: Okay. And then second question, sir, is a judgment on your part.

When you issue your maybe third final report or whatever in 2021, will it be enough R&D done at that point from a technical viewpoint for a policy -- people who make key decisions to make a decision on, yes, this is a path forward that we should pursue technically?

And if there isn't enough information to make that policy decision, what other R&D would be required to reach that level of information required by key decision-makers?

GUNTER: Right. So yes, it's my hope by then we'll have enough technical information to make a recommendation and move forward in the different areas.

I think the filler material is maybe a bit behind. You know, it got a late start compared to some of the other areas that we were looking at.

And also, in terms of recommendations, I mentioned that, you know, the specific as-loaded criticality analysis, I mean, if we did that for every area DPC out there, I mean, that's going to -- certainly wouldn't be done by 2021, but that doesn't necessarily mean that, you know, we

wouldn't make a recommendation, you know, that that would be the approach that we should follow.

PEDDICORD: Okay. And again, I'm thinking of, you know, high-end executive branch or in congress, them being able to make a decision that this is a path -- technical path that should receive high priority.

GUNTER: So again, in 2021, I hope -- that's our goal to have enough that we could move forward. And like you said, it would be somewhat of a judgment call, do we have enough or not, and it won't be totally my call.

But I would like to see it move forward to some of the policymakers that would be in conjunction with the legal opinions and to move forward to those that actually make a decision.

PEDDICORD: Okay. Thank you.

BAHR: So we have a question from Steve.

I also know that Tissa wanted to ask a question. We are running into our break time.

So Steve, if you can make this succinct, that would be helpful.

BECKER: Yes, I will make it succinct.

Tim, thanks for your presentation.

You mentioned that the safety of workers is a priority. Could you briefly talk about the hazards that would be involved in handling DPCs and what kind of work is being done to identify ways that those could be mitigated.

GUNTER: Well, some of our earlier work that we looked at in terms of safety to workers, I don't think we identified anything that was particularly hazardous other than the typical handling of large canisters. I mean, certainly there's hazards there, but that's something that would be done regardless.

And you also have to factor in -- so you have your safety say at the site, that disposal site. You're going to be handling canisters and waste disposal packages anyway -- right -- so in getting them underground. So there's not a huge difference between whether you're handling a TAD or a DPC.

And then I think on the positive side of safety for the workers is the reduction of the repackaging of all these DPCs. So you cut out an enormous amount of work there.

And just from the standpoint of, you know, less repackaging, less radiation exposure, less risk or opportunities for the workers to have something not go as planned.

BECKER: Thank you.

BAHR: I'm going to bring Tissa on. You had a question, Tissa.

ILLANGASEKARE: Yes. Thanks for your presentation.

You answered part of my question for Lee, but my question is in your slide 13, multi-scale testing. And you mentioned that you are looking at external conditions, you mentioned geology. Are you looking at the drivers -- external drivers like climate and what produces, for example, water leakage or infiltration?

GUNTER: In terms of -- I think we're looking more right now at near term effects of criticality.

For example, the engineered barrier system components, the backfill, if you're using backfill, the transmission through the near field and far field.

But in terms of like climate, there's assumptions for these different models for different geology types that I mentioned. There has to be some basic assumption to get you the water infiltration rates.

So climate was originally -- I know originally considered. I don't know if there's any variations between repository sites.

Again, that would, I think, come down to a future -- you would need a future specific site to actually evaluate the climate impact.

BAHR: Okay. Thank you.

So I think we are now scheduled for a break. And that will -- it's a bit of a shortened break, but I'm trying to keep us on schedule. So we will reconvene at what is 2:00 p.m. eastern daylight time, 11:00 p.m. -- or 11:00 a.m. pacific, where I am.

So we'll see you all back in about 15 minutes.

Thanks.

(Recess taken.)

BAHR: Okay. We are back. It's 11:30. So I hope that you all had a good break, short

as it was.

Our next speaker is Dr. Ernest Hardin from Sandia National Labs, and he's going to be talking about the engineering feasibility and thermal management research.

I see Ernie, but I didn't hear him.

HARDIN: Here I am.

BAHR: There you are. Okay. I'm going to go away and let you on.

HARDIN: Very good. Let's see, we're buffering here, but anyway, I'll get started.

In response to the last presentation, I just want to make a couple quick comments.

Filler cost, yes, it's addressed in the comparative cost analysis report that was cited by Tim Gunter in his slides.

On the last slide, the PWR fuel graphic was whited out, different from the BWR, because the PWR fuel is generally more reactive and we think it might be getting more so with time. But Kaushik will have to answer to that.

As far as groundwater composition range, yeah, we've looked at it. We've gone all the way from freshwater to saturated chloride brine.

We actually went looking -- after we realized that brine would have a salutary effect on postclosure criticality, we went and did a kind of literature study of all the locations in the conterminous U.S. that might have groundwater that would work in that regard. We did not find very much.

There is a trade-off. Typically, you know, a geologic formation with really saline groundwater is one that doesn't participate in the hydrologic cycle. So it doesn't get flushed by recharge over millions of years, which means that it must have very limited movement in groundwater.

So the trade-off is that saline groundwaters are favorable to waste isolation by the natural system and we wouldn't -- we probably would not propose to use a corrosion-resistant waste package in such a setting.

So that's about it for the go-backs.

I want to talk to you about the feasibility study we started in 2013 and ended in 2017.

If I can figure out how to advance the slides. Okay. Here we go. Beautiful.

Here's the -- the disclaimer. Tim explained this very well. I will not try to do so.

And here is Sandia's legal notice. Also required. Basically says Sandia has done this work under the sponsorship of the U.S. government, but does not represent any position of the U.S. government in so doing.

So here's the outline of my talk.

I was also invited to present a summary of this work in October of 2018 at the public meeting of the board, and so I will -- I will not spend too much time today on the points that I made in that presentation.

The feasibility study in the first few years really dealt with these four different questions: Safety, both preclosure and postclosure, engineering, thermal management, and postclosure criticality.

I will mention a little bit about DPC dimensions and weights. I will also describe briefly the emplacement concept, because there

are some limits on how you implement a repository. But spend more time on thermal management, which we really haven't dived into in great detail. And next to postclosure criticality it does pose some of the more important technical constraints on DPC direct exposures.

And I will give you an overview of the postclosure criticality topic, but to be followed by at least four more presentations in this meeting.

There we are.

So these are some talking points about DPCs, which you might have seen before.

Basically, DPCs are about the same weight -- if we take one of the larger DPCs, 37-PWR -- you saw a picture of this system in Tim's talk. It weighs about the same as the proposed TAD canister for 21-PWR assemblies loaded in Yucca Mountain, LA. Also, the dimensions are about the same.

Here I give you length and diameter and calculate volume and you can see that the numbers are very close. And there's a reason

for that. I'll get to that later.

The question comes up, if you have to access your repository only with shafts, can you lower something this heavy?

And it gets a lot heavier if you apply shielding. Even a temporary shield would raise the weight of a DPC waste package with temporary shielding to well in excess of 75 metric tons and it would approach the 175 metric ton payload that was used in a conceptual study by the German agency BGE Tec of a very heavy hoist design.

So another point here is that -- this is one of the themes of this talk -- is that it would require time to cool DPCs to the point where they can be emplaced in a repository.

So the findings of that earlier phase of feasibility study, mainly that direct disposal of spent fuel in DPCs is possible with all the geologic settings that we evaluated and those are -- in a nutshell, those are salt, unsaturated, argillite and crystalline. And we consider the differences between unsaturated and saturated disposal systems to be greater than

the differences between the media that you could select for unsaturated disposal. So therefore we have described them this way.

Given that statement, however, thermal management and postclosure criticality control or treatment could vary significantly among those geologic settings.

And also, with respect to waste isolation performance, the relative reliance on natural engineered barriers would also vary significantly as it would for a repository with purpose-designed canisters. So these are generalizations that apply as well to other types of repository concepts.

Now, some additional considerations that fell out of that study, we need to think about the disposal overpack reliability. We believe that estimates can be improved versus what we were doing back in the 2000s.

Why is this important? There was some discussion of this earlier. If you are pursuing an argument for low probability exclusion of postclosure criticality from PA, it turns on whether fewer or more than one package in 10,000

is associated with the criticality, then you need to think about whether a similar number of packages would be affected by manufacturing defects and would -- would leak. So that's why reliability is important.

We also noted from the work at Oak Ridge that the differences among DPC basket designs could have a significant effect on their ultimate structural longevity when being degraded by groundwater. And given that there are more than 50 different design versions out there, there are a number of different configurations and materials that have to be considered.

And the major recommendations of the study were to investigate injectable fillers and to look at screening postclosure criticality on low consequence.

Now, I'm going to give you a rundown on the four basic objectives of the study, starting with safety, preclosure and postclosure.

So the statement is that general attributes of a safe repository also apply to DPCs, and this is because for preclosure

handling and packaging, it's well within the state of the practice. And we do not presume to improve on operations as they are currently undertaken by the utilities and the vendors.

For postclosure, you know, we find that the attributes are the safe repository, one that isolates waste for geologic time are the same whether you put DPCs or some other purpose design canister in them.

That said our PA models need to be able to discern the differences between the repository loaded with DPCs versus one that has purpose-designed canisters, and so we're working on that. And we find that we likely need to use cementitious materials, shotcrete or possibly cast concrete in repository for DPCs.

Why is this a safety issue? Because the repository is going to be big and you need to use all the tools available to the engineer for ground supported construction.

As far as engineering feasibility goes, I've got four subbullets here, and they're a little bit different.

First of all, we recognize that extended

thermal aging is going to be needed. I mean, think at least 100 years.

So your fuel and DPC canister condition have to be preserved for that length of time.

So we have to take good care of these things until we're ready to dispose of them directly.

We're going to need some engineering work on the transporter for these and the machine that replaces them in the disposal drifts.

We're going to need some packaging materials potentially that corrosion resistant in a range of generic geologic settings.

I mean, we know a lot about the chemical environment at Yucca Mountain, but we are currently in a situation where we have to extend our thinking to a range of geologic settings, and we have not done the kind of testing that we would need to choose corrosion-resistant materials or choose corrosion-resistant neutron absorbers for that whole range of settings.

I mentioned overpack reliability.

The first and third of these are

actually being studied currently in the R&D program; whereas, the second and the fourth would be reserved for future work by a repository implementer.

So in thermal management we could see a need for a higher temperature, low permeability buffer or backfill material, think clay-based materials.

And there is work underway to extend the peak temperature limit for those materials up to 150 or even 200 degrees C, and there is an international collaboration.

In addition, the thermally driven process models are for the system especially in the near field and possibly even in the far field would need to be enhanced so that they could represent fully the effects of thermal loading from DPCs in the repository.

And then finally, postclosure criticality control. We recognize the need to continue on a year-to-year basis the analysis of DPCs as loaded.

So as the data come in, as they're collected by the GC-859 process, they're being

organized, scored and analyzed by Oak Ridge.

