United States

Nuclear Waste Technical Review Board (NWTRB)

Transcript

Fall 2020 Board Meeting

Wednesday

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VIRTUAL PUBLIC MEETING - DAY ONE

NWTRB BOARD MEMBERS PRESENT

Jean M. Bahr, Ph.D., Chair

Steven M. Becker, Ph.D.

Allen G. Croff, Nuclear Engineer, M.B.A.

Tissa H. Illangasekare, Ph.D., P.E.

K. Lee Peddicord, Ph.D., P.E.

Paul J. Turinsky, Ph.D.

NWTRB EXECUTIVE STAFF

Nigel Mote, Executive Director

Neysa Slater-Chandler, Director of Administration

NWTRB SENIOR PROFESSIONAL STAFF

Hundal Jung

Bret W. Leslie

Chandrika Manepally

Daniel G. Ogg

Roberto T. Pabalan

NWTRB PROFESSIONAL STAFF

Yoonjo Lee

NWTRB ADMINISTRATION STAFF

Davonya S. Barnes

Jayson S. Bright

Sonya Townsend

Casey Waithe

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BAHR: Okay. I think we're live. So, hello and welcome to the U.S. Nuclear Waste Technical Review Board's Fall Meeting. I'm Jean Bahr, Chair of the Board.

Before opening this meeting, I want to pay tribute to John Garrick, a former Chairman of the Board who passed away on November 1st this year due to complications from a fall. And I expect that many of you attending this meeting will remember John from his time as Chairman between 2004 and 2012. As his obituary in the American Nuclear Society website says, "He was a towering figure in science and -- in the science and engineering community and a brilliant engineer." His work was essential to building the foundation for probabilistic risk assessment, a technique now used to assess risks and identify complex technological systems in many engineering fields, including nuclear waste. John will be remembered for his groundbreaking work over his long career. And while his legacy will be secured through the work of the John -- B. John Garrick Institute for Risk Sciences at the University of California, Los Angeles, that he -- this was launched in 2014 with a grant from John and his wife, Amelia.

So now, I would like turn to today's meeting. This meeting will focus on the U.S. Department of Energy's non-site-specific geologic disposal research and development program and will allow the Board to assess DOE's technical basis for developing alternative viable disposal options for spent nuclear fuel and high-level radioactive waste.

Because of the COVID-19 pandemic situation, we're holding this meeting in an online, virtual format. And then we're also holding the meeting in two half-day sessions, today and tomorrow, instead of our usual format of holding the meeting in one full day session. This will keep both sessions within the working day for the Board members, for most of the presenters, and other attendees who are in the United States. Mr. – Paul sorry. Mr. Mike Hamberger of Precon Events will serve as the host of the meeting.

I'd like to now introduce the other Board members and then briefly describe the Board itself, outline what we do, and tell you why we're holding this meeting and preview our agenda for today and tomorrow.

So, at this point, we're going to introduce the Board members, and I think we need to switch to panel view. I'd ask that as I introduce them, the Board members raise their hands, so that the audience can see who they are. I'll begin. I'm Jean Bahr, the Board Chair. All the Board members serve part-time and we all hold other positions. In my case, I'm Professor Emerita of Hydrogeology in the Department of Geoscience at the University of Wisconsin-Madison. Our first two Board members that I'll introduce today are only able to join us by audio. First is Dr. Steven Becker. Steve is a Professor of Community and Environmental Health in the College of Health Sciences at Old Dominion University in Virginia. Then we have Mr. Allen Croff. Allen is a Nuclear Engineer and an Adjunct Professor in the Department of Civil and Environmental Engineering at Vanderbilt University. And there is Steve's logo and Allen's logo as well. So, when they ask questions, that's what you'll see. Dr. Efi Foufoula-Georgiou, who is supposed to be next, Efi is going to be joining us for part of this meeting but I know she has a couple of conflicts. So, I think she is not currently online. But Efi is a distinguished Professor in the Departments of Civil and Environmental Engineering and Earth System Science, and the Henry Samueli endowed Chair in Engineering at the University of California, Irvine. Next, we have Dr. Tissa

Illangasekare. Tissa is the AMX endowed distinguished Chair of Civil and Environmental Engineering and the Director of the Center for Experimental Study of Subsurface Environmental Processes at Colorado School of Mines. And then we have Tissa. Then we have Dr. Lee Peddicord. Lee is a Professor of Nuclear Engineering at Texas A&M University. Dr. Paul Turinsky is next. Paul is professor emeritus of Nuclear Engineering at North Carolina State University. And last, but not least, is Dr. Mary Lou Zoback. Again, I'm not sure if Mary Lou is on. I see -- oh, there's Paul coming up. I'm not sure if Mary Lou is on yet, but Mary Lou is a retired geophysicist at the U.S. Geological Survey.

So, I've just introduced seven Board members plus myself, not the full complement of eleven. The Board currently has two vacant positions and Dr. Susan Brantley from Penn State University was not able to join us for this meeting. As I usually do at Board meetings, I want to make clear that the views expressed by Board members are their own, not necessarily Board positions. And our official positions can be found in our reports and letters which are available on the Board's website.

So, we're now going to switch back to the slides and say goodbye to the other board members. All right. Bye. And back to the slides. So, onto 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's 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 evaluate the technical and scientific validity of DOE activities related to the management and disposal of spent nuclear fuel and high-level radioactive waste.

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. And 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 admin -- information, which I've just shown you, can be found on the Board's website, www.nwtrb.gov. That Board -- that website also includes Board correspondence, reports, testimony, meeting materials that includes webcasts of the recent public meetings. If you'd like to know more about us, a two-page mission document that summarizes the Board mission and presents a list of Board members can be found on the Board's website.

We will 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 the meeting today on the right of the screen, you should have seen a comment for the record section where you can submit a comment. If you are viewing the presentation in full-screen mode, you can access the comment for the record section by pressing your escape key, so you need to go out of full-screen mode. Comments we receive before the end of each day's last break period will be read online by Board staff member, Bret Leslie, in the order that they are received. Time for each comment may be limited depending on the number of comments that we receive, but the entirety of the submitted comments will be included as part of the meeting record, including those that we don't have time to read. Comments and other written materials may also be submitted later by mail or email to the points of contact noted in the press release for this meeting, which is posted on our website. And these will also 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.

This meeting is being recorded and the archived recording will be available after a few days on our website. 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 meeting? Well, in the past, the Board has independently reviewed and identified technical gaps in DOE's research and development programs. For example, in 2010, the Board identified research and development gaps while reviewing DOE's program for storage and transportation including DOE's gap analysis of those programs. Previously, the Board evaluated the scientific and technical aspects of specific portions of DOE's non-site-specific, or as DOE calls it, generic disposal R&D program. For example, research and development related to disposal of dual-purpose canisters that we discussed at a public meeting this past July. And, advances in repository science from international underground research laboratory collaborations which we discussed at a public meeting in spring of 2019. However, the Board has not undertaken an evaluation of DOE's non-site-specific disposal R&D program as a whole.

In 2012, DOE formulated a roadmap outlining its generic R&D activities and their priorities for developing a sound technical basis for alternative disposal options, for increasing confidence in the robustness of non-site-specific disposal concepts, and for developing tools needed to support disposal concept implementation. DOE updated its R&D roadmap in 2019, and DOE's current approach focuses on disposal concepts in three potential host rocks, crystalline, salt, and argillite. Recently, DOE has begun investigating higher temperature disposal concepts.

Today and tomorrow, we will hear about the progress -- the overall progress DOE has made on these R&D efforts, including important crosscutting R&D issues and international collaborations.

Today's session will start with Tim Gunter, from the DOE Office of Nuclear Energy, who will provide an overview of DOE's disposal research and development program. We'll then hear a presentation on DOE's technical approach and prioritization of activities. Then we'll have a 15-minute break at 1:50 p.m. Eastern Time and reconvene at 2:05 p.m. Eastern Time. And we'll continue our meeting with a presentation on crystalline host rock. The next presentation will be on salt host rock. Then, we'll again have a 10-minute break from 3:45 to 3:55 p.m. Eastern Time. And the final presentation will be on argillite host rock. Then, as I mentioned earlier, we'll have a public comment period. We'll adjourn today's session at about 5:00 p.m. Eastern Time.

We'll resume the meeting tomorrow at 12:00 p.m. Eastern Time with additional presentations on ongoing DOE R&D activities, as well as two presentations by speakers from other countries who I will introduce tomorrow morning.

Okay. So, at this point, we're going to close down the slides. So, if we can do that, or else I'll continue with my intro. 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 virtually on November 4th and 5th. I also want to thank Board members, Allen Croff, Steve Becker, and Tissa Illangasekare, who acted as Board leads and who coordinated with the Board's staff to put this meeting together.

So, now it's my pleasure to hand over to Tim Gunter, who will get the meeting started. So, Tim, welcome.