And one -- the focus of the analysis with regard to disposal is that we have two stylized degradation scenarios for the neutron absorbers in the basket, as they might degrade in a repository, and the reactivity of the fuel as loaded is evaluated for those scenarios.

We also see the need to look at -- in more depth to develop mechanistic models of the degradation of the fuel and the basket particularly the effects of radiolysis. Why? Because uranium oxide corrosion is going to be important for analyzing the process of criticality and its consequences.

And we also saw the need for an advanced burnup credit methodology for BWR fuel. That's because, as you'll learn later in this meeting, the BWR fuel is generally less reactive and it's possible, with the right sort of burnup credit methodology, we could show all of it was subcritical under a degraded repository condition. That would take a big bite out of the postclosure criticality problem.

And finally we recommended work on

fillers and -- for both moderator exclusion, or think moderator displacement, and neutron absorption.

Okay. This slide basically summarizes a few things that would be pertinent to the engineering of repository. I'm not going to spend really much time on it. We talked about this in 2018.

There are engineering challenges, but they can be met. Particularly in slide 10 summarizes what we call a concept of operations for a repository.

We maintain that for DPC-based packages in repository, the concept of operations would be essentially the same as it would be if you had purpose-designed canisters.

This would include things like the layout of the repository, the construction method and sequence, the use and the construction of shafts, the need for a ramp for waste transport and so on.

How you would build the ground support and invert, there are options that are pertinent to different geologic media. The way that the

packages would be handled and emplaced in the disposal drifts, there would be a need for some very specialized heavy-haul equipment. And also shielding and remote operation.

And then backfill, we include in these concepts the purpose of backfill in salt is clearly to hasten reconsolidation.

In other media, such as clay/shale or crystalline, it has the purpose of limiting groundwater flow.

And in various concepts it has the purpose of limiting damage from rockfall and seismic motion.

You know, if you have extensive collapse in the rock above an opening, you get an effect called chimneying, which results in fractures that would run parallel to the direction of the drift. So that type of damage is something you could limit using a backfill.

And plugs and seals, of course.

One important point to make about disposing of DPCs directly is that some function would be assigned to the overpack and the overpack design would be site specific.

In preclosure we require containment for at least 100 year or so of repository operations until permanent closure.

And so the overpack would provide the structural robustness to withstand handling and drops during that period.

We don't think that the overpack would provide effective shielding for personnel because if we did that it would add at least 40 metric tons in weight per waste package, not to mention the cost of that and its impact on all the handling systems up and down the line.

For postclosure we are expecting containment consistent with the disposal concept which might be as little as 100 years or it might be greater than 10,000 years. It depends on the balance between engineered barrier performance and natural barrier performance. To that end, the material selected for the overpack could be a corrosion allowance material or a corrosion resistant one. And the overpack could also provide protection from rockfall, crushing from groundwater pressure, and other protective functions for the canister during the

containment period.

So by doing that, we make it possible to talk about DPC direct disposal in various geologic media knowing that the overpack would provide kind of an interface to those media.

Okay. Now, I have extracted some data from a literature source. The point of this is to show you some typical dimensions and weights of DPCs, and in the next slide I'm going to compare these to the Yucca Mountain TAD or transport aging and disposal canister.

The point being, as we noted earlier, that they're about the same weight and very similar dimensions.

In other words, all of the handling and transport and other engineering aspects of disposal have been worked out, including an exhaustive preclosure safety analysis.

So we're basically riding on the coattails of a lot of work that was done for the Yucca Mountain license application.

So the handling and packaging of DPCs is within the industrial state of practice.

Note that the -- by comparison to DPCs,

TAD canisters are somewhat heavy. They are robust. And that's the reason why the weights are similar.

Moving along. This slide is a little out of place, but it shows pictorially what the emplacement disposal concepts would look like.

We're talking about in-drift axial emplacement practices on the floor. That's virtually the only practical way of doing this.

That's similar to what was proposed for Yucca Mountain, although we would space these out farther to spread -- help dissipate the heat, spread the heat out.

They would be unshielded.

We would try to use a system with rubber-tired transport so that we didn't have to install steel rail throughout the facility.

We would definitely need thermal aging, and we'd try to use backfill to create a more robust disposal system, and there would definitely be remote operations involved.

Okay. Let's jump to thermal management. Why do we need thermal limits for disposal? That's the question.

Well, for protection of cladding, we have ISG-3 from the NRC which gives temperature time limits for -- well, actually temperature limits and cyclic temperature limits for preclosure handling. This is when you would want to dry a DPC and so forth. Those have been applied.

Limits like that have been applied. For the Yucca Mountain, LA, we chose 350 degrees C as the peak cladding temperature.

That was not difficult to meet in the thermal analysis.

Another reason why we have thermal limits is to protect certain materials that might be sensitive. For example, there was 500-year, 300 C limit for alloy 22.

External to the package there would be other temperature limits associated with a particular type of repository.

If you're trying to protect a clay-based buffer or backfill, you would have a limit somewhere between 100 and 200 degrees C for the peak temperature which would be found at the surface of the waste package.

For siliceous rock, there's a tendency for microcracking to occur. You've got a polycrystalline aggregation of crystals difference orientations and different compositions. They expand differently when heated and that does produce crack and damage.

For salt we got a decrepitation effect. It's an explosion of the interstitial water that occurs at about 270 degrees C.

We identified 200 C as a limit for the salt host rock. It protects not only halite but other are minerals that are sensitive as well.

For injectable fillers we're talking about an aqueous-based cement slurry which would have to be monitored for temperature because, of course, the temperature of that water equates to pressure, and for safety reasons you want to control both during the filling and curing process.

For molten materials the temperature would -- at filling of the molten material would approach the cladding limit temperature. So you'd have to pay careful mind to thermal

conditions inside the DPC during filling.

Ultimately, for implementation of the repository, other limits come in -- other lesser known ones.

For example, for Yucca Mountain, the limit at emplacement was 18 kilowatts per package. It was not a geologically determined limit.

That was a limit on the off normal performance and behavior of the transport emplacement. So you couldn't keep the package cool for beyond a certain point in that vehicle if it stalled.

The next slide shows you also from the same source a collection of thermal limits in kilowatts for different kinds of DPCs, generally different limits given for storage and transportation because the overpacks are different and have different injection characteristics. The point here is to compare those on the next slide with the limits for Yucca Mountain.

So the conclusion to be drawn here is that the thermal limits, power limits for

storage and transport are going to be greater than the limits for disposal, which means that we should not have a problem for disposal once they're cool enough to transport to the repository. There still may be some aging involved, but there's no inherent conflict in the thermal power output requirements.

And the duration of that aging would depend on the disposal concept. What are the temperature limits for EBS materials and for the host rock?

The next slide is one that appears fairly often in our -- in our briefings.

And this basically compares a burnup curve showing heat output versus time for different burnup of PWR fuel with the thermal limits for various kinds of repositories.

So the black curves represent power output for 32-PWR assemblies, typical for a DPC, at 60, 40 and 20 gigawatts for ton of burnup.

And the horizontal lines are for four different generalized disposal concept with unsaturated hard rock, which is essentially the Yucca Mountain concept.

We have salt where we assign an emplacement thermal power limit of 10 kilowatts.

We have argillite, which are clay or shale, which would be backfilled and the power limit would be around four kilowatts. And then we have a crystalline concept where you have a somewhat more sensitive clay-based buffer that you had to protect, and the red line drawn is for a three kilowatt limit which might work with -- if you had a peak temperature limit of 200 C for the buffer. And you can imagine if your buffer limit is 100 C that pushes that red curve down even further.

Point being that if you take the intersection of the horizontal lines with the black lines and then trace downward to the axis you can see about how much aging time you need before you can emplace the waste in the repository.

So it varies somewhere between less than 100 years up to 300 years or longer, depending on which disposal concept you're talking about.

This next slide, number 19, compares the different disposal concepts on three different

numbers.

One is the host rock temperature tolerance, how hot can it get for the host rock.

The host rock thermal conductivity. That's a measure of heat dissipation.

And the power limit that we calculate would be necessary to cool the packages down for emplacement.

And some comments over on the right-hand side that I will not attempt read, but they give some context to this and we have references for the various power limits.

Take away from this is that in an unsaturated medium in Yucca Mountain the limit was 11.8. We've adopted approximately 10 kilowatts.

In salt we've adopted 10 kilowatts. That's about 11 watts per square meter. That's comparable to previous studies that have been done on thermal loading in salt.

And then for argillite, you'd be at about 4 kilowatts. And even so, you'd be overheating the near field host rock to around 125 C and you'd be overheating the -- or you'd

be heating the backfill in the immediate vicinity of the packages to well over 200 degrees C. That's a hot -- hot system.

You'd have to space the packages apart if you wanted part of that backfill to maintain a lower peak temperature like 100 C.

And then crystalline, of course, we're trying to protect the buffer, which is fairly vital to the performance of the crystalline repository.

And we've done projections using a logistical simulation code called Calvin. You've probably heard of that before.

And basically we can set a thermal power limit to which packages must cool before they can be disposed of, and the curves represent the number of packages that do that per year -- per each year.

And so the take-away from this, if you look on the right-hand side with a 10 kilowatt limit, fairly generous thermal limit, we can cool the BWRs to that -- 98 percent of the BWRs will be that cool by 2100 and the PWRs by 2130.

This is why we say we can implement of

some of these repository concepts in the next 100 years or so. And that's very comparable to the whole thermal management strategy that was put into the Yucca Mountain, LA.

On the other hand, if you go to the left-hand side, now we're talking about a 4 kilowatt limit. It takes a lot longer.

The blue curve is for BWR DPCs which would get to 4 kilowatts, most of them, by around 2170, and it would take the PWRs 100 years longer to get to that point.

So this shows you the kind of thermal aging time that you would be up against.

The reason why the Ps are hotter, basically, take longer to cool, the first reason is there's actually more tonnage in a PWR DPC than there is in comparable BWR. And then another reason is the burnups tend to be a little bit higher.

Another metric that we could use, we could talk about is the fuel age out-of-reactor at disposal.

This was a concern a few years back when we were considering what would happen to the

cladding as a result of its temperature time exposure and whether there was significant weakening of the cladding could occur at some point in the fuel management process.

And so we looked at the best-case scenario, which would be let's repackage all the fuel from DPCs into 4 PWR NPCs for disposal. And this would have to somehow minimize the fuel age at disposal and it does. And I'll show you that in a second.

As a sort of intermediate case, what if we transitioned from DPCs to NPCs at some point in the not too far future, is that then some of our waste inventory would be in smaller, cooler packages and some of it would be in hotter DPCs, and we found that the fuel age at disposal would be sensitive to a couple factors.

One is what is your thermal limit, and so if your thermal limit is high enough it doesn't matter so there's no point in repackaging in small canisters for disposal.

But the other factor was that if you're going to repackage like that, you're going to have to do it soon to have an impact on thermal

management.

So that means the repository would have to be implemented and we would have to transition to NPCs at the power plants sooner than something like 2048. So this is somewhat conjectural.

Here are graphical results of that study. And basically for a fairly low power limit of 6 kilowatts, the left-hand side shows an early repository implementation at 2036 and the right-hand side shows 2048.

And the take-away is that the advantage in fuel age emplacement from going to a repackaging strategy sort of goes away if you wait too long.

So this sort of shows you where we are. This does not provide a compelling basis for it ch switching to a repackaging study.

Finally, the overview on postclosure criticality.

This slide you've seen before. It just details some of the factors that determine whether you might have a criticality event.

Groundwater availability, there's some

formations where there just isn't enough water to flood a package.

Whether that water contains chloride in sufficient amounts, and I'll tell you sea water does not have enough chloride to impact the criticality situation very much. Kaushik may relate some of the details of that.

You have to get up into a nearly saturated chloride brine before you begin to have that benefit.

Also, then we can control things using moderator exclusion, such as a highly -- call it super overpack, a high integrity overpack that would last a long time.

Or we could use fillers to achieve something we call moderator displacement.

There could be some water that got in, but it wouldn't be enough, and Kaushik can -- sooner or later, he's just finishing a study on that. He can provide details.

To those fillers we could add a neutron absorbing material such as borane carbide particulate.

And then for future DPCs, we could use

control hardware.

We talked about zone loading. This was brought up by EPRI. That's something we're going to look at. I'm not sure it's going to provide what we need for direct disposal of all the DPCs.

And then the criticality analysis methodology itself has an impact on your success in this in dealing with postclosure criticality.

And so that's still a topic of research.

It's of interest to other agencies such as NRC, besides DOE, in respect to DPC disposal.

Okay. Moving along, if I can get this right. There we go.

So again, what are the measures available to us for postclosure criticality control

Reactivity margin being one.

It turns out that for our two stylized degradation scenarios that not all of the DPCs that we've analyzed -- and we've analyzed 800 or more of them. Not all of them are -- many of them would be subcritical.

And the -- so they could be disposed of

directly in freshwater -- fresh groundwater conditions. And possibly in a way that was -- that could be licensed. And that's important.

So the criticality control features as mentioned in Tim's talk, talking about control rods in PWR assemblies, mainly it probably wouldn't work in BWR assemblies.

We took a look at that and we figured out that there's such a diversity of BWR assemblies and so few opportunities for insertion of control rods, that probably is not a viable strategy.

But the BWR assemblies can be rechanneled.

You would use a corrosion-resistant neutron-absorbing material, such as a composition equivalent to alloy 22 that's been spiked with gadolinium. So that's something that's actually being tested right now. We're just getting started with that.

The Chevron inserts, they came out when the spent fuel cool racks, those which use Boraflex, showed degradation of the absorber, so they had to do something to retrofit neutron

absorption to those racks. And that's what the inserts do.

They could be applied to DPCs if there's enough clearance and if there's enough hook load margin for the crane at the spent fuel pool loading facility.

And finally zone loading. We talked a little bit about that.

The injectable fillers would involve cutting the covers off the existing ports and then rewelding them when you are done.

The high performance overpack, the super overpack strategy is out there, but because of reliability concerns and our lack of any site-specific context we're discussing how well an overpack could perform, we would assign that to the consequence screening aspect.

So for now, in our thinking, this represents a way to reduce the overall consequence of any tendency for criticality events to occur in the repository. Reduce the frequency.

And then there was cutting lids off. Yeah, you can do this. Of course, the vendors

already know how to do this because the DPCs, according to the standard contract, are going to have to be open in the field delivered to DOE one assembly at a time as bare fuel.

They do it using a method called skiving, which is essentially kind of a large scale machining operation. It works the tool around and around the weld until the weld is gone.

As far as what you would do if you cut the lids off, you could dump in dry fillers, and we showed -- Framatome showed this back in 1995 and '96 that a fine steel shot could fully penetrate PWR fuel assemblies.

In addition, the AECL in Canada has done a test where they were able to infiltrate CANDU fuel bundles using various particulate materials, and Charles Forsberg suggested that we use some sort of oxide glass, mixed with depleted uranium.

If you decide to use dry particles, it would have to be done dry, so that's kind of a new development. You'd be operating on fuel under an inert gas cover. If you know much about

that, that presents a new set of hazards and engineering controls.

However, if you are opening the existing DPCs in order to install control hardware, you could do that wet, which of course you then dry and reseal the canister. And of course, if you cut the lid off you're going to have to weld it back on.

So the next three slides summarize.

So I'm going to restate our finding that at least some DPCs are disposable for all of the generic geologic settings that we looked at.

And this would be -- excluding postclosure criticality from PA on low probability.

If you went to a low consequence screening strategy, then potentially all of them would be disposal.

And then we looked at safety. We would be operating within the state of industrial practice in fuel handling, packaging.

We could find no difference in postclosure waste isolation from a hypothetical repository using purpose-designed canisters.

And then we identified a number of different engineering challenges which can be met.

As far as postclosure criticality goes, it's quite unlikely for any disposal concept that really doesn't allow flooding of the package.

There are examples of such concepts.

We already have been able to determine that a significant fraction of existing DPCs would be subcritical if degraded and flooded. This is again using the two stylized degradation cases.

However, there are many, many types of DPCs, 50 or more variants, but of course if you look at more basic indicators of variation, there really are only around 20 different variants looking at size and construction materials and so forth.

For thermal management, it depends on what you define as your emplacement thermal power limit, and as that limit goes down, which it must for some disposal concepts, the duration of thermal aging increases.

We're not going to do this in less than 100 years, and it might take up to 300 years for some waste in some concepts.

We found that BWRs cool significantly faster than PWRs once you get to a thermal limit that's less than 10 kilowatts.

Final slide looks at -- just reviews some of the major recommendations that we documented in 2015.

There's a chapter in that report which summarizes the feasibility study up to that point. That gives a list of information needs. We're chasing down those information needs now in the program.

We continue to collect and analyze information on existing DPCs. That's being done at Oak Ridge.

We are looking into a burnup credit approach for BWR fuel.

And we're trying to understand whether the service lifetime of DPCs is going to be compatible with thermal aging of 100 years or longer.

We're researching injectable fillers,

and we're looking at criticality consequence analysis.

So that concludes my presentation.

Thank you.

BAHR: Thank you very much.

Ernie, you mentioned sort of briefly in your last slide the issue of whether the DPCs are actually suitable for storage of more than 100 years. And I think the current licensing of those does not assume those kind of long times.

What kind of aging management might be needed for these long storage times?

HARDIN: Well, you know, I'm really not the expert on that.

My understanding is that the current position on that is that we could reasonably expect 100 years or longer, and as you pointed out, aging management is part of that. And will it develop an experience over the next few decades that will help refine those numbers.

BAHR: So I see Mary Lou has a question, and do we have her camera and microphone activated, Mary Lou?

I'm going to make her go live. Okay.

There we go.

ZOBACK: Hi, Ernie. Thanks. That was really an information-packed presentation.

Thank you very much.

I've got several questions, but I think they're more clarification for me and I think they can be answered straightforwardly.

Somewhere early around slide 10 or 11 you were talking about packaging and overpack. What's the difference between packaging and overpack?

HARDIN: Right. So I throw these terms around with abandon.

So we're talking about, you know, a canister that goes into a disposal overpack to make a waste package.

ZOBACK: So that's -- packaging is the same as the overpack, then?

HARDIN: Yeah, I think in the context was we're talking about making a disposal load.

ZOBACK: Okay. And I realize this meeting is on dual-purpose canisters, but remind me what percentage of the dry casks that are out there are not currently licensed for

transportation? Is it 5 percent, 20 percent?

HARDIN: Yeah, it's -- I'm going to say 20 percent, plus or minus 10 percent.

ZOBACK: Okay. And then you use sort of as your basis for talking about the engineering challenges to dealing with these heavy things -- you showed a slide of canister designs that was referenced as 2013.

Have the manufacturers been continually increasing the size of these casks since then, or is 2013 still representative of what they're selling and providing today?

HARDIN: You know, that report was perhaps a little ahead of its time.

It did capture all of the largest canisters that exist to date. So we're talking about 37-P, 89-B.

There's kind of a reason for that. It's all limited by the hook loads that the utilities want to present at their spent fuel management facilities. Crane hook loads. It can always be increased, but at no small cost. Yeah.

ZOBACK: Okay. And then this idea that you may need in excess of 100 years on the

surface aging. At one point -- I didn't write down the slide number -- you talked about natural ventilation in the repository.

And I know that was a positive characteristic of the unsaturated fractured volcanic rock at Yucca Mountain, but is there natural ventilation in salt or shale repositories?

HARDIN: No. Yeah, we could -- we could change around any of these concepts to use forced ventilation to remove heat if we needed to, and some of them would be a lot easier than others. The unsaturated definitely easier than trying to do it in clay or granite.

So we could do that, but we don't recommend it. That is not included in the concepts that we're putting forward.

ZOBACK: Okay. And then just -- sorry, Jean, I had a lot of questions.

The final one was from slide 25 where you sort of -- I think you just sort of said, oh, and by the way the standard contract requires delivery of individual fuel assemblies.

So that means every one of these

containers has to be opened?

HARDIN: Correct. Subject to -- you know, subject to interpretation and perhaps litigation, but the way I read it, yeah, every one of them would be reopened and the fuel transferred into bare fuel transportation containers.

ZOBACK: And to change that would require renegotiating the standard contract, on act of congress? What would change that?

HARDIN: Okay. That's -- I think I might punt that question to one of the managers at DOE. Perhaps Tim or Bill. But there are complications there.

ZOBACK: I see Bill has joined us.

Okay. Thank you, Ernie.

BOYLE: You both have got to the basic issues here. It wouldn't require an act of congress. I mean, congress would be involved because this would cost money, so they would have to appropriate for us.

But the two most likely scenarios to change what's in the contract today is -- I think, as Ernie mentioned, is litigation, is for

the utilities to go to court and say, well, here's how we interpret the contract and here's what's happened since it was signed. So that's a possibility.

And the other possibility, as you mentioned, Mary Lou, is to renegotiate the terms of the contract.

But Ernie was right on the money. The existing words in the contract today, and the Department of Justice maintains that what the contract says is we will pick up spent fuel assemblies.

So absent litigation or renegotiation, that's what the contract says.

I must point out, we're not going anywhere tomorrow or next year likely. It's an issue that's been known for the longest of times. And nobody has bothered to renegotiate, and nobody has filed suit over it yet, even though everybody is aware of the situation.

But those are the two likeliest ways to change what's in the contract, litigation or renegotiation.

ZOBACK: Okay. Thank you. I have

totally missed that before.

BAHR: So thanks, Mary Lou.

We have a comment from Efi. But she needs to activate her camera and mic. There we go.

FOUFOULA-GEORGI OU: So thanks for the nice presentation.

In your slides 7 and 8, you listed a long list of recommendations from the 2015, 2017 report.

It was an impressive list with verbs consider, need, update, continue, develop, investigate, start, et cetera, et cetera.

So my question is this: Are they to be addressed before evolution of the technical feasibility can be completed?

And we've heard about criticality efforts, but what about all this other efforts that need to be addressed?

You know, time frames, efforts around all this elements, do they need to be addressed before the technical feasibility is completed?