GUNTER: Thank you, Jean. I'm assuming everyone can hear me. It's my pleasure to talk to you today. My name is Tim Gunter. I'm with the U.S. Department of Energy, in the Office of Nuclear Energy. And our sub-office is the Office of Spent Fuel and Waste Science and Technology. I'm the Program Manager that leads the research and development for disposal-related research and development. I've been with DOE coming up on 29 years or so. I started with nuclear energy back when we really started this R&D program in 2010. Before that, I was with the Office of Civilian Radioactive Waste Management, and a long time ago, before that, I was with the DOE office at Savannah River Site at the Defense Waste Processing Facility. So, let me see. All right. I just got to find the slide advance, which you guys seem to -- here we go. Okay. I'm -- I'm on slide two. The -- this is just the outline of the disposal research program, kind of the overview of what you're going to hear in my talk. And a lot of the things that I'm going to discuss, there'll be more detailed presentations that follow by the additional presenters. So, I'm going to cover the program mission and purpose, disposal concepts, scope and goals, a conceptual timeline with R&D structure and focus, and then our prioritization and planning.

So, as I mentioned, this R&D program actually started back in 2010, when the repository program that was in place at the time was suspended. A lot of the DOE folks that were working there moved over to support this program. And it was established under the Office of Nuclear Energy. The mission is stated there. Mission of the campaign is to identify alternatives and conduct scientific research and technology development to enable storage, transportation, and disposal of used nuclear fuel and waste generated by existing and future nuclear fuel cycles.

So, we refer to this as a campaign which includes our national laboratories that actually conduct the R&D activities. So, when you see the term "campaign," that's what that is referring to. It was originally called the

Used Fuel Disposition Campaign; but a few years back that was changed to the current title you see now, Spent Fuel and Waste. We -- one of the first things we did was to put together our campaign implementation plan that laid out what our goals and how we were going to accomplish those and that was updated and that has – I have the title page of that update from October 2014 shown there.

Okay. This shows our disposal concept and a little bit about our scope and goals. We want to provide a sound technical basis for multiple viable disposal options in the United States. So, we're focused on three main geologies. We're developing reference cases for those three geologies there are examples shown there, the three, which are salt, argillite, and crystalline. The examples shown are just, you know, for visual information. Gorleben from Germany for salt, which at the time this was put together, that looked like it might be where they were headed; things may have changed since then. Argillite is an example from France and then the crystalline repository from Sweden. So, the other -- our other goals going down the left side there is to increase confidence in the robustness of generic disposal concepts. So, we want to refine our models that we are putting together for the different geologies, reduce uncertainties in the modeling. As you know, the US was focused on Yucca Mountain for the last -- well, since the mid-'80s, late '80s. So, we didn't really do any research or pursue any other options since that time in other host rocks. So, the reason that we picked these three is this seems to be what the other countries in the world were pursuing. And of course, the U.S., being a large country, we got a lot of different host rocks to choose from, so we picked these three as representative cases to pursue and develop. So, the third goal is to develop a science and engineering tools needed to support disposal concept implementation. A lot of R&D we do is focused on performance assessment, models, integrated modeling, and process modeling. A lot of it on how radionuclides move through the geologic system from the time they potentially leave the waste package and are transported through the host rock and ultimately potentially out to the biosphere. And then the last bullet on the left side, we wanted to utilize international experience and develop our program capabilities, collaborating with other international programs. As I mentioned, we, for a long time, had been focused on volcanic tough and not other host rocks. So, we felt that we could leverage the advanced experience of other countries that have been working in these areas.

Some of the examples of areas we're looking at internationally would be the engineered barrier system, for example HotBENT. We're working with Nagra at the Grimsel Test Site. HotBENT is a -- an EBS experiment where they're looking at how temperature affects bentonite backfill. A couple other areas focus on near-field perturbation and flowing radionuclide transport. And you'll hear a lot more about our international collaborations coming up.

Just on the right side, the bullets there, disposal options, this is, you know, what kind of material are we actually wanting to dispose of in a geologic repository? Well, there's two main types, one is the spent nuclear fuel, both from commercial nuclear power plants, and then the DOE-managed fuels. So, that's from DOE reactors, research reactors, and reactors they used in the weapons program in the past.

And then the other category is how that one nuclear waste glass that is processing the waste from the liquid waste that was used in the production, weapons production program, borosilicate glass, such as -- was produced at Savannah River where I worked at, Defense Waste Processing Facility.

And this is -- okay, on slide 5, this is a table from the Fifth Worldwide Review that was led by Lawrence Berkeley Laboratory back in 2016. So, it's a little old but the point of the slide is to show at the time, you know, few years ago, these were the main host rocks that other countries were focused on. So, you can look down the right side and see a lot of nice granites, argillites, sedimentary, more granites and gneiss and then salt. So, the point of this slide is just to show that when we were developing our R&D program in the beginning and determining what we wanted to focus on in terms of developing base cases or reference cases, the three that we came up with are -- were consistent at the time and still are consistent with the type of geology that other international programs are pursuing.

Okay, slide six. Jean showed a version of this. So, if you think of a repository program in three phases, one is, you know, the red, green, and blue there, the concept evaluation, followed by site selection and characterization, and then finally the development. The point of this slide is to say that most of -- all our R&D supports the concept evaluation phase. So, the red phase or, you know, the first of the three phases. Very little R&D is being performed in site selection or characterization or repository development. However, some of those activities and those other phases were considered in our R&D roadmap, our initial determination of what R&D we would focus on. That's not an absolute statement because we are doing a little bit, I think Jens Birkholzer will mentioned in one of his talks about some site characterization techniques that we're participating in. This is in borehole characterization of sites. So -- but the -- the vast majority of it is done in the concept evaluation phase. Developing and technologies, modeling, and that type of thing. I did want to mention that sometimes you see the term RD&D, development and demonstration. I think most of what we do is R&D and not so much into demonstration. Potential exceptions to that, I mean, a few years ago, we were looking at deep borehole disposal as an alternative and we were actually trying to establish a deep borehole field test to demonstrate technologies on drilling techniques and larger drilling diameters. So, that would have been an example of some demonstration, but that program was suspended several years ago.

Okay. On slide seven, this is our campaign structure and focus areas. If you start at say at the top there, it's SFWST Campaign Leadership, David Sassani is the lead for that, for the national labs. He's referred to as the National Technical Director. And then there's two main areas in that campaign, storage and transportation research, and then disposal research. We're not talking about storage and transportation today, but this entire two-day meeting is focused on the disposal research that you see on the right side of the screen in blue.

So, under the first three focus areas, under disposal research are the host rock investigations. I've talked about why we picked those three argillite, crystalline, and salt and you're gonna hear a detailed presentation later today on each of those host rock and the R&D that's being conducted. Carlos Jové Colón is going to talk to you about argillite. Yifan Wang is going to talk to you about crystalline and I think Kris Kuhlman is going to do a presentation on salt disposal.

The areas below the host rock we refer to as crosscutting investigations just because they tend to go across all three geologies. The first one, the host rock -- below host rock is the geologic disposal safety assessment. And Emily Stein is going to speak to that tomorrow and give you a lot of details on that. But basically, it's -- think of it as an integrated performance assessment program. It does a lot of advanced modeling. It takes inputs from processed models that are developed under the host rock investigation. So, it picked up with the old sort of like a TSPA, Total System Performance Assessment, for those that you're familiar with the Yucca Mountain and that licensing approach.

The next topic is direct disposal of dual-purpose canisters. That's also going to be spoken to tomorrow but just briefly because we've already had a separate meeting on that topic. But just as a quick reminder, that program is to look at the feasibility of directly disposing dual-purpose canisters and dual-purpose canisters, or DPC's for -- are DPC's that were only originally designed for storage and transportation, they were not designed for permanent disposal in a geological repository. So, if they cannot be disposed directly, they would have to be repackaged, so we're looking at the feasibility of just directly disposing that, which would save a lot of time, money, and exposure to personnel.

Next topic down is the international collaborations. Jens Birkholzer is going to give you a presentation on that tomorrow and I spoke to that in an earlier slide briefly about working with international partners and the reasons for why we -- why we're doing that.

And then the next topic, Engineering Barrier Systems, looking at the integrity and performance of the EBS, which are those barriers including the waste package and surrounding it if the -- if you have backfill in your particular design. The things that impede progress to the radionuclides that could escape from the containers. And Ed Matteo and Liange Zheng are going to talk to you about that. We have presentations upcoming on the EBS and then also specifically Liange is going to talk about the HotBENT. I mentioned that a bit earlier. But it's a high temperature experiment. We're partnering with Nagra, at the Grimsel Test Site, on the effects of the temperature on bentonite backfill.

The last two topics, inventory and waste form characteristics and performance, R&D activities focused on source term, waste form, degradation, that type of thing. You will hear bits of pieces of that sprinkled in some of the other presentations but we're not going to do an actual dedicated presentation on that today in this meeting. And likewise, on the last topic, technical support for underground research laboratory activities, we are not going to discuss that today. But that's just potential support for any future underground lab R&D that we may be able to implement. We are doing some R&D underground at the WIPP -- the Waste Isolation Pilot Plant in Carlsbad, New Mexico, related to salt behavior and Kris Kuhlman will talk some about that in his salt disposal presentation.