HARDIN: Interesting question.

We -- we are working on all of the

components of this problem that we can at the moment. Some of them are really -- are really don't belong in an institution like Sandia. They probably should be dealt with by an engineering company that is hired as a repository implementer.

And I worked with Bechtel, for example, and they have resources for designing things and testing them and making them work that are kind of beyond the focus of what Sandia does, or the other national labs.

Furthermore, we don't compete with private industry in matters such as that.

So we're either working on them or we probably should not be working on them. So I think we're covering our bases.

That's a general answer to your question.

FOUFOULA-GEORGIU: Yeah, because of course priorities as to what you do, what you have a company do for you.

But are all the items that have to be checked off one way or another before the technical feasibility can be assessed and

completed?

We can come back to that.

HARDIN: Yeah. To one degree or another. I think you said that.

Some we're able to address it in a more complete way than others.

Some may require site-specific information in order to really get to the bottom of it.

FOUFOULA-GEORGI OU: Okay. Thank you.

BAHR: Okay. We have a question from Lee Peddicord.

PEDDICORD: Ernie, thank you very much. Again, interesting. I concur with my colleagues.

A couple of quick questions.

When you showed the reactivity curve, that's around number 25 or so of your slides, and the peak occurring somewhere greater than 10,000 years, the question I have on your criticality analysis is to what extent -- there you go -- to what extent are these -- have conservatisms built into them or are they best estimate calculations.

And the reason I ask this question is in the slide where you get your reactivity peak at this number greater than 10,000, it's still subcritical. In fact, it's pretty subcritical, even with that number you've got of about .975. In reactivity world, that's pretty subcritical.

So as they say, as you're doing the analysis of criticality, are you making these on the basis of, again, best estimate kinds of analysis, or are you compelled to build in some conservatisms because we went round and round for a long time on burnup credit and so on?

HARDIN: Yeah. So I use this figure in a relative way. It shows the trends. And it does show that the peak and reactivity comes around 20,000 years for a hypothetical generic 32-PWR cask, 4 percent enrichment, 40 gigawatt day burnup.

So the value to me is it -- in showing the relative trends and reactivity, the fact that there are three curves on there represents different burnup calculation, credit calculation strategies.

As far as the details of the

calculation, whether it's conservative or not, I am going to ask somebody like Kaushik to answer that.

PEDDICORD: And we don't need to get into the details.

The reason I ask this question, when we're looking at some of the issues on high burnup fuels and so on, and there was again thermal analysis and peak clad temperatures and worrying about hydride reorientation and so on, with kind of the standard analysis -- let me put standard in quotes -- then it was kind of pushing thermal limits. When we got to best estimate and based on measurements, the temperatures really dropped.

So that was my motivation in asking are we pinning this down with our best known approaches and values? Again, we don't have to go into that.

Let me ask one other quick question. Maybe I can do a follow-up with you.

You talked about uranium oxide corrosion as being a driver early on in your talk, if I understand that correctly. What on earth are

you talking about?

HARDIN: What am I talking about?

Well, once the cladding exposes that oxide fuel, you know, the fuel reacts, and how it reacts has been discussed many times and studied since probably 1980. And -- but it will degrade. And we -- the premise here is that with criticality that you're hotter for longer and so you degrade more completely, and that could be a factor eventually in encroaching the reactivity.

PEDDICORD: So what's a degrade 2?

I mean, uranium loves to be uranium oxide. You have a terrible time turning it into anything else.

HARDIN: Yeah. Well, in an oxidizing environment, you get one set of minerals, and in a reducing environment you get far less degradation, but we have to consider radiolysis which is an oxidizing influence in the degradation of the fuel.

And so that's why the -- Argonne is working up the -- they call it the fuel matrix degradation model, FMDM.

And it's really an informed attempt to combine the chemical reactions that are going on inside a waste package.

And you have to consider the production of hydrogen by corrosion of steels because that influences how fast the uranium oxide reacts, things of that nature.

So I think this rolls together into a more complete picture of how the package and its contents degrade and how that could affect criticality.

PEDDICORD: That sounds interesting.
Okay. Thank you.

Thank you, Jean.

BAHR: Okay. One other question that we talked about a little bit when we were previewing this is the filler materials are going to add mass to the -- to these DPCs.

How much is that going to change the weight, if you know?

HARDIN: Yeah, that's pretty easy.

If we use a cementitious filler, typical density around 2 grams per cubic centimeter, that adds about 12 metric tons to a large DPC.

And if we went with a molten metal filler, you know, low temperature alloys are pretty few and far between. One of the prospects is 97 percent tin and 3 percent silver, and there you have a density around 9.

So that would add 54 tons to the same -- double the weight, basically, of the large loaded DPC. So that's concerning.

BAHR: (Inaudible) to the handling and all of those kind of --

HARDIN: You would have to reengineer the lifting apparatus for a canister like that.

BAHR: So the concepts that you have -- you said it's feasibility for the size that you have, but has anyone done any design or prototyping of lifts for things that would weigh twice that much?

HARDIN: Well, it's definitely within the state of practice to safely lift things that weigh 100 tons versus 50 tons. That's how I would answer that.

This would be done in a dedicated facilities. We don't have to resort to operations in a utility fuel management area.

We'd build a separate dedicated facility.

BAHR: Okay. We're just about out of time, but are there any pressing questions from staff? Pabalán.

PABALAN: Just following up, Ernie, on waste and engineering feasibility, based on the past studies, you stated confidently that engineering challenges can be met.

I'm wondering about the basis for that statement in particular with respect to the heavy hoist system. You gave the example of 175 metric tons. It's a concept developed by BGE Tec.

Now, has there been any hoist system that's actually operable that comes close to that number?

HARDIN: The closest we have is the 50 metric ton friction hoists that are now being used extensively in potash production in Canada, 50 metric tons.

But yeah, the next weight point is 85 metric tons which was -- that was the goal of the original German study, and then they produced a conceptual design recently for the

Belgian program, because their super container would be about that heavy or close to it.

85 tons represents what happens -- what you need to directly dispose of a Pollux cask that has rod consolidation and uses for 10-PWR assembly.

And then the next data point we have is 175 tons that I mentioned.

PABALAN: Okay. I know engineers are confident that they can build it. Okay.
(Inaudible)

HARDIN: Yeah. We've even got a rough order magnitude cost estimate for a 175 metric ton hoist. The cost, according to BGE, is fairly manageable. In the tens of millions of dollars.

PABALAN: Okay. Thank you.

BAHR: Okay. We'll have one last question from Dan Ogg.

OGG: Hi, Ernie. Thanks.

I wanted to follow up on an earlier question that Lee Peddicord had for Bill Boyle regarding the possible implications of accident tolerant fuel or new fuels for advanced

reactors.

And I recall that some of your colleagues that are at Sandia have been doing a new gap -- a new evaluation of technical information needs regarding advanced fuels for advanced reactors in accident tolerant fuels.

I think they were primarily focused on storage and transportation, but I wanted to ask you if you're familiar with that effort and whether or not that effort also includes the disposal aspect for those new fuel types.

HARDIN: Yeah, I'm not sure --

OGG: (Inaudible).

HARDIN: I'm having a little trouble pinning down the effort you're talking about.

I have been asked to consult on an effort that racks up advanced fuels with disposal needs. But that's barely getting started.

Dave Sassani is the point of contact for that.

SASSANI: Hi, Dan. Dave Sassani here.

I'm the NTD for the SFWST area for here at Sandia. I also work within the sibling pin

testing in storage and transportation. So I'm a little familiar with the gap analysis you're referring to.

It is currently only for doing the type of testing we're doing with the sibling rods currently looking at the ATF fuels and their differences in their cladding and characterizing cladding. It does not involve any disposal aspects at this point.

OGG: Okay. All right. Thank you.

SASSANI: You're welcome.

BAHR: Okay. So I think we need to keep on schedule here.

So we're going to move on to our final presentation for today, which is by Kaushik Banerjee on ongoing research and development in the reactivity analysis of dual-purpose canisters.

So if we can bring Kaushik and his presentation on.

BANERJEE: So thank you, and good afternoon. So Ernie talked about criticality in the previous presentation, so criticality could be an issue for DPC deck disposal, and we are

investigating the ways to address that issue and find out if and how we can safely dispose DPCs in a geological repository.

So in this presentation what I'm going to talk about, I'm going to talk about criticality of DPC in a repository, and I'm going to talk about our criticality analysis approach.

My name is Kaushik Banerjee. I work at Oak Ridge National Lab.

So we have seen this slide a couple times. I'm not going to talk about this one. I'm going to skip this one and dive into our criticality analysis approach.

So we all know, like, we are storing spent nuclear fuel in dual-purpose canisters, so the majority of the spent nuclear fuel actually is in dual-purpose canisters and most of the canisters we are loading nowadays (inaudible).

So dual purpose, that means like they are licensed for storage and transportation but they're not designed for long-term disposal.

So what is the issue for disposal here? So all these canisters, they use aluminum-based

neutron absorber for their criticality control, for loading, for storage, and for transportation, but it's hard to justify that aluminum-based neutron absorber is going to provide the criticality control functionality over a repository time frame, which is 10,000 years or more, especially in aqueous environment.

So now if we cannot take credit for that basket neutron absorber in our criticality calculation, and we need to perform design basis calculation -- and I will talk more about the design basis on the next slide -- one can show the majority of the DPC would be critical in the repository.

So what are we doing to address this issue right now? So on the top level we are actually investigating three different options, and the pie chart at the bottom of this slide kind of shows those three different options we are investigating right now.

One is we are trying to find out what is actual reactivity of these canisters by analyzing the as-loaded contained. That means

we are actually modeling the as-loaded DPCs and find out what is actually effective for actual criticality compared to the design basis. And I'll talk more about the difference between as-loaded and design basis on my next slide.

So this also includes the -- this animation, we are also looking into loading approach to see if we can improve our loading approach or we can redesign the basket to support direct disposal of DPC in the repository.

The second one -- and I'm going to talk more about this detail criticality analysis approach today. The second approach we are looking is up here. That means that if you can fill the DPC with some kind of aluminum filler before putting that into the geological repository. We'll talk more about that tomorrow.

And the third approach is criticality consequence. That means like what if one DPC or more than one DPC go critical in the repository. What would be the consequences of that? So I will touch on that today, and then tomorrow

Laura Price is going to talk about that in detail.

So before going into the detail, we need to understand a couple of things because I'm going to use them quite a lot. So criticality is measured by effective neutron multiplication factor, or K_{eff} . If K_{eff} is plus one, that means the system is critical. For example, the reactor is a critical system and we try to maintain K_{eff} plus one during the nuclear reactor.

So if K_{eff} is less than one, that means subcritical. Outside the reactor we always like to be in the subcritical area. That means we always like to be in the K_{eff} of less than one. If K_{eff} is more than one, then it's called supercritical.

We also need to understand that DPC can only go critical if they have some kind of moderator or water in the system. Without water, they cannot go critical.