Okay. Slide eight is about our prioritization and planning. Jean touched on these topics I'm going to touch on briefly and then you'll hear a lot more about them later on. But the prioritization activities that are documented in documents that we -- the campaign issued, first of which is the Used Fuel Disposition Campaign, Disposal R&D Roadmap back in 2012. As I mentioned, the campaign was originally called the Used Fuel Disposition Campaign. But that was kind of an informal expert elicitation. We gathered experts from most of the national labs and went through all the activities. It was done on a FEP base, features, events and processes, looking at the importance of the activities, kind of where we stood, and the impact of the overall performance assessment, and then the knowledge state. And they put together a listing and a ranking of those topics which helped us formulate our initial R&D priorities. That was followed in 2019 by a R&D Roadmap update and you'll see the campaign name changed to SF -- SWFST. So that was similar, but just updated based on, you know, additional information of where we stood. It was more activity-based as opposed to FEP base. You know, the progress and knowledge that have been gained and then what additional work needed to be done. And then finally, our last document, which was just recently completed, was the R&D Five-Year Plan. So what we tried to do there is to look ahead and take the activities that we identified as needing to be worked on and try to prioritize those and split them into near term, like one to two years, and then long-term, three to five years, and discuss what would be done, what we needed to complete that activity. And then this plan will be updated annually to make sure that we're current in our program of where we need to be headed and what we need to be focused on.

Okay. The next bullet there, congressional appropriations. This is here because it has a big impact on our prioritization and planning. Obviously, the funding levels that Congress provides us for our R&D program has the -- you know, and funding levels has the potential to vary widely from year to year and between the Senate and House levels. They have to come to some agreement on what our final appropriation is so we -- one year, we get lower funding, we have to adjust our R&D activities, maybe we can't do everything that's, you know, we think is on our -- on a high priority, but that's just an example of one impact.

And then the second sub-bullet there, the appropriation language. Sometimes in the appropriation, they will -- the Congress will specifically call out things that they want us to work on. For example, as in the past or three or four years ago, they actually put in language about the feasibility studies for dual-purpose canisters. And then DOE management and administration priorities, depending on, you know, what the management view is at the time, and the administration, they may have certain priorities they want us to work on. I think one of the biggest examples of that is, again, going back a few years under the previous administration, our Secretary, Ernie Moniz, had a high interest in deep borehole disposal. So, we spent a lot of money pursuing R&D activities on that, which obviously took money from other R&D activities.

And all those three -- the first three bullets that I discussed, all those come together in our annual baseline planning we do obviously every year. We just completed it recently for Fiscal 21. So, we take all those things into consideration and, you know, put together our plan based on the appropriation levels. Now this year, as it's becoming typical, we're operating under a continuing resolution, so we don't have our final appropriations funding level for the R&D. We expect that -- we expect that shortly, hopefully, but that could potentially require us to do a re-baseline based on what our final number is.

Okay. And that, I think, is my last slide. There's a list of references and ready for questions.

BAHR: Okay. Thank you, Tim. And I'm going to start with one sort of overview question. You -- you mentioned that you chose the three host rocks because other counties are looking at them and you're at the stage of formulating conceptual models for these kinds of repositories. At this time, are there significant differences in the disposal concepts for those three host rocks compared to what's being considered in other countries that are looking at those host rocks? And maybe we'll hear more about that in some of the subsequent presentations, but sort of in general, are you taking the concepts that they're using and running with them. Or are they being modified as a function of either the types of host rocks we have in the US or the types of waste and the waste forms that we're dealing with?

GUNTER: Okay. So, yes, you will hear some in the future presentations coming up. But let me just say that, so the host rocks that we chose, you're right, it was because a lot of it countries were pursuing those particular host rocks, but also as I mentioned because the US had those rocks available, too. We have a wide selection of geology in the US. As far as differences. We're not trying to copy any other particular design. In fact, we're putting together a reference case that really just serves as a -- as our modeling, you know, tool for modeling our models and developing our assessments, performance assessments, the GDSA. So, there's no particular drive to try to copy any specific design. So, I'd say that, you know, it's a -- it's, kind of, a competition of what the modelers put together in terms of a reference case.

BAHR: Okay. I see several hands up from Board members. I'm not sure which order they came in but I'm going to go first to Lee Peddicord, if we can bring him on live.

PEDDICORD: Thank you, Jean. And, Tim, thanks for the presentation. Good to get the overview. Question, you had talked about the review of the 2012 Roadmap and the five-year R&D plan. Is that -- is that something you, kind of bake in or build in to do periodically in terms of seeing what you were looking forward to, how you're doing against it, maybe if there's new or refined directions you should be going with it?

GUNTER: Right. So, in terms of periodically, the five-year plan, we're going to do that annually -- or annual update to that plan. Before that, we didn't have any defined period like, you know, we did the 2012 and then after a few years, we decided, well, you know, it's probably time to go back and relook at what we did and update it. So that was the updated R&D roadmap that we did. And then the last document, the five-year plan, that's the one that we're going to look at annually and, kind of, take stock of where we at, where we've come, you know, are the things we're working on, do they still need to be -- or is the priority the same, do we still need to be working on them, are they, you know, to a point that we can call them complete and move onto something else?

PEDDICORD: Is this where you sometimes get some direction from Congress in the language or appropriations of where you are in those plans or are these more documents that the DOE has and oversees and takes care of?

GUNTER: Yeah, the -- so these -- the R&D roadmap and the five-year plans don't really take into account congressional -- well, they would take into account congressional language because they'd be aware of it, but it's really more of just the priority and knowledge state of what we think should be worked on. But then that is one input into the eventual baseline planning that we put together, which takes into account the funding and the appropriation language and the DOE management priorities and that type of thing.

PEDDICORD: But you don't get Congress drilling down to that level in terms of their guidance?

GUNTER: They don't do it very often. Like I said, there was -- a few years back, they had some language in there about, you know, the dual-purpose canister work, so --

PEDDICORD: Okay. Thank you.

GUNTER: Yeah.

BAHR: Okay. Thanks, Lee. Next, to Paul Turinsky.

TURINSKY: Thanks, Jean. Tim, two questions, and it is sort of follow-up to what Lee was asking. In -- it seems that having site selection criteria is really important to understand what questions have to be answered, and in turn, that would define what your R&D priorities are. Do you have fairly well-defined site selection criteria? And do they come in then selecting your R&D program?

GUNTER: Well, we used, you know, in the first R&D roadmap, like I said, we used the features, events, and processes. So, the FEP base, you know, from the International Atomic Energy Agency, IAEA, has a list of FEP's that should be considered for, you know, the general reposit[ory]. So, I think those would be consistent with -- you know, because when they develop the FEP's, they're, you know, they have site characteristics in mind. But, like I said, we are in a generic phase so even though you can have some site characteristics in mind, then you know, it's going to ultimately depend heavily on the specific site that gets chosen. So, I think there's enough there to influence the decisions on the R&D activities.

TURINSKY: Okay. And the second question is -- calls for some subjective evaluation on your part. Of the three rocks that you're -- that you're studying, from a modeling viewpoint, which rock type would you say you have the most capability now to model and the flipside is which one would you say you have the least capability to model at this point?

GUNTER: That might be a question for our modelers coming up. But I mean I think we're trying -- what we're trying to do is, to kind of, have a level playing field so that what we can have roughly similar capabilities for any of the three host rocks. Such that if the US, at some point in the future goes back to trying to implement a repository program and decide it is going to be one of those three host rocks. So we would be prepared, you know, to just pick up and go on any of those.

TURINSKY: Okay. But don't you have some sort of feeling for -- well, I mean, kind of, influence where your -- where your funds go based on your current level of knowledge.

GUNTER: Well, I mean, you know, yeah, the -- that's taking into account to develop priorities. I mean obviously, you know, there's a lot of experience in salt. WIPP is a operating repository, but it's not for high-level waste and not for high-heat waste so there's some significant differences there. Yeah. I don't -- yeah, I just say again, I think, you know, our goal is try to keep things on a level playing field and bring up those different geologies so that they're ready to -- ready to go.

TURINSKY: Okay. I'll ask you a question again when the modeler is presenting.

GUNTER: Yeah. Okay.

TURINSKY: Okay. Thank you.

BAHR: Okay. Thanks. We -- it looks like we have a question from Tissa, but his camera and mic aren't on. Okay. Maybe not. Anyway last --

ILLANGASEKARE: You know, I'm on.

BAHR: You're on? Oh, okay. Okay. Go ahead.

ILLANGASEKARE: Yeah.

BAHR: This will be the last question because we're about at time for this --

ILLANGASEKARE: Yeah. Thank you for your talk. I have two brief questions. You mentioned that the R&D "process -- process research" and then another one is integration. So, seems like in your slide number seven, so we have this through -- the first three blocks are focusing on the three -- three types of rocks and the other blocks are focusing on the integration. So, my question is, the first one, what do you mean by integration in the cross-cut -- cutting? So, integration in the sense of, yeah, integrating these process models to focus our work, primary model or -- or variable models, what do think -- what do you mean by integration in that second cross-cutting block?

GUNTER: Second cross-cutting block.

ILLANGASEKARE: No, that --that's in your disposal research, there are a number of blocks, the three are focusing on the host rock and the rest of them, cross-cutting. So, you mentioned in your talk that you are looking at processes and my thinking is the processes should be sort of dependent on the host rock, the processes can be different. But when you do integration, I want to know a little more, but maybe later it will come out, but what do you mean by integrating models in that case?