So as I mentioned in my previous slide about the design basis and as-loaded, so let's talk about the design basis and as-loaded. For

the majority of my presentation today I'm going to talk about as-loaded, so it's good to understand the difference between the design basis and as-loaded at this point.

So vendors, DPC vendors, they are performing design basis calculations, and the design basis, what they do, they use the bounding fuel calculations. That means they use the bounding enrichment and bounding burnup for doing their calculations. And they are using the design basis because when they are doing the design basis calculation for the DPC, they do not know what kind of fuel DPCs are going to put in their DPC or in their canister. So they try to bound all disposed, all discharged assemblies from the reactor. That's why they perform the design basis.

So here's an example. Like if we see the bottom left figure right here, so in this one, so this is our 24 as-loaded PWR canister, and the vendors they have done the calculation using 3.7 percent initial enrichment. They did not take into account any kind of burnup or cooling time. That means in this canister

we are allowed to load any assemblies that has enrichment lower than 3.7 percent, but in reality you do not have all the assemblies exactly at 3.7 percent, so the middle picture, that's basically showing the reality. The middle picture is just a discharge population from a couple of reactors, and the Y axis is basically the burnup and the X axis is the initial enrichment.

Now, If we draw an imaginary line from 3.7 right here, we'll see there are a lot of assemblies there on the other side of 3.7, and they are all assumed to have some burnup. So they are not (inaudible). And we call them used or spent nuclear fuel because they're using them in the reactors, so they will definitely have some burnup. So in reality you would not see these. You will see something like this one.

So this is an actual loaded canister and you will see like they are loading, maintaining the limit. That means they are loading less than 3.7 percent, but those assemblies also have some burnup, like for example if you think about this one, so they have a (inaudible) burnup.

So now if you use the design basis for the Keff calculation, we'll end up with something like Keff plus .90, and if you use as-loaded, you will get .66.

So the difference between the design basis and as-loaded is what we call the uncredited margin. And we are actually using the uncredited margin to find out what percentage of DPC will be disposable without any criticality concern. So all we are doing, we are actually taking credit for the actual content of the DPC in our criticality calculation.

Now, as we can see, we are performing criticality calculation for each loaded canister and as a function of time. That means we are performing thousands of calculations. Just think about that there are 3,000 -- at this point, there are about 3,000 loaded DPCs, and if we have to perform criticality calculation for 20 times this, that means we are talking about 60,000 calculations, and we cannot do that by hand, so we developed a tool for doing this calculation in an automated fashion. We call

that tool the UNF-ST&DARDS. It stands for Used Nuclear Fuel Storage Transportation and Disposal Analysis Resource and Data System. A mouthful.

So what we have in UNF-ST&DARDS, we have a comprehensive database of spent nuclear fuel and integrated analysis tool. So currently we are mainly using the scale analysis tool for doing our criticality and shielding calculations, but by design the UNF-ST&DARDS also allows you to use other tools like NCMP for doing nuclear calculation.

On the right-hand side I'm showing the kind of data we have. So we have -- at this point we have data for about 250,000 discharge assemblies from the reactor, so what I've done on this plot, I'm going to group them by burnup and enrichment, so my Y axis is the burnup and X axis is the enrichment. And inside each of the bins the number is showing how many assemblies we have in that particular bead.

So we can see the majority of the assemblies in this region right here, that means the majority, as soon as they are above 40,000 megawatt-day per MT burnup and about 4 percent

enrichment.

So the relationship defined between UNF-ST&DARDS and data relation defining the UNF-ST&DARDS allow us to do the criticality calculations and other calculations like shielding calculation in an automated fashion. So all we have in the UNF-ST&DARDS, we have models for different kinds of calculation. We have models for doing depletion calculation, we have models for doing criticality, dose, etc.

So these models are nothing but a structure without the data. And when you perform the calculation, we supply the data from the -- from our database. We supply the discharge data. We supply the assembly data. We supply the reactor data for performing automated calculation within the UNF-ST&DARDS.

So now when we are talking about we are actually performing as-loaded criticality calculation for all the DPCs, that means we are talking about we are doing a full burnup credit analysis for all the loaded DPCs. By full I mean we take credit for both actinides and fission products.

So burnup credit calculations are done in two states. There are two stages. In number one, we find out what is your time-dependent isotopics. That means if you are doing a criticality calculation for 3,000 years in the future, you need to find out what is your spent nuclear fuel isotopic composition at that given date. We use the SCALE TRITON and ORIGEN for doing the calculation. We find out the number of densities. That's step number one.

In step number two we get the number density or we get the composition of the spent nuclear fuel and put that in our three-dimensional Monte Carlo DPC model to find out what is the Keff, if that particular canister or that particular DPC scan was critical or not.

And we are currently using the KENO-VI. Keno Six is a model using a scale system for doing criticality calculations and we are using ENDF/B 7.1 cross-section libraries for doing our calculation.

So there is two steps. In step number one we are finding out the isotopic composition of spent nuclear fuel. In step number two we

are putting that isotopic composition into a (inaudible) model to find out the K_{eff} of the system.

So when we are performing these as-loaded analyses, we make some assumptions for the reactor side of the calculation. That means we make some assumptions for the critical -- or for the depletion part of our calculation. So why we need to make these assumptions, because at this point we do not know the actual reactor history for each of the discharge assemblies from the reactor. That means we do not know whether an assembly was burned with one absorber rod or whether that assembly was burned next to a control rods and things like that. So we make some conservative assumptions for doing our depletion calculation of the reactor side of the calculation.

So for PWR we assume there will be high soluble boron concentration. We assume low moderator density, and we assume the burnable absorber throughout the life of assembly in the reactor. Also for PWR we use the bounding burnup profile from NUREG/CR-6801.

On the BWR side we assume the blade --

the control blades are inserted all the way and they are there inside it throughout the life. And we also assume a high void fraction for our depletion calculation. We also use limiting BWR burnup profile that we (inaudible) from the Commercial Shell Reactor Criticality Data.

So all these assumptions, what is it trying to do, it's trying to increase the residual reactor nucleus reactivity for that assemblies. And that way they are bounding for doing these kind of calculations. Keep in mind so we are making assumptions for the reactor side of the calculations, but for the canister side of the calculations we are actually using the actual content. That means we take credit for the actual burnup, actual enrichment, actual (inaudible), everything which is in the canister.

So for criticality calculations we need to assume some repository scenarios. Ernie mentioned this before. Right now we are analyzing two different scenarios. Number one scenario is loss of neutron absorber. So in this scenario we do not take credit for any

neutron absorber, any basket neutron absorber, in our calculation. So this is actually given for all DPCs we analyzed at this point.

Our number two scenario is the basket degradation. In this scenario, if there is a carbon steel -- keep in mind, if there is a carbon steel component inside the basket, we assume and we do not take credit for the carbon steel component and we assume the basket will degrade accordingly.

So there are two scenarios. One is the loss of neutron absorber. In that we do not take credit for the neutron absorber on the basket. And second one is the basket degradation. In that one we do not take credit for any carbon steel component inside the basket.

So also we need to understand there are two types of -- mainly two types of design, and this is kind of important because the results are different for these two types of canisters. One kind of canister we call the flux trap design. In the flux trap design -- you can see this is the flux trap design right here. And in

the flux trap design, you can see there's a gap. There's a gap between the assemblies. Do you see there's a gap here? So that's what a flux trap design is.

The other one is the egg crate design, where the assemblies are adjacent to each other and there is no gap. So also at the bottom we are showing one of our degraded basket scenarios. So this canister is kind of constructed by tube and disk. So inside the tube we put the assemblies and the tubes are put in place using the actual disk, and these disks are actually made out of coated carbon steel. Like we assume this would be gone, this will be corroded. We do not take credit for disk, then all the tubes, they will collapse and they will form something like this. So this is one of our degraded basket scenarios.

So there are two things we need to keep in mind from here. There are two types of basket design. One is the flux trap and one is the egg crate. And I'm going to use that when I'm going to talk about the results we have for criticality analysis.

So now we are making models for different kind of DPCs and we also need to benchmark the model or do some kind of validation of the model before using that with our as-loaded contained. So right now the way we do these things, we make a model for a given canister and within that design basis as needed for that particular canister and then compare with the safety analysis for Keff and make sure our Keff is matching their Keff and then we say, okay, this is benchmarked, now we can use this model for doing our as-loaded calculations. That is our validation, our benchmarking approach, for our DPC model.

So in this table here we can see there's a canister name. It's also kind of pointing out if the canister is a flux trap design or not. It's also showing us what is the B10 content of the neutron absorber for that particular DPC. Talking about the construction, whether it's a tube and disk or egg crate, and also saying whether there is a carbon steel component in the basket.

As you can see, there are only two

baskets, the TSC-37 we analyzed, and also FO/FC-DSC, those two, they have carbon steel component. So a degraded basket scenario only applicable for these two canisters, not for any other canisters.

The next one is the different Keff coming from the SAR, the safety analysis report. And the last column basically the Keff we calculated. And as you can see, our Keff is quite close or similar to the Keff from the same canisters as before. That means all our canisters, the one we are using on all the DPCs, we are using for as-loaded calculation their benchmark, and then we are using that for our criticality calculation. So this is the way we do our validation, our benchmarking, our model, before start working on performing the as-loaded criticality calculation.

So I will switch gears a little bit. So we talked about design basis versus as-loaded. We talked about some of the assumptions we are making for doing as-loaded calculation. Now I'll switch gears and start talking about the results we have in the criticality space.

So we have done calculation for 708 loaded DPCs and at 32 different sites, so this plot right here is showing all the sites. The red ones are basically shut-down sites. That means Zion, Yankee Rowe, they are shut-down sites, for example, so they're highlighted as red. Also, the plot is showing different colored bar, so the color are based on what type of canister or what type of DPC we have in that particular site. You can see some of the sites, like Arkansas Nuclear One, they have like two different type canisters, like NPC24 and NPC32.

So to date, we analyzed 24 assemblies, PWR canisters, 26 assemblies, 32, 36, and 37 assembly PWR canisters, and for BWR, we analyzed 61, 68, and 80 assembly canisters.

So we perform all our calculations up to 22,000 years. As Ernie is going to show, that is when the peak happened, the second peak, but recently -- by recently I mean like a couple of weeks ago we actually extended all our calculations to one million years just to see how the Keff is changing over time.

So now I'm going to talk about some of

the results we have. So what we found by doing the as-loaded calculation, not doing the design basis, like the way vendors are doing, 68 percent of our analyzed DPCs, we can actually dispose them safely without any criticality concern. So keep in mind that 68 percent is based on the 708 analyzed canisters. So if we analyzed more canisters, that means over 3,000 that percentage can change.

So previously I mentioned if you are below one, if your Keff is below one, then you are subcritical, but for our statistics we actually used .98 to define whether a canister is subcritical or not. That means if a DPC is below .98, then it is subcritical. If it's above .98, then we consider that as a critical. So we use the .98 to actually take into account that biases and uncertainties we have in our calculation.

So here's the statistics. So until now we analyzed, like, 708 canisters and if we had done design analysis calculation like the way the vendors are doing, none of them would be subcritical. All of them would be critical.