GUNTER: Okay. So, I think I mentioned like an integrated model, like the GDSA, Geologic Disposal Safety Assessment. So, the -- well, first off, I think all these different blocks are integrated. So, the fact that we've separated host rock investigations out from cross-cutting, I mean, they're -- they all come together to support the overall program. So everything is integrated. But in terms of the GDSA, a lot of the process models are developed in the host rock investigations, but then they feed the overall performance assessment model, the GDSA. So they're integrated, but they're just developed in a -- they're just shown here as being developed under the host rock activities. Did that answer your question?

ILLANGASEKARE: Okay. Integration means you'll be integrating the model for the specific things in the blocks, yeah.

GUNTER: Yeah. Because there's, you know, there's many, many process models that have to come together. One of the things the GDSA is trying to do is be -- be able to be more responsive to changes in the process models. Some of the, you know, the TSPA work was sometimes difficult if you made a change in some of the lower level inputs. It was a bit complicated to get the end result based on those changes. So, the GDSA is trying to be more user-friendly and better integrate in terms of processing, so to speak, the process models.

ILLANGASEKARE: Just a short question. Second question. So first one is, the process models will be sort of validated through experimentation in different host rocks as seen in some of the -- so in the -- in the second cross-cutting investigation, is there an experimental component in there? Like do you have some experiments where this integration is going to be checked?

GUNTER: You're talking about the DPC block, the second one under --

ILLANGASEKARE: Oh, yes.

GUNETR: Yeah. We actually do have some experimental work going on in the DPC's. They're doing, you know, one of the concepts for making a DPC disposable is filler materials that could be put in the DPC that would preclude moderator, water, from entering and therefore preventing criticality.

There's some experimental work going on at Oak Ridge with some surrogate materials like glycerin and oil and things on how well they can actually fill. They have a small-scale canister. The thought is filling through the vent ports and venting through the other vent port. And so, they model the filling of the canister and then they also have an actual mockup demonstration where they fill it and can see how it actually spreads out and fills the void spaces and compare that to their modeling results.

BAHR: Okay. Okay. Well, thank you, Tim. Thanks to the questionnaires. I think we need to move on to our second technical presentation. This will be David Sassani from Sandia National Labs and he's going to be talk -- talking about the technical approach and prioritization of activities. If we can get David and his slides on. Hi, David and I'm --

SASSANI: Thank you, Jean.

BAHR: -- going to go away.

SASSANI: I appreciate the intro. Ah. There are the slides. And I'm not actually seeing the toolbar at the top, so I can't see how to get my pointer. There it is. Thank you very much. That's probably Mike that did that. I appreciate that. And so, I'm David Sassani. I'm at Sandia National Laboratories. I'm the National Technical Director, as Tim mentioned, of the Spent Fuel and Waste Science and Technology, the SFWST Campaign. And my background from a technical area, my background is a geologist-geochemist by training. I began working in radioactive waste disposal on the Yucca Mountain project in 1993 in the performance assessment group primarily looking at models, geochemical models for water chemistry, interaction with engineered materials, waste packages, spent fuel, and other waste forms and incorporating, and developing those models and incorporating them into the performance assessment integrated site models, the TSPA, the Total System Performance Assessment, from that program. And I worked on that program all the way through until and helped submit the license application that DOE submitted in 2008, putting together technical bases and building the performance assessment work.

I've also worked a little bit on the Waste Isolation Pilot Plant, the program there doing some source term aspects and in other DOE campaigns on geochemistry, and boreholes, and geothermal systems, and high-tech computer modeling in the DOE-NE advanced modeling systems, the NEAMS program.

But today, I'm going to talk you about the technical approach and prioritization of activities on our campaign. And with that, I'm going to go to the next slide here.

And it's just an overview outline of my presentation. I'll give a little bit of an introduction on the disposal research plan and prioritization. And I'll get to some context of what we do and some of the listing of the completed disposal research program activities. Tim has covered this, but I'll say a few other things. And then my presentation will focus on the 2012 Roadmap, the priorities and the assessment of that that we did covering the background, the bases that were used, the R&D issues outlined, and how that occurred, and the prioritization approach. And then what we accomplished in -- in that part of the program utilizing that prioritization, and the evolution of an -- our -- our R&D focus from there. Then I'll move into our 2019 roadmap update covering, again, the evaluation bases, which were a little different because this 2012 Roadmap was the initiation of the campaign. At this point, we have a mature program and so it builds upon the previous work. And I'll cover the major findings there and talk to gaps and defined focus areas that come out of that, and I'll provide a summary and look ahead at the end.

So, here's a figure. It's a bit busier than what Tim showed and what Jean showed initially. But, again, this is just giving you the whole entire approach to a disposal program, which some of the questions we've had really focus on development of siting criteria, which happens here. The current US program is in this red zone, which is the concept evaluation. And you can see the evolution of the whole system, goes from generally generic RD&D to more site-specific work, which gets more detailed and more linked to very specific aspects of a particular site and a particular design until a license application occurs and then construction can occur. This RD&D term is research, development, and demonstration. And demonstration's initially focused on analytical capabilities where we are, so this would be demonstration of our safety assessment capabilities, demonstration of taking process level models, and integrating those all the way up through in a coherent fashion into that safety assessment aspect, and then things like characterizations and operational demonstrations increase later in a program, such as this. But our current focus is in this area. And what do we have as challenges? Well, the challenges in this type of a generic program is that we're looking at a wide range of geologic disposal concepts, not just a single one. So, this is very early stage. So, we have a very broad set of information to look at. And we're trying to constrain the generic R&D most important for each of those areas. And we have to define what is complete enough for a generic R&D program, which can be a little fuzzy at times. So, there's --there's uncertainties that relate -- relate to this. And we utilize the vast international experience that occurred to kick off the campaign. We relied on all the work that was done around the world and getting up to speed with that and using what was useful and modifying it and taking it forward in our program. And we need and to integrate the cross-cutting aspects clearly, throughout this program.

So, the planning/prioritization disposal research activities that have already occurred, you've heard about each of these, the Used Fuel Disposition Campaign 2012 Roadmap. This is when the campaign was initialized. It started in FY-2010. It was conceived earlier than that in the previous summer. It was, this used the basis of the features, events, and processes, doing a gap assessment synthesis of that. And it rolled the prioritizations into high priority topics to direct the UFD Campaign work planning. And that resulted in 2012, the roadmap report, Rev. 01. And this was about a two-year process.

Then in 2019, we published the roadmap update. This was also Rev. 01 of the report in 2019. And it reviewed and prioritized the disposal research activities for their progress, the remaining gaps, and any recent program direction. And this assessment began in fiscal year 2017. So, again, it's about a two-year process to reach that final result. So, these large-scale prioritization activities take a little bit of time and effort.

They are not the same as what we are doing with the Disposal Research Five-Year Plan published in 2020, which incorporates and addresses the updated priorities from the 2019 roadmap update. And we identify short-term primary objectives, one to two years, as Tim pointed out, which is a relatively certain timeframe for the program and that's certainly relative. It all depends on what the appropriations and budgeting process holds every year. And it -- we also provided longer term vision, which was a three to five years activities which is more of a general guide. And this is planned to be updated on an annual basis. So, that activity, which is a shorter-term prioritization, is a little easier to do based on annual prospects.

So, I'm now gonna go into the 2012 Roadmap, the priorities and assessment that we did on that, that we started in 2017.

So, in terms of starting a program, first was defining the key objective -- objectives of assessing the safety of a geologic disposal system. Primarily, what you want to do is demonstrate a sound understanding of the repository system. These are high level overviews and that's all the processes from the surface to the engineered barrier system, EBS for short, and to the geologic barriers that provide that safety and including the biosphere. You want to show how this understanding is the basis for the evaluation of the long-term performance and safety of those systems. We want to provide multiple lines of evidence and we want to quantify and substantiate these aspects with requisite confidence so you can do other things that provide confidence even though they are not directly assessing the safety, things like validation of models or using natural analogues. So, this whole aspect provides the framework to help plan and prioritize the technical work. And as the repository moves through the various phases of repository development you update that as you go. This also provides a valuable vehicle to communicate the understanding of safety to a very broad audience of stakeholders. So that's the high level of objectives.

Now, I'm coming back to another version of this diagram with the program evolution, specifically for the 2012 Roadmap because what the 2012 Roadmap did was not just think about what do we need to do from a generic standpoint but it also looked at the major decision points as defined by screening of sites, which is decision point 1, right in here. The selection of sites, which is decision point 2 in here. Characterization of a site decision point 3, which happens here. And then suitability of a site which would be occurring here in conjunction with repository design efforts prior to a licensed application being submitted and reviewed. So again, the licensed application is looking for a construction license which currently Finland has, and has been constructing their repository.

So given all of that with those decision points, this is just a little background. Again, it was -- the whole program was conceived of in June 2009. It was new. The FY10 activities for the program focused on evaluating knowledge on other disposal concepts. What's been done out there in the international community? What is state of the art? Where are the key technical gaps that we want to get after? And then they held a workshop in June of 2010 to look at R&D opportunities but did no prioritization. And they issued this status report in September of 2010 with those opportunities.

In FY11, the activities were expanded to establish the process for prioritizing the R&D issues. The second workshop was held in December 2010 and this developed the information prioritization matrix that they review -- was sent out for review and this was completed in March of 2011 and revised into the 2012 Roadmap Rev01 September of 2012.

So that, 2012 Roadmap used a very systematic approach to the R&D prioritization. It was based on the objectives of fulfilling the safety functions for a repository system containment, limited release by both the natural and engineered barrier systems, and dilution as a secondary function.

It utilized features, events, and processes structure to identify those R&D issues. So, this is a very, very detailed listing of all the features of a system, the various processes that play or at play and potential events that occur, things like seismic events, igneous events, human intrusion. It identified the R&D issues. These were based primarily on the features of the system and those were mapped to the objectives and the processes also were used to identify additional issues. The features, events, and processes list was -- that was used was from the campaign Fiscal Year 2010 list.

So, this systematic priority -- prioritization asks some questions like can an actual R&D issue, one particular process or feature, can it be addressed through generic R&D? And in some cases, the answer is no. It's too site specific or design specific, so it's really not going to get focused on in the program. Could it be partially, some aspects of the issue is amenable, some of the engineered barrier. We can look at mechanical aspects, chemical changes, processes that are driven by movement to equilibrium or drives by thermal coupled processes and then in other cases, the answer was yes.

So then assessing all of those R&D issues for their importance to safety was done at a rough level of high, medium, and low, and what does this mean? Well, it was looking at how important were things to the safety assessment. And these can be media and design specific, so that has to be taken into account. It also looked at aspects of safety that related to the design, construction, and operation of a system with respect to the things like engineered materials, how well-known are they, can you include them in a facility design readily? Also, construction fabrication and operational technique -- techniques and processes, are they well-known and have they been demonstrated? It also looked at this aspect of broad confidence in safety, which may not be directly related to these above items but may build confidence in the overall safety bases for any particular generic system. So, this was done for each of those four decision points one through four that I talked to as well as assessing the state-of-the-art of the knowledge level for each issue.

So, this was rolled into the overall priority of any issue as the function of, it's importance to safety and the importance of the issue to safety at each decision point. And the adequacy and state of art of the current information, which evolves with time of course, so you want to do a review every so often as we did starting in 2017. And those issues that are important for nearer-term decision points so that decision point 1 which is site, which has to do with siting criteria, those are higher priority than decision points that are farther out in the program. Issues that are well-understood, of course, tend to be a low priority because they're well-understood and we can just adopt that information. And for all the issues evaluated for the different disposal media, the media specific priorities were considered. So, this is a fairly high level overview of the prioritization but it was done in a very systematic way.

So, what do the results look like? Well, these are from the 2012 Roadmap Appendix B results, and the plot I'm showing is a priority score as a function of the number of the features, events, and processes that map directly to each R&D issue. You can -- you probably can't read this but it's in the 350 region. And it was broken into low -- low priority -- low to medium priority, and then this break here from medium to high priority aspects. But these relative priorities of the R&D issues were not simply implemented as a ranked R&D priority list of what to go do as work. Instead, the issues were synthesized to define a ranking low, medium, and high for these higher-level topical areas, R&D topics to plan the work on the program.

And I'm showing those here. So, I've listed the R&D topics and a little bit about what they're about. And then their priority is shown in parentheses and the color is -- are -- was my initial assessment in FY17 of how did the program do in meeting that priority. Design concept development was a high priority. And in fact, we had a range of generic disposal system design concepts defined, so we did pretty reasonably there for the conceptual aspect. Also, the disposal system modeling which was GDSM then and now is the Geologic Disposal Safety Assessment, GDSA, that was a high priority and we worked on that very well. So, we did pretty well there. Operations related research and technology development was given a low priority and, in fact, we didn't do much there, so we reasonably met that as well.

This next slide shows a few that are yellow, things like knowledge management, which was a medium priority but in fact we fell relatively short in our activities related to that. That's not the case anymore. But -- so there's site screening and selection tools which was a medium priority and we did some aspects for this, but of course it's longer term and farther off. Experimental and analytical techniques for site characterization, the program seem to fall a little short on because it was also medium priority. And so, we got a little bit of focus on that now and you'll hear a little from Jens on that tomorrow. And underground research laboratories which we've been using very well from the international work that goes on in all of these and we're moving into a different phase now with some of our own work.

So, here's a summary, in terms of the use fuel disposition campaign and SFWST campaign activities from FY12 through FY17, we reasonably covered many of the roadmap priorities. However, there were some disposal research R&D issues and gaps identified when we did this reassessment.

In particular things like waste package degradation, the engineered barrier system abbreviated here as EBS, chemical environment, and the coupled thermal-hydrologic-chemical processes therein. That was a gap. And those gaps were kind of understandable because those issues are both very dependent on either the EBS design details and/or site-specific conditions. They also involve the dimensionally most complex aspects of the system involving a lot of chemical aspects, a lot of chemical variables but the responses were already being built into some of the safety assessment work.

The safety assessment itself is a driver for the Roadmap reevaluation in the update because it is an integrating overarching set of activities. So, when we did this reevaluation of the disposal research activities, and their priorities, we consider the program direction, the R&D progress to date and the knowledge levels reassessment that we did. And a lot of this was top-down driven by the safety assessment. For example, waste package degradation, we had some stochastic representations but we wanted to get more deterministic and process level. And also the bottom-up approaches were used because we involved all of the PIs within the program for doing the 2019 Roadmap update.

So here again is the system for doing a disposal program laid out in our red, green, and blue colors. And the 2012 UFD Roadmap was done right here at the beginning. And then the 2019 Roadmap update occurred approximately here but as you can see we're still in the concept evaluation, still doing generic R&D. Primarily, R&D with some demonstration activities that Tim mentioned. But this is the context for doing this reassessment.

So, what's different? Well, the granularity of the disposal research quanta or items in the 2019 Roadmap update was different because it was a mature program, the Roadmap -- the 2019 Roadmap update was done based on the existing R&D activities as the starting point for prioritization. Again, it was a mature program of R&D activities. The activities generally address multiple FEPs each, multiple features, events, and processes each. And we used the features, events, and processes listing as -- by mapping the activities as a completeness check to make sure we weren't missing things. The target level is between the fine level of the features, events, and processes and then broad -- and the broader level of the entire disposal research work scope which goes to higher levels than that.

Prior to the workshop, all the principle investigators were utilized to define a strawman for the set of R&D activities. Let's refine those items to be evaluated and prioritized. The features, events, and processes that map to each the relevance and their connection to the safety assessment and in the potential implementation path to the safety assessment, and an assessment of the initial importance to safety. This was preparatory to conducting the workshop to develop a consensus on the importance to safety aspects and the prioritization in the workshop.

So, the workshop update Roadmap -- 2019 Roadmap update workshop and the report are laid out here. The workshop was in 2019 January held in Las Vegas. And for each of the R&D activities we identified, we meant -- we met to decide upon a state-of-the-art level rating and its justification knowing that knowledge -- the knowledge basis was now improved since earlier, since 2012. And also, to add any gap activities to this list of activities we were already working on as appropriate and then to decide upon the importance to safety rating and justification for each of those activities.

So, this evaluation was performed in breakout groups that were organized by each host rock where everybody participated and then a second set where it was based on the cross-cutting activity groups which had members from each host rock area in it. And then we met as an entire group to discuss the ongoing, unresolved integration issues.

And that resulted in this 2019 Roadmap update published as Rev01 in 2019 that gave the assessment of the existing R&D activities identified the gap activities and it gave the prioritization of all of those across the board.

So now I'm going to talk to a little bit of how that was done, this slide just shows the extensive list of individuals that were involved in running the meeting. The meeting was organized and run primarily out of the safety assessment group but then as you can see, there were technical lead, session chairs, and rapporteurs from each of the host rock types and cross-cutting areas that had been defined as Tim covered. And in addition, many of the campaign and integrated waste management campaign experts, the other DOE NE-82 campaign, and national laboratory staff and DOE staff took place and participated in this Roadmap Update workshop. It was a large group of individuals.

So, this is giving just a real quick look at the delta between how the 2012 Roadmap looked at things with all the decision points outward because it was a new program just starting. While the 2019 Roadmap Update builds on all that because it has a mature set of activities that were prioritized this way. But it also emphasized the current mature program to create a simpler priority function. So, it still contains all of this but the focus was more on, okay, what we -- what we're doing now and how does it relate at the most proximal aspect.

So here are the prioritization metrics that were used in the 2019 Roadmap Update, both the State-of-the-Art Level and the Importance to Safety. The State-of-the-Art Level was defined as five levels shown here in the table which goes from -- there are fundamental gaps in our knowledge and fundamental data needs or both all the way to very well-understood which would be relatively low priority. Importance to safety had three defining rankings, high, medium, and low. And this was really just its general priority to our understanding of its importance to the overall safety of the system. So the breakout groups were each given strawman initial set of values and the rationales that was an initial cut only to facilitate the discussion in the breakout groups, which were free to change all of those and come to a consensus on the values and the rationales in those sessions.