With our as-loaded approach, and with loss of neutron absorber is the only disposal scenario, we can show like 79 percent of the 708 analyzed will be subcritical. If we add basket degradation on top of that loss of neutron absorber scenario, we can show that like 68 percent will be subcritical.

And one thing we need to keep in mind, we do not consider misload in this calculation. I will talk about misload later.

So this is basically all the results we have, so this is the density plot. So the Y axis is the K_{eff} , X axis is the calendar year. So we have like a finer time resolution initially, that's why we have like more points initially and post time resolutions later in the year, or later in the calendar year, so we have like less points in the calendar year or less points on the plot during the calendar year.

So one distinct feature of this plot is like if you see the BWR, the blue cloud is basically showing the BWR, and you can see like the majority of the BWR, they are actually below

subcritical limits, so again we can see like the majority of the BWR will be subcritical in a repository time frame and we'll see more about this later.

So in the previous slide I talked about our results, like, in general. Now I will go into more deeper. So here what I've done, I've kind of grouped our DPCs by PWR and BWR, then I grouped them by scenarios, like loss of neutron absorber and basket degradation. And then I grouped them by the basket type, flux trap versus egg crate.

So this plot is basically showing the loss of neutron absorber for PWR, and on the left side you can see the plot for flux trap design and on the right side we can see the plot for egg crate design. So we have two lines. The yellow line, the orange line, is basically the subcritical line at .98 and the black line is the critical line, so that's the Keff plus one.

So if you are on the left side of the yellow line or the orange line, then you are subcritical. If you are on the right side, then

you are not subcritical. So as we can see, the majority of the flux trap design, they are actually subcritical. That will be the black circle. But that is not quite true for the egg crate design. So the majority of the egg crate design, as you can see, they are on this (inaudible) side.

So there is one more push here, as you can see by the hash line. So some of these DPCs, they also contain damaged fuel in the DPC. So if there is damaged fuel -- and most of the time we do not know the extent of the damage of the damaged fuel, and then we make some conservative assumptions based on the safety analysis report.

So what do we do if there's damaged fuel in the DPC? We assume that there is no burn up for that fuel. That means we do not take credit for the burnup. And we also model that as optimum fuel pin-lattice spacing. So that increases the reactivity of the system.

So as you can see, like, for most of the egg crate design, so they are critical and they all have some kind of damaged fuel in them.

That means if we can improve our damaged fuel modeling and if we can take credit for the burnup, then we believe that some of these canisters, they will move on the other side and improve our system statistics.

So as I mentioned, like so the issue with the damaged fuel is we do not know the extent of the damage. So when they are storing the fuel as damaged fuel, if you know the extent of the damage, then my understanding is most of the damaged fuel they actually have a small -- really small damage, then we definitely should be able to model them as, like, actual fuel as with full burnup. So we are actively considering the ideas of improving our damaged fuel, but we need more data to begin to understand what industry is putting -- what industry is declaring as damaged fuel. If we know that, then we can take credit for the burnup and we believe that that will improve our statistics.

So this is the same thing. So this is for the loss of neutron absorber results and for BWR, and as we have seen in the cloud plot, the

blue cloud, so most of the BWR, they are not subcritical. There are only a handful of them that would be on the other side of the subcritical line. That means they would be critical. And they are critical because they are damaged fuel and our damaged-fuel model is quite conservative at this point, and we believe if we can improve them, then these DPCs will end up on the other side of the subcriticality line.

So this is for the basket degradation (inaudible) scenario, and on this plot I plotted both our egg crate and flux trap design together, but as you see, like, the majority of them will be critical. That means, like, if we need to consider -- if we need to consider basket degradation, then there's a chance, like, the majority of the DPC will be critical.

So there was some question about this one during the previous talk. So all the results we have seen until now we assume the DPC will be plotted with fresh water, which is not the reality. So in reality, the water -- if the DPCs are in water, the water will contain some species or some element from the repository. So

we analyzed, like, there are all the -- most of the commonly available species or elements in the water. We found, like, the chlorine, that can help. That can help quite a bit.

So on this plot what I'm showing here is so your Y axis is Keff and X axis is your NaCl, also the salt concentration. And as you see, like, if you keep increasing the salt concentration, then the majority of the canisters that are actually critical that will become subcritical. And we found, like, all the 708 canisters we analyzed, we found like with slightly above two molal concentration, we can bring them down to subcritical zone.

So we also found, like, if there is lithium and boron in the repository water, that can also help, but for other dissolved ecospecies we found that they do not provide a lot of reactivity -- neutron absorption effect or reactivity reduction, so if there's a chlorine, we can definitely use that for -- take credit for the chlorine and that can help us, and if there is lithium and boron in the repository, we can take credit for that and that

will definitely help us with our reactivity scenario.

Also, like, when, like, industry are increasing their loading of spent nuclear fuel in the DPCs, especially for the PWR fuel, sometimes they load this PWR fuel with a nonfuel component. So nonfuel component would be burnable poison rod assemblies, or BPRAs; wet annular burnable absorbers, or WABAs; or control rod assemblies, or CRAs. So what they do, when they load them with PWR assemblies, they actually go in the guide tube of that assembly. That means they can displace water from the guide tube and then provide some reactivity -- reactivity reduction if we can model them.

So we have done some limited study using the components. So what I've done, like, I have taken, like, a couple of canisters. Those canisters are from a site. And then I modeled that in WABA. So I assumed the WABA had 16 fingers, so 16 rods. They means, like, they will lock, the 16 guide tubes. As shown in the doc here. So as you can see, they got -- some of the guide tubes, they have the WABA in there.

And then we compare the criticality of the Keff with and without the component.

And for this small sample, we found the criticality impact in terms of delta K, as seen by the last column here, it's not that big. But this is something we are actively pursuing and we are actually planning to extend that through all of our PWR canisters to find out, like, what we can get out of modeling this nonfuel component in our DPCs.

So we are performing as-loaded criticality analysis. As I mentioned before, that means we are taking credit for full burnup for this, and if we see the ISG-8 Rev 3, it's saying if you are taking credit for the burnup and if you are not performing any burnup measurement, then you need to analyze for misload. And as you know, typically when you put assemblies in a DPC, we do not measure the burnup. That means we need to consider misload and we develop a misload analysis methodology for as-loaded criticality calculation.

So misload could be -- there are two types of misload. One, you can select the right

assemblies from the pool and put them in the wrong location inside the DPC. That means you are supposed to select a one, you are selecting a one, and you are supposed to put that in location one but we are putting it in location two, so select the right assemblies, put them in wrong location.

Number two, what NRC is mainly concerned about and what is part of the ISG-8 Rev 3, that is if you are selecting the wrong assemblies and putting that in the right or wrong location inside your canister. So NRC recommends for this type of misloading you can take, like, two different approaches. One, you can model that as severely unburned assemblies, and the second approach is to model that as moderately unburned assemblies. I will not go into details for this one, so the misload analysis I put together for our as-loaded criticality (inaudible) presentation and we had some papers. If you want to know about the research, maybe you need to go to the paper and understand, like, what we've done there.

So now if we think about a repository

scenario, and we would expect most of the DPC will go from shut-down site to the repository, so the scenario two, the misload scenario two, is not quite probable. That means, like, if we select the wrong assemblies from the pool, at some point during the subsequent loading we should begin to know about it, so we know, like, misload happened. But for scenario one, where we are selecting the right assemblies and putting that in wrong locations and we are kind of shearing -- kind of (inaudible) that DPC, there's no way to find out if the misload happened.

So we believe for DPC disposal, scenario one is the most likely. Scenario two is unlikely, especially when you are talking about disposal from shut-down sites, because if you select the wrong assembly, you should know about that doing subsequent loading.

So the way we have done this calculation -- I'll be really brief on this one. We analyzed, like, each assembly to find out the K infinity. K infinity is I need to get the reactivity and interact them, so we know what is

the most reactive assemblies, what is the next one, and et cetera. Then we do a criticality calculation for a given canister with the fission density to find out the most reactive location inside the canister. So we know the most reactive location inside the canisters and we combine all these things to find out what will be the K_{eff} in the case of a misload. And this has been automated inside the UNF-ST&DARDS so you can actually perform all these calculations in an automated fashion within the UNF-ST&DARDS.

Here is the results. So on Y axis we have the K_{eff} . X axis we have the number of canisters to be analyzed. If you see the line, this line going up, that's the as-loaded K_{eff} . The straight line, the one is like the orange and the other one red, the orange one is showing that subcritical limit and the red one is showing the criticality limit. As you can see, some of the canisters there have all subcritical limit.

Now, the blue spike or the light blue spike, they are basically indicating the

scenario number two. The one NRC is concerned about and the one we think is not likely for disposal scenario. So the scenario number two, just keep in mind what we are doing is selecting the wrong assemblies and putting that in the most reactive location in the DPC. The pink spikes here, they are scenario one, where we are selecting the right assemblies and putting them in the wrong location in the DPC. And we think that that is the most likely scenario for the DPC deck disposal.

So now if we compare between the light blue spike and the pink spike, you can see the pink spike will not impact Keff by that much, but we need to consider the light blue one because it's scenario two, then that putting back our criticality results and our statistics will change quite a bit. We need to balance for that.

Also need to keep in mind this is the way -- we assume, like, all the DPCs will be misloaded, but that is not realistic, so at some point if we take this to licensing space, then we need to combine this with actual probability

of the misload. We haven't done that yet.

So Ernie already mentioned during his talk, and Tim mentioned this one. So during our misload analysis we found some interesting aspects of DPC loading. So we knew this before and we saw that during this calculation. We knew, like, industries loading DPCs to reduce dose or to reduce peak cladding temperature. That means that they are loading from the standpoint of those or from the standpoint of (inaudible). They are not loading taking into account the criticality.

So the top right plot which looks like a candle, that is kind of showing a picture from one of the sites. As you see, all these red dots, they are actual Keff for each of the DPCs. Now, what I've done, so I've taken those DPC and rearrange the assemblies inside the DPCs and figure out what could be the minimum Keff. That's the bottom of the black line. And what would be the maximum Keff. That is the top of the black line. And as you can see, there are many, many canisters or many DPCs that are loaded close to the maximum Keff. So we wouldn't -- we could load them in a better way,

that means close to the minimum, and that would help us with our DPC direct disposal.

So we've done the same calculation for all the DPCs, and so the black line is as-loaded DPCs, and the pink spike is kind of showing the span, like the minimum, the maximum K_{eff} . And you can see, the DPCs that are above subcritical, if we would have loaded properly, taking into account criticality, then some of them would be subcritical. They would not go critical.

So we are doing that as-loaded calculations and we are -- as I talked about, we are making some assumptions for the reactor side of the calculations and we need to do some kind of validation approach for the reactor side of the calculation. And we are using detailed information from some of the reactor sites, like getting information from one of the PWR reactor sites and one of the BWR reactor sites, and trying to find out if there is any excess margin in our (inaudible) approach and if there is any nonconservative approach. Nonconservative doesn't mean (inaudible). So we need to know

both. If there is an excess margin in our (inaudible) approach, then we can use that. (Inaudible) if they are nonconservative, we can also change that canister approach.