So once that consensus was done, which also involved the entire discussion at the end with the entire group to certify and agree on all of that, these two ratings were used to convolve together to give the final R&D priority score for each of the R&D activities in the program including the identified gap activities. And then the combinations of these either put -- put things into a low priority, it might be highly important to the safety of the system, but we know it really well. So these are all low priority. Also, if it's a low importance to the safety of the system, it doesn't really matter our understanding of it. It generally is low. Then there's medium levels, there's a medium to high level and a high level. And these really are the focus of the prioritization going forward. So, I'll show you a little bit about what this looks like.

And this is just one example from the report. And what you'll see here is the importance to safety showing -- this whole box here gives the importance to safety, which is high, it gives the rationale for that high rating. And then it gives the state-of-the-art level and knowledge, and this one got a four which means we don't know -- we -- it's fairly unknown. We need an improved representation, but we have some basis and knowledge already. And this example is the thermal-hydro-chemical coupled processes in the engineered barrier system. So, this was not a gap activity. The gaps are identified by asterisks on the ID. But these two scores combine to give it a medium-high score which puts it into the very highly prioritized groups and I'm going to show you some of those now.

These are the summary slides for all R&D activity scores and on the left-hand side, the histogram shows the number of the activities, their priority levels and they are color coded based on the host rocks; argillite being blue, crystalline being this middle burnt umber color, and then salt being the darker maroon color on this. And the main point of this is if you look at the cumulative number here for going from zero to one of all these activities, all three of the host rock groups ended up being fairly close together, so it looks like we gave them a pretty good calibration at the beginning of how to do the assessment of these. And then what's being shown on the right-hand side is a couple of graphs, the histogram, and the cumulative plot showing the current activities without any of the identified gap activities in them. So, these bars are all lowered down and what you'll see is the gap activities tend to be more of the medium-high and the high priority areas because they're gaps in our program. And you'll see a little bit more spread here where the crystalline is shifted to a little bit lower priority values without the gaps included.

So, this is a listing, this table here, of all of the high priority identified R&D activities out of the 2019 Roadmap Update. And you'll see the whole bunch of letter and number designators. The letters act -- for the activities designate that -- where they have -- where they were originally slotted either from the argillite host rock, crystalline host rock, salt host rock, or from some of the cross-cutting activities and you'll see performance assessment which is listed here and other performance assessment. There's one here in this table which was the waste package degradation model framework to move from just a purely stochastic representation to a more rigorous process-based representation. And there's -- there are things like the gap activities which is shown with the asterisks for example the in-package chemistry work, which was identified as a gap. Here is E-14, so that was an activity gap that was slotted in the engineered barrier system area initially. But they got evaluated by everybody across the board.

This table then shows the high-impact topic groups that were defined based on both the high priority R&D activities and the medium-high priority R&D activities. So, this is the summary similar to the 2012 Roadmap of taking all the individual activities and slotting them into high-impact topics like high temperature impacts, which of course became much more important in the last few years with the work on dual-purpose canister direct disposal. So again, here's the legend and the stars identify the gap activities. Some of which were high, some of which were medium-high as shown here.

So, what are the insights that we get from this 2019 roadmap Update? Well, much of the generic research and development was accomplished since the 2012 Roadmap gave us a lot of matured generic concepts in the U.S. program. So, the U.S. program effectively was brought up to speed with the rest of the international community after focusing primarily on unsaturated tuff up through 2009, 2010 timeframe. And the international collaborations was a big part of this and we went from simply starting out harvesting information from the international work to actively collaborating with the international programs, mostly in the underground research laboratory areas where they are doing very site-specific work in some cases which informs our program very well for those types of host rocks. The state-of-the-art knowledge level had improved for many of the R&D issues over this time period as well in 2017 because we had done a lot of work, we collected a lot of work, and we put that work from process level implementations up through some safety assessment implementations together in the program.

The 2019 Roadmap Update indicates the continuing the generic R&D focus is appropriate and it looks at, again, these high-impact topic groups which span multiple activities and each activity may span multiple features, events, and processes. And there's several other activities that were defined individually that maybe -- activity -- activities that we may pursue as a high-priority specifics.

There were program directed new priorities throughout this time period for example, the expanded work on dual purpose canister studies for direct disposal of those -- Tim mentioned the deep bore hole work that went on for a number of years, but then was ended in Fiscal Year 2017, I believe. And the safety assessment, the Geologic Disposal Safety Assessment models provide an enormous amount of information that's relevant to the importance to safety of these R&D activities themselves. So these are what we took out of this.

And moving forward, the planning and prioritization for generic disposal concepts RD&D includes evaluating these multiples -- evaluating the safety of these multiple generic geologic systems, these different repository concepts, the geologies and their engineered barrier systems. Continuing international collaboration, we get a lot of site-specific foreign programs and work in underground laboratories that give us specific insights to those particular sights that we then figure out how does that relate to the generic understanding? And also, program direction changes which can occur either through a direction from our DOE management, or from congressional appropriations as we've discussed already, and Tim went into detail about.

In terms of the 2012 Roadmap priorities and assessment, the R&D through 2017 reasonably covered it, although there were some gaps that we identified in that assessment. And it was primarily model based, with targeted experiments and testing and we're working to expand this aspect. It integrated the international data well, the models, and did a lot of collaboration internationally.

And then in the 2019 Roadmap Update, we prioritize our whole set of activities and identified other gap activities. We synthesized high-impact topic groups in order to give us direction going forward for prioritization of work and identified several other high-priority R&D activities beyond that. And it needed generic R&D as identified by consensus of the program experts all the way from top-down to bottoms-up. And that was covered in the three-day update workshop in January 2019.

The program R&D progress synthesis and updated prioritization was used for the disposal research annual five-year plan. That is the final presentation in the program. It's combined with Jens Birkholzer talking about the international collaborations and the prioritization that comes out of that and used for that. And so, I'll be speaking to that at the end of the day tomorrow.

So, what I want to leave you with is a diagram that's maybe a little controversial but I'll try to explain it clearly. This is a visual depiction of our disposal research host rock and cross-cutting technical areas. The host rocks are shown by these pie wedges which have patterns in them for the different rock types, argillite shale shown here, crystalline host rock shown here, and salt host rock shown here with these different patterns. The cross-cutting activities and investigations are shown as colored concentric circles here and some of the shading of those colors indicates where the work is currently focused. So, international shown in the blue here overlaying on all the host rocks, cross-cutting them all and it's at the center and I like it there because it really is a central basis for understanding of the site-specific work being done in other programs and other countries for very -- some very site-specific work particularly Finland, Sweden, France, and et cetera. And then there's no real meaning for the EBS being outside of that. It's just another cross-cutting activity shown in green. Dual purpose canisters are shown in orange and our work is focused primarily in the argillite shale area, but also we've been doing conceptualizations as well in the other rock types. This with no label is just where the host rock is for each of these, so but there's another cross-cutting activity which is the safety assessment. And this is shown at the boundary because in fact, the safety assessment work itself and the approach to the safety of these geologic systems is an overarching integrating top-down look at what matters in all of these areas. And some aspects of the safety assessment, the approach in the process and the framework and the technology for that is common throughout, even though it -- the implementation is different host rock to host rock and the engineered barrier system to engineered barrier system which also vary depending on the host rocks. So, these are all shown here.

The unsaturated zone activities you'll hear about, they're a little less mature. Emily Stein will speak to those and along with some Geologic Disposal Safety Assessment approaches tomorrow. Today you'll see the rest of the day are host rock investigations and the details of those technical work areas and what's being executed, some examples there, and how they integrate the concepts, the overall safety evaluation concepts for each of these generic systems. And they'll also speak to some of the international work that relates directly to each of those.

So, I believe that brings me to the disclaimer which relates to the standard contract and any discussion of direct disposal of dual-purpose canisters.

And backup and reference materials and I believe that is the end of my talk. And so, I'll be happy to answer any questions. Thank you very much for your attention.

BAHR: Okay. Thank you, David. And we have about 10 minutes for questions, so let me see if there are any hands up. I see Paul Turinsky.

TURINSKY: Yes. Dave, thanks for the -- for the overview on this. If I went to a specific item, would that point me to another document that has the details of the research approach that would be used, the budget, the timeline, the sort of things you would find in a research proposal to lay out, you know. What's this gonna cost me, how much time is it going to take, what are my dependencies on other things being -- being done? Would I have that very high priority item and would I have that for the medium priority items?

SASSANI: So, if you go to the 2019 Roadmap Update document, you'll see a lot of discussion of those activities. You won't see so much the budgeting aspects or -- or how exactly we're going to execute those things. The disposal research five-year plan provides -- it's still a pretty high-level indication of what our short-term priorities are and the longer term vision of where we want to get to within five years. But the place that you'll see the detailed planning in terms of budget is actually in the PICS NE system which is DOE'S system for managing the campaign, and the program, and actually other campaigns and programs as well. And that is where you'll see the description of the scope and the objectives, and the budget, and the timeline, and of course all the deliverables for each. You'll -- if the 2019 Roadmap Update has lots of reference materials in it that were cited. But there's -- I don't know that you're gonna see a research proposal on each of these topics. I mean, the 2019 Roadmap Update and prioritization, which is fairly large and has lots of appendices with the details of the activities and what was done, and how it was done in each of the breakout sessions and then in the summary discussion, that may be the closest you get. And this is -- you know, and these -- these activities for doing that scale of prioritization and planning is -- it seems to be about a two-year activity from the start to the finish at this point.

TURINSKY: Okay. But this pixy system, whatever it is, those are ongoing activities?

SASSANI: Yes.

TURINSKY: Okay. But…

SASSANI: Those are all the activities being executed within the campaign. Yes.

TURINSKY: I guess my question was even broader. What about the ones that aren't being executed that's still a high priority? Do we know what they're going to cost? How much time they're going to take, et cetera?

SASSANI: Well, for the -- for the things that aren't in the highest priorities and those high-priority R&D topics, below that level it -- we would only get into detailed planning for those if for some reason we had, the direction and the appropriations to spend way more money. I mean, we do an integrated priority listing for the Department of Energy that is a little bit open-ended, but it's at a relatively high level just in case the funding conditions change. But the funding related to each of these programs and each of those technical areas that Tim showed on the flowchart and I just showed within that pie diagram, the funding levels reflect the prioritization of those activities.

TURINSKY: Okay. And are all the priority items under active investigation or what percentage of them?

SASSANI: Yeah. And, you know, I would be speaking out of turn if I said yes absolutely they are. I think each of the high-level R&D topic areas are being pursued and funded but I would have to go sit down and go activity by activity to check them off. I have not actually done that, so I don't -- I don't want to tell you something that may not be correct. But I can check on it for you.

TURINSKY: okay. thank you.

BAHR: Okay. So next we have Tissa. and I see his camera there says mic so we should be good.

ILLANGASEKARE: So, I saw the word biosphere. So, what is the definition of biosphere in the context of these activities?

SASSANI: So, the biosphere area which tends to be somewhat site-specific has not been an enormous focus for us. It is being engaged in our capabilities this year for building biosphere capabilities into the safety assessment, so that is going on. But the biosphere is the accessible environment where radionuclides transition from simply being in an aquifer to then being in a system where they can be ingested by animals and humans. So that's kind of the handoff and -- and we -- that has not -- that was not a priority in the 2012 Roadmap. They tend to be a little bit more site-specific and so -- but we are building capabilities into the safety assessment now which are more of a generic nature that would allow us to start assessing that aspect.

ILLANGASEKARE: So, you -- but you are also focused with process? So, you don't have any activity looking at processes in the biosphere? Are you looking at these processes eventually that, you know, come into -- you know, the bio processes integrated into the systems. Then you need to understand those processes, too?

SASSANI: Sure. Absolutely. Those tend to be activities which come to higher importance later in the repository program when you actually have some sites that you're looking at and can define site-specific biosphere systems. I mean, we'll build in generic capabilities at this point which will allow ingestion, inhalation dose, dose from water consumption, things like that that can then be made more specific in a -- the future portion of the program.

ILLANGASEKARE: Thank you.

BAHR: Okay. I see Steve Becker with a question.

BECKER: Thank you for a very informative presentation. So, I have a kind of hypothetical for you. So, the overarching graphic that you showed toward the end of your presentation provided a great deal of useful summary information about DOE'S approach and priorities. I know that that particular graphic has not always been used but if it had been used as a kind of summary of where things stand and what DOE's approach looks like, how would you say that it would have changed over, say, the past 10 years based on the work DOE has done and what DOE has learned?

SASSANI: Sure. If we can -- if we can go to that slide, I'll -- I'll speak to that a little bit. It's -- that -- that particular graphic was developed for this meeting. It -- I tend to like it, some folks don't like it. But it -- it all depends on, you know, what you -- what you like.

I mean, you know, we've -- as Tim showed in just the flowcharts actually, when you've had all these. And, you know, these two areas are just grayed out down here because we're not really having presentations on them in this meeting. But, you know, as I said, the international work has always been a priority for this program, as has been the safety assessment. Then, the three -- these three host rocks for generic repositories were defined right upfront in the 2012 Roadmap. These have not changed because they are some of the most dominant systems being explored across the international programs. But also, they provide a range of repository conceptual types which rely differently for safety on the engineered versus the natural system barriers. Salt, for instance, relies predominantly on the natural system barriers, the salt being highly impermeable and has much less reliance on the engineered barriers.

Where if going clockwise around here, argillite is sort of the goldilocks place because depending on what the argillite is, it can be more malleable versus more fracture prone it -- it's can be more like the salt system or more like the crystalline system but it relies on a balance of the engineered barriers and a more even balance and a natural barriers. Whereas the crystalline system has a very high reliance on the engineered barrier system because it has a highly transmissive fracture pathways in a natural system. And even though those are unlikely to intersect the package, that is the primary transport pathway and it's fast.

So, these three host rocks are still the primary aspects because they give us a broad look at the different dependencies on safety between the natural system and the engineered barrier systems and that includes the waste form. So, I haven't shown the waste form on here anywhere but I will actually speak to that a little bit in the five-year plan, and give you guys an update from what we did in planning. But of course, the waste forms considered throughout here, spent nuclear fuel, and glass being the prime glass high-level waste being the two primary ones. The DPC aspects primarily were not in here 10 years ago. The dual-purpose canisters, they existed but as time goes on there's more of them, which is understandable from a safety standpoint for storage and for transportation. And so, a number of years back, we started looking at the dual-purpose canisters, and is there a potential for doing direct disposal of them. That's one of the biggest differences in this diagram. And there's a lot of thermal aspects related to that because they tend to be loaded with a lot of spent fuel and they tend to be a bit hotter. So that impacts also our studies in the engineered barrier system because in the international community, many of the engineered barrier systems will not be going above a hundred degrees or so, a hundred degrees centigrade or so. But these dual-purpose canisters would certainly push that in a local sense, depending on the spacing of waste packages and drifts in the repository system, but could also drive it in a broader sense, depending again on the waste package spacing and drift spacing in your repository concept. So -- so the dual-purpose canisters, is one of the biggest differences in the last 10 years. And these are just showing again our areas of the program that we focus on and, you know, the underground research laboratory, which is not shown on here, that work here is becoming more prominent in time now, within our program as opposed to just utilizing the international programs underground research laboratories. So those are -- those are some of the big -- the big deltas.

BECKER: Thank you. That was a very helpful, very informative answer, appreciate it.

SASSANI: You're very welcome.

BAHR: Okay. Thank you. I see there's a question from Lee but we're at time for a break. So, I think I'm going to -- just to keep us on time, cut this off. And perhaps Lee can chat separately, and we'll have time for some other questions later on. So, we're scheduled now to break until 2:05 p.m. Eastern Time which is -- would be 11:05 on the west coast, so we'll see you back in about 15 minutes.

SASSANI: Okay. Thank you.

BAHR: Thank you, David.

(Whereupon, a break was taken.)

BAHR: Okay. I think we are live. Welcome back for the next set of presentations in our meeting. And the next three presentations are going to focus on the three different types of host rocks and the reference disposal concepts that DOE is considering. And the first presentation is by Yifeng Wang from Sandia National Laboratories. He's going to be focusing on crystalline host rocks. So, I think I saw his pointer, which meant he was there. If we can bring him live, we can get started. All right. There we go. There he is. Welcome. And I will go away.

WANG: Okay. So, let me make sure I can advance the slides. Okay. So that's really good. Okay. And my name is Yifeng Wang. I'm from Sandia. And I'm a Nuclear Chemist. I -- actually, nuclear waste disposal is -- has been a bigger part of my whole career in Sandia. I started a long time ago. Twenty-five years ago on WIPP project at – as a Principal Investigator of near-field chemistry. And then -- and after waste isolation license application for WIPP -- so I can move on to Yucca Mountain project. And then after Yucca Mountain was suspended, then I started working on DOE Used Fuel Disposition Program. Now it's called Spent Fuel, Waste Science and Technology Program, SFWST. So, what I'm going to talk about is one of those three host media you already seen in the previous presentations. I'm going to talk on crystalline rock.

So, this is an outline of my presentation. I will -- just a briefly touch on the key characteristics of the host rock and then talk about disposal concept. And then I will show you some of the key technical gaps we identified, we are currently working on. And then talking about what we have accomplished for -- to bridge these technical gaps, especially in about the process model development and integration. And then I think one slide talking about what's the immediate step that we plan for this FY.

So, as opposed to other media like salt or argillite. We call it crystalline rocks. It's kind of a harder rock. So here we -- by crystalline rock, we refer to both igneous intrusion and also the metamorphic rocks. So those rocks that's what we know have high mechanical strength, and they are -- and they all originally form under very high temperature. So, there's no problem with thermal limit on those rocks. So that means crystalline rocks could be a good media for disposal of larger and hotter waste packages like in DPCs. And also, another key characteristic of those crystalline rocks, as Dave mentioned earlier, they are usually fractured to various degree.

And if you visited some underground facility, here it show -- I mean, this is from a Finnish disposal site in Onkalo. If you are in the tunnel, you can see many fractures and microfractures and some of the larger fractures. And also see in some of -- the same fracture in some -- in groundwater -- seepage -- in seepages.