So we have done the calculation using the detailed data. So on this plot the conservative is at current UNF-ST&DARDS, as-loaded in this approach, and the (inaudible) is why we are using the detailed information from the reactor sites. So this is the decay heat. We are plotting the difference in decay as a function of time and as you can see, like our detail -- so our conservative approach, the one we that is using UNF-ST&DARDS, provide about more than 8 percent margin through most of the analysis we have done.

So on the right-hand side we have done the same thing for Keff date for canister. So the blue line here, that's the conservative one. That's the UNF-ST&DARDS current approach. And the orange line here, that's using the detailed information. And the green line here is representative information from a reactor site. So keeping quite a bit of margin in our current

as-loaded criticality analysis approach.

So we can use this margin, for example, like we are using the actual burnup, actual enrichment, and cooling time for analyzing all these things, and we do not really know how much uncertainties we have in each of those burnups reported by industry, by degrees. So we can actually accommodate that uncertainty using this margin in our calculation as well.

So I will quickly talk about -- as I said, we started working on this lately. We are working on a criticality consequence and Laura Price is going to talk about this in detail tomorrow. So we are working on -- at Oak Ridge National Lab we are working on a multiphysics coupling between a neutronics core and a thermohydraulics code. The idea here is the neutronics core will provide the power distribution to thermohydraulics, thermohydraulics will provide the water density and temperature, and we will do that in iteration for each of the power level. And when they converge we provide that for the depletion code and then find out the changes in isotopics and that is back to our multiphysics

simulation.

So for the neutronics, we are using a new code from Oak Ridge National Lab. It's called Shift. It's a Monte Carlo neutronics analysis code. For depletion we are using ORIGEN with Shift. For thermohydraulics, for TH, we're using COBRA-SFS. Currently we have done some scoping calculation also using remap and at some point in the future we thought about doing some kind of coupling with the mechanics, hope to find out if there is a change in temperature and pressure, how that is going to deform our canister. We haven't done that yet.

So we have done some simple calculations, and so this is basically a 17-by-17 assembly, just to see, like, our coupling is working properly. So we assume our 200-watt power for this system. We assume a 60-degree boundary for temperature. We assume reflecting boundary condition for the neutronics. We assume 18 axial levels and 6 million particles, and the analysis converged in three iterations.

So some results are here. As we expected, so this is the results for the central channels. If we increase the power, the temperature will increase, and if we

increase the power the moderator density will go down. So the results are as expected. Now we are moving from this single assembly analysis to a full DPC calculations, and I'm hoping we'll have some results by the end of this year.

Okay. So this is my last slide. So we have done calculation using as-loaded contained of DPCs. We have done the calculation for more than 700 DPCs at this point and we found more than 60 percent of them will be subcritical in a repository time frame. And we use two different kind of scenarios. One is the loss of neutron absorber and one is the degraded basket.

So we found, like, there are two types of DPCs. One is the flux trap design and one is the egg crate. And we found the flux trap design was not likely to be critical, so there's a high chance all the flux trap design will be subcritical. But the egg crate design, they could be critical, as we have seen the results.

We have done the calculation for BWR, but most of the BWR assemblies we analyzed, they

were old and – we developed new methodologies for analyzing multilattice fuel with like with (inaudible) rod and things like that. So BWR is more challenging because they use different kind of fuel design. So one of the challenges here, we need to gather some information from the industry to come up with a good approach for modeling the modern BWR fuel.

So we also need to find out the bias and uncertainties in our approach, and the last things, we also have started working on our criticality consequence model which is basically a coupling between our neutronics and TH code, and we show it works for a single assembly.

So with that I will take any questions.

BAHR: Okay. Thank you, Kaushik. I saw -- okay. Geoff Freeze's hand was up. But let's go to Paul.

TURINSKY: Okay. I have a bunch of questions, and I think the answers are yes and no, so let me go through them rapidly.

Have you looked at any cask systems?

BANERJEE: What do you mean by cask

systems?

TURINSKY: The bolted.

BANERJEE: The what?

TURINSKY: Bolted. Not welded.

BANERJEE: Oh, no, not really. We have some information but that is not quite a priority at this point, but we do have some information about the boarded system. So the one issue is that they have to be transported. So the issue is the transportation. So we can transport that in a repository. I don't think there's an issue with doing that disposal part but the transport is an issue.

TURINSKY: Criticality-wise is what I'm asking.

BANERJEE: We are not in (inaudible).

TURINSKY: Okay. Are you assuming that vacuum boundary conditions outside the canister?

BANERJEE: No. It's water reflected.

TURINSKY: Okay. All right. Great.

Damaged fuel. The vendor does the calculation just like you did for the undamaged fuel. Have you compared your k-effective calculation damaged fuel to the design basis

against what the vendor's predicting?

BANERJEE: Yes.

TURINSKY: And how did they grade?

BANERJEE: They record -- they agree like there are (inaudible) that's what they are doing. So for the damage to it, they do not take credit for the burnup and for the damaged fuel, we do not take credit for the burnup as well.

TURINSKY: Okay. And why would you not consider basket degradation? Isn't that inevitable?

BANERJEE: We need to consider that for all our cases in the future but currently we are not. For stainless steel basket, we are not considering any kind of basket degradation at this point.

TURINSKY: Okay. It seems to me that would be a hot research material area to examine.

BANERJEE: Right.

TURINSKY: Because it would change dramatically based on that.

BANERJEE: I completely agree.

TURINSKY: Yeah. Yet I don't see

materials -- maybe there is and we'll hear it later -- of material research --

BANERJEE: Right.

TURINSKY: -- on basket material.

And then the last one is misload of assemblies. I think that's very, very unlikely because if they do the loadings just like they do in the reactor, at the very end of loading, they're going to go and do a camera scan of all the serial numbers and they're going to be verified independently by two people that the right assembly is in the right location.

BANERJEE: I -- I completely agree with that and I do not think there's a chance of a misload, but according to the ISG Rev. 3 we need to perform that calculation. That's why I say we need to combine that actual probability, the probability is almost null.

TURINSKY: Okay. Well, I think probability would probably rule it out.

BANERJEE: Okay.

TURINSKY: Okay. That's it, Jean.

BANERJEE: I can't hear you.

MOTE: Jean, I wasn't hearing. You're

inviting me?

BAHR: Sorry. Sorry. I was muted --

MOTE: Okay.

BAHR: -- Nigel.

MOTE: So Kaushik, I'm looking at slide 12 on the copies that you provided us ahead of time, but I see you changed your presentation so it may not be slide 12 on yours. This is the one with the two bar charts for flux trap and egg crate design canisters.

That one. Yes. Go back to the previous one.

BANERJEE: This one?

MOTE: The right curve you've got there, as you indicated, the canisters that are the high end of the k-effective range are dominated by what you call failed fuel.

One thing that I know has happened and I know Zion and Main Yankee, for example, cite to where this is true. They have put high burnup fuel into failed fuel cans and then loaded those into the designated pockets for high burnup and failed fuel in the storage canisters that then go in the storage casts.

To what extent have you counted high burnup fuel as failed fuel because it may be defined that way as being in a failed fuel can?

Because high burnup fuel necessarily starts out with a higher enrichment and that might give a real skew on the results that you have on that curve.

BANERJEE: So if we know the information like they are putting a high burnup in the damaged fuel can, then we actually model that as high burnup. We do not model that as damaged fuel.

MOTE: Okay. Thank you.

BANERJEE: For Zion and Main Yankee, we are not modeling them as damage; we model them as high burnup.

MOTE: Okay. Okay. Good. I'm just surprised you've got a 1.1 k-effective. I've seen numbers in some reports that are higher than that. That's -- that is really quite -- quite reactive fuel. Is this because they're fuel assemblies that were discharged earlier because they failed?

BANERJEE: Yeah, there are two reasons

for this. Some of the shutdown site. If you think about the last discharge cycle, so there are quite a few assemblies coming out from the last discharge cycle with really low burnup.

MOTE: Yeah, they tend to -- they load the last course so that they end up not with -- not discharging a lot of value in the residual enrichment left in the fuel assemblies. They try to either run to low -- low residual enrichments or they're going to coast down just so they don't have the economic waste of discharging fuel without sort of enrichment.

BANERJEE: Yeah, we found that is not quite true for some of the sites, and so this assemblies we are talking about, they have like a 10-gigawatt, 12-gigawatt burnup, and if you combine that with our fresh fuel, our damaged fuel, then that can drive that data really high.

MOTE: Okay. All right.

Jean, can I have another two?

Okay. Kaushik, would you go to the slide before, the one with the red and blue cloud presentation for Ps and Bs. Could you spend a moment just to tell us what that means?

I don't know what the two bars are on the right. Obviously the blue is for Bs and the red is for Ps. I'm not sure what the bars are and I don't know what the -- what the calibration on those apply to. I see -- and this is all linked. I see the heavy red spot and the heavy blue spot at, and then 4,000 years.

Could you say what those accentuated color designations mean?

BANERJEE: Yes. So for the initial time, like from zero to a thousand years, we have like really high resolution in the time scale. That means we model like almost like in each 20 years. So we have more points in this location than out in like 20,000 years. And this is a density plot, so all you're doing is taking the number of points and it's finding out what is your density. So this is just showing the density patterns.

MOTE: And by density, you mean the number of analyses that you've done; is that what you mean?

BANERJEE: Number of analyses we've done

normalized by the total number of analyses.

MOTE: Okay.

BANERJEE: Assuming more than one.

MOTE: Okay. All right. Thanks.

And that means that you did no analyses -- I'm sorry, there was a gap in there between 16 and 19,000 years. You did no analyses in that period; is that what that means?

BANERJEE: Right. Because like, again, you have the second (inaudible) for 20,000 years, we have not done any calculations for that particular time frame.

MOTE: Okay. All right. Thanks. Thank you.

Thanks, Jean.

BAHR: Okay. Lee Peddicord?

PEDDICORD: Yeah, thank you.

In fact, back on that same slide 13 you were just discussing with Nigel, so could -- so let me understand the table there on the left, 708 DPCs analyzed. Total below the subcritical limit with the loss of neutron absorber, zero.

What's that mean?

BANERJEE: That means that if you do the calculation in the design basis, like the way the vendors are doing the calculation, then all of this will be critical. None of it will be subcritical.

PEDDICORD: I see. Okay. Even though some are at .8. Okay. Then total DPCs below the subcritical limit. Now, is the subcritical limit .98 k-effective?

BANERJEE: Yes, that's what -- that's what we are using at this point.

PEDDICORD: So do you have the -- the percentage, though, that's below 1.0 from that instead of the .98? You can run that number pretty easily.

BANERJEE: Right. We can easily find that out from our database.

PEDDICORD: Yeah, that would be kind of interesting.

BANERJEE: Okay.

PEDDICORD: Would you -- now, I think it's back on slide 6, where you were showing, I believe, burnups in enrichments, does that sound right?

Yeah. You went -- well, say again what this is telling us.

BANERJEE: So this is basically we're using a tool called UNF-ST&DARDS for doing our calculation. And UNF-ST&DARDS, they are a database and we have about 250,000 assemblies. I'm just showing the type of information we have. What I've done, I've taken all those 250,000 assemblies and beaned them by burnup and enrichment. And each of the bean is showing like how many assemblies we have in each of the beans. It's not really showing any criticality but showing what kind of information we have in UNF-ST&DARDS and what kind of information we are using for doing the as-loaded criticality calculation.

PEDDICORD: So this is initial enrichment and then the subsequent burnup; is that correct?

BANERJEE: Yes.

PEDDICORD: Got it. Okay. Thank you. Well, so tell me what your little circle means. That's where most of them are. Roughly 4% in burnups of -- whatever the burnups are.

BANERJEE: It's more than 40,000 megawatt-days per MTU.

PEDDICORD: Yeah, okay.

BANERJEE: Next slide.

PEDDICORD: So it's the number -- okay. So going back, your discussion with Nigel, some of these outliers would be ones that -- of higher enrichments and higher burnups; is that right? If I'm reading up and to the right.

BANERJEE: No, it'll be higher enrichment and lower burnup.

PEDDICORD: Okay. Okay. Yeah. It's a little hard to tell with the fine print.

Okay. Thank you.

BAHR: Okay. Thanks, Lee.

Do we have any other questions from board members or staff?

Bret Leslie?

LESLIE: Kaushik, nice talk. It's been a while since I looked at the disposal criticality methodology report. Does that allow for as-loaded calculation?

BANERJEE: Yes.

LESLIE: Okay. Thank you.

BAHR: Okay. Anyone else?

Going once, going twice.

Okay. So that brings us to the end of the questions for the presenters. We do have some time for a few public comments. I understand we have about three of those. And I'm going to turn it over to Bret Leslie, if he can put his hand up or -- there, we've got him.

LESLIE: Thank you, Jean.

There are just -- two more came in at the last minute. They're all fairly short, and I'll just go through them one by one.

The first comment is from Barbara Warren, with no affiliation, and it was a question. For this study, did they consider the impact of high burnup fuel? And she asked this in the very beginning of the meeting, and I think both Ernie and Kaushik provided some information on that.

The next comment is from Chris Schneidmiller from Exchange Monitor Publications. Regarding the 20 billion in anticipated savings, would that be for the nuclear utilities or by the Department of Energy

under its requirements in the Nuclear Waste Policy Act? And he also asks, and does the department have an estimate of the remaining costs?

The third comment --

BAHR: That seems -- we want to -- I think that's a question for Dr. Boyle; is that correct, Bret? Should we give him a chance to answer that?

LESLIE: Or Tim.

BAHR: Or Tim?

Do one of you -- Bill Boyle -- William Boyle -- or Tim Gunter?

Thank you.

GUNTER: I'm on, right?

BAHR: Yes.

GUNTER: Well, I'll start. Bill, if you want to add in or take over.

But, I mean, in terms of where the cost savings -- who would see the cost saving I think is yet to be determined. You know, going back to the legal issues of the standard contract, we don't know the answer -- or at least I don't know the answer to that yet. What I do know is

it would be money that would be saved either the utilities or the taxpayer, rate payers, but it's, you know, less expenditure of money.

BAHR: William, anything -- anything to add to that?

You're muted.

BOYLE: Yeah, no, Tim's got it right. That's -- at this point, it's unknown who would pick up that tab over the legal issue that was discussed before. That's something that either through litigation or renegotiation will potentially be settled some day.

And as long as I'm discussing that again, it's -- I think I mentioned to Mary Lou, people have known about this issue for a long time, and I think people are choosing not to address it now because they have other things that are more pressing concerns to them.

You know, everybody knows it's a problem, but it doesn't -- maybe they have enough on their plates with problems that exist today and they're just waiting for sometime in the future to address it.

But it was the motivating factor for all

this research in the first place, the potential cost or savings, however you want to view it. And who was going to pay for it, in some ways doesn't matter, but it would matter to who did have to pay for it.

But it was that potential savings or cost that caused us to want to look, well, could we dispose directly as they are?

BAHR: Since I have both of you on there, in terms of the cost or savings, does that include consideration of the longer surface aging management times? Because there certainly are costs associated with that. Or has that been factored into the analysis?

BOYLE: I do believe it has been. There was reference in somebody's talk, maybe it was Tim's, maybe it was Ernie's, to a Sandia report that mentioned about -- it has alternatives in its title -- and it looked at getting a repository at different times which is driven, in part for some scenarios, by extended storage.

So I think there's some insight into, okay, if you dispose directly as is but you've got to wait longer, people have -- have some

knowledge of what that turns out to be.

BAHR: Okay. Thank you.

BOYLE: I think in all circumstances, the cheapest repository alternative considered is to directly dispose and to do it sooner rather than later.

BAHR: Okay. So, Bret, do you want to go back to the --

LESLIE: Sure. Absolutely. I have three more.

The next comment/question is from John Boucher from the Sierra Club, and it's a question. Assuming a permanent repository does not experience criticality on any DPCs in the first 10,000 years, what risk exists in the 10,000 to 1 million time frame, groundwater migration, et cetera?

I'm going to go on to the next comment.

BAHR: Can I just say, I think we have -- we're going to have a discussion tomorrow of the consequence analysis of criticality, and so I hope that that will be addressed in that presentation.

LESLIE: Okay. The next commenter is

Sven Bader from Orano Federal Services, and it was for Kaushik. And he asks two questions.

Are you analyzing at all for damaged fuel during disposal conditions, and with slump fuel damage, can sufficient water get between the fuel pins to get to critical conditions?

BAHR: So can we get Kaushik on to try to address those issues? If he's still...

BANERJEE: So I think what Sven is asking about, if we are taking into consideration any kind of fuel degradation in the repository, and we do not. Currently our criticality assumption is based on the intact fuel assemblies and degraded baskets. We do not assume any kind of degradation of the fuel assemblies.

LESLIE: Okay. Thank you, Kaushik.

Then the last commenter is Donna Gilmore from sanonofresafety.org. And her -- her comment is, over half the HOLTEC canisters at Diablo Canyon were loaded incorrectly over three loading periods. Hotter fuel assemblies loaded on outer basket sills. It's way to get hotter burnup unloaded into canisters. NRC is aware of

this. It's documented.

And that's the extent of the comments we received today.

BAHR: Okay. Well, thank everyone for their attention and their comments and questions. And --

LESLIE: Hold on a second. I just got three more while I was speaking.

BAHR: Oh, okay.

LESLIE: If you don't mind.

BAHR: Sure. We've got plenty of time.

LESLIE: Okay. So the next comment is from Carlyn Greene from UCX [sic]. Regarding the \$20 billion in avoided costs, is that assuming all 3,000 currently in service casts will be directly disposed, or does that account for future inventory, also?

BAHR: I'm not sure who should be the person -- we've got William Boyle.

BOYLE: I'd have to go back and look at the report, to be honest. I don't recall off the top of my head. But, I mean, it's quite obvious, the more you don't have to repackage, the greater the savings. So that might be --

might, not -- oh, Ernie might know. There you go.

HARDIN: Yeah, the study that I'm most familiar with assumed a certain amount of fuel projecting out into the future, yes. The total amount is 109,000 metric tons.

BAHR: Okay. Thank you.

LESLIE: Okay. Let me get to the next one. Boy, I'm getting more and more. So we might run through the public comment period.

The next comment is from Donna Gilmore again, from sanonofresafety.org. What is the cost to build a hot facility for repackaging? Are there any document references for this information?

BAHR: Anyone from DOE want to provide information on that?

LESLIE: I'll go on to the next one then.

BAHR: We have Bill Boyle -- we have William Boyle and Tim Gunter.

BOYLE: Yeah, there almost certainly are, but I don't have any at the tip of my fingers or whatever. It's -- I don't know.

Tim?

GUNTER: Well, I was going to say, I don't know for sure, but maybe referenced in the cost analysis report that Sandia did. Ernie might be able to confirm.

BAHR: And I believe that that cost analysis report was cited in at least one of the presentations.

GUNTER: It was a reference in my presentation I know for sure.

BAHR: Okay. And those should all be -- those reports are available on the web as well, correct?

GUNTER: Right.

BAHR: Thank you. Okay.

LESLIE: Next comment is from Karen Hadden with no affiliation.

The existing casks were not designed for permanent disposal. The band-aid approach being discussed is deeply concerning and it appears that money is the overriding concern as opposed to safety.

I'm going to move on to the next one, which is also from Donna Gilmore,

sanonofresafety.org. The December 2019 DOE technology gap report states short-term throughwall cracks are priority one problem to resolve and states cannot inspect or repair canisters at this point. Not optimistic for future based on research I found.

BAHR: Okay. I think at one point we saw William Boyle and Timothy Gunter with their hands up again. Would you like to respond?

I've lost their hands. There we go.

BOYLE: There I am.

This is -- I think it's Ms. Hadden's comment, I think is a misrepresentation. I believe it was in Tim's presentation where he brought up if you must repackage the existing DPCs, there are consequences beyond cost, right, you know.

I'm sure it would all be done safely, don't get me wrong. It would have to be licensed by the Nuclear Regulatory Commission, but the cutting open and moving things around, people would get doses, all within limits.

So it's not a decision that's being driven solely by money. It may actually be

safer to dispose of them as is.

BAHR: Tim, do you want to --

GUNTER: Right. And I was just going to add that safety was one of the, you know, four components of our initial look, that whatever we're proposing, we're looking to make sure it's done safely both to the public and the workers.

BAHR: Okay. Thank you.

LESLIE: And the last comment is from Carlyn Greene, again from UxC, which is, how do we find the reports that are referenced, such as the R & D roadmap updated that was noted on slide 13?

BAHR: Hopefully -- yeah, we've got --

BOYLE: Okay. Here's what I generally do to find any document, even if produced by DOE and the national labs. I go to this website called Google. And if I have the title and -- Google is pretty doggone good. Anything, just about, setting aside classified or attorney-client privilege, many of the reports paid for by the taxpayer, they do become public sooner or later, and it really does help to -- if you know the title, just go to Google. Trust

Google.

BAHR: Okay. Thanks for that advice.

Tim, do you have anything to add?

GUNTER: That was gonna be my advice, also, as the first -- first step.

BAHR: And, again, the references are listed in the presentations. The PowerPoint presentations are available on our website, so you're welcome to download those.

We might think about extracting the references to just put them up as part of this -- that were cited as another document to put up as part of this meeting so that people can get the titles easily.

Does that make sense, Bret?

LESLIE: That's probably pretty possible.

BAHR: Okay.

LESLIE: That's it in terms of the public comments for today.

BAHR: Okay. Well, again, I want to thank everyone for our first ever online public meeting, and thanks to all of the staff who worked hard to get this set up. Thanks to all

the presenters who also worked hard to learn how to use the software and practice. Thanks to board members and staff for good questions, and we will look forward to seeing everyone again tomorrow. We'll be reassembling at 12:30 Eastern Daylight Time. That's 9:30 Pacific. And we will have additional presentations.

So thank you all.

(End of meeting.)