So, in the chemistry part, the water chemistry in most of this crystalline rock side varies vertically. And also as -- and we expect in some of those, in climate changes. If you have glaciation, deglaciation, and then those water chemistry will also vary with time.

So, this is the diagram – pH/Eh diagram that show the general chemistry condition at the depths of like -- in 500 to 600 meters below the -- you know, beneath the surface in this rock. Basically, at that depth, the water chemistry is -- usually is reducing. and -- but yet -- it's in around like -200 millivolt which is corresponding to sulfate and iron reduction zones and then the pH is about neutral. So those chemical conditions put general constraints on a lot of things on the inside in a repository, like radionuclide mobility and waste packages integrity.

And so for the disposal concept for crystalline repository, it heavily relies what we call the multiple barrier -- engineered multiple barrier concept. So, in crystalline repository those engineered barrier system and natural system almost play an equal role. And so inside in engineering barrier area you have like waste form that I -- we're saying the reducing environment, the waste can be degrade -- can be dissolved or degraded very slowly. And also, that reducing environment will also help to maintain the integrity of waste packages for a long time. And in the other side of engineered barrier system, and now you have a natural barrier system. In general, the crystalline rocks are, at least in their matrix, they're very impermeable and very -- and move can -- the water can move through those -- in fractures. But -- and it depends in which site you select. I think -- in properly selected site -- those fracture are kind of very sparse or not very well connected. So again, in general, they are very impermeable. So for my -- for crystalline waste packages, overall goal is to advance understanding of long-term disposal of used fuel in those -- in crystalline rocks, and then develop those experimental and modern capabilities to evaluate various disposal concepts in those media.

So in the -- in the -- in a reference case, we consider both, spent fuel and also -- and in glass high level in waste. For glass high level waste, we consider like five logs waste package which will be disposed of in-drift, and then it's filled in with bentonite. And then for spent fuel, we consider two different size of the waste packages. The smaller one is very similar to KBS-3 in concept developed in Sweden. So, in this configuration, there's -- one feature is the waste packages is coated with a layer -- in about a five-centimeter-thick metallic copper. So that metallic copper plays a very important role in waste staying in isolation.

But our -- in our disposal concept, we also consider a larger waste packages which -- consists of -- containing 12-PWR, and we consider in-drift axial emplacement. And, again, the waste package will be in backfilled -- I mean, whole tunnel were backfilled with waste and bentonite.

So for the R&D activities for crystalline rock packages, we developed those activities under guide of this R&D roadmap and their team -- already in target in the project, so this is kind of a master document that we use to prioritize R&D activities for the crystalline work packages. So, this is just a list of high priority R&D activities identified in this roadmap, like for crystalline rock, specifically to identify why is the -- both in engineering -- various system licensing how to design affective backfill or seal in material. And also, to developing new waste packaging concept for long-term disposal. Those are the two activities identified high in this roadmap.

So, based on this high and medium priority activities identified in this Roadmap -- so we developed those specific set of research activities as shown here. These set of research activities we are currently working on. So, these activities -- also mapped -- in the parentheses, these are coded map -- back to the R&D roadmap. So, as you can see, we have a quite diverse set of research activities, covers most component of the whole disposal systems. And overall themes behind those activities are to -- one is to build characterization and understanding the fracture media, and -- so the flow and then -- and the transport in such a media. And then, the second one is to design effective engineered barrier systems for waste isolations. And the reason we emphasize those two -- so we already mentioned in crystalline disposal system, both natural system and engineered barrier system play almost an equal role -- yeah, an equal role.

So all these research activity ultimately will synthesize to develop what we call process models, as shown in different boxes. And then those different process models will link together and then -- to form together in we call total system performance access model. We also call it -- here we -- for this project, we call it Geological Disposal Safety Analysis model, GDSA model. So the GDA -- GDSA models will be -- eventually, can be used to predict the total release of the system of radionuclide release from the system, and then use Monte Carlo simulation. You can now use this GDSA model to do sensitivity analysis, which is very important for prioritization of huge research activity. So this is the overall goal of crystalline rock path and work package.

And so -- in the next few slides, I will -- just to help you to walk -- to walk you through what we accomplished for each of these boxes for some of these process model in boxes, just give you a sense of what is the status we are at now.

Okay. So I'm going -- first, let me start at the very inner part of engineered barrier which is waste form. Here -- so we last a few years at Argonne, and they do -- the Argonne team developed a so-called fuel matrix degradation model, and this model can -- a comprehensive set of chemical reactions that can happen at the interface between the spent fuel and the incoming groundwater. This takes specific account for the radiolysis in effect. And then recently, they started to look at the potential effect of waste package and material degradation of fuel and fuel matrix -- fuel matrix degradations. Specifically, they look at -- they found -- for example, the hydrogen gas generated from waste package in corrosion can have significant impact on the fuel degradation rate. So, they are trying to couple the fuel degradation model with the waste packaging degradations.

So at Argonne, they developed these three electrochemical cells which can be used to measure the degradation rate for different -- for relevant waste packaging materials, as shown here. And then they can use this, use -- to measure the rate so they can feed it back their model to calculate the hydrogen gas generation and other parameters, and then -- and, eventually, they can and they can give a kind of mechanistic prediction of the fuel degradation rate.

And so -- and then here they show the -- another component of engineered barrier system that's right outside waste package, which is a buffered material. So currently -- no. I meant -- let me -- you know, I take it back. So, this slide shows the waste package material. So in KBS-3 concept, as I mentioned, so -- that concept heavily relied on the outer layer of metallic in copper, so which is about five centimeters thick. But the problem with that concept with the copper, it's liable to sulfite induced in corrosion so in repository up to the -- that -- reducing environment, you may have sulfite present. So that's one concern. So, we look at an alternative material to metallic copper. S,o what we look at -- here is kind of lead or lead alloy as a kind of like an alternative outer layer packaging material to existing copper material.

So, what we show here, this is the long-term degradation rate of -- and corrosion rate of -- in lead. And the experiment show, the rate decreases with time. And this decrease actually is caused by the passivation, the formation of lead carbonate. So, basically, our experiment shows lead can really last very long, and because of this passivation.

And then, more importantly, we show in this thermodynamic -- I mean, the stability field based on thermodynamic calculations. You can see in the presence of this hydrogen sulfide for copper, and the stability field is right beneath this red line. Very small. And then if we use lead and then stability field, given you have a high concentration of sulfide, and this lead is still kind -- thermodynamically stable in much larger and wider conditions. So, this experiment show that lead could be a good alternative to copper material, in outer layer packaging material. So, we check out the other specification requirement for outer layer material. It seems that lead is a good candidate.

Now I -- now I show you the -- in the buffer material, there is some work on the buffer material in this study. So, currently, the most commonly used material for buffer is sodium montmorillonite and calcium montmorillonite. What we found is if we reacted this material at a high temperature, about 150 degrees C, in some kind of alkaline environment -- you can see these are the initial material. This is XRD peak. You can see after the reaction the peak changes completely. This actually form some kind of zeolite. So that mean this montmorillonite be not as stable at that kind of environment that is relevant to high level waste repository.

So, we looked at other materials. This just shows saponite. This is the initial saponite material, then reacted with different time periods, and different temperatures, and also in alkaline environment. You can see there's no change of -- based – of these XRD peaks can be seen. So that means those materials, the saponite is quite stable in that harsh environment. And in addition, the saponite has very -- impressive -- comparable swelling pressure as a montmorillonite. So saponite could be a good candidate for -- you know, for harsh environment.

And so, after we get out of material and property from experimental tests for buffer materials, so we have also developed this so-called thermal-hydrologic-mechanical-chemical model to predict those materials at drift scale. This work was done at Lawrence Berkeley. So, the LBNL teams based on the slide -- so tested their model against the actual -- like full -- in full-scale test, which was conducted in Grimsel in Switzerland as a part of the FEBEX in program.

So, this basically shows actually the model they developed or the THMC model they developed. They did a pretty good job in predicting both hydrologic/thermal and hydrological. Here negative water content, and also chemical evolution basically, in buffer materials.

And so -- and then let's move toward -- to far field. And so colloid transport -- colloid formation and colloid transport is always an important issue we need to address for nuclear waste and disposal. So at Los Alamos, they developed this multiple column, experimental setup that can be used -- very useful to integrate, like, the newly – radionuclide absorption of colloid in our rock matrix.

And then they developed this so-called multiple site sorption model to extract the modeling parameters. So, this is just the one model fitting to the experiment -- to the experimental data. So, you can see the model match the experimental data very well. So, this actually -- so this multiple site sorption model now it's available for -- to be integrated into GDSA model.

So more on far field and transport, as I mentioned -- so in this crystalline rock and how to characterization or to -- representation of multiple scale in fractures is a very challenging problem, but it's a very important one. So, at Los Alamos, they developed a whole suite of toolkits to -- for meshing the discrete fractures, and then it can do -- flow and transport in those -- in fracture networks.

In general, there's two approaches that can be used to model a fracture media. One is just to use the discrete fracture network work model, as the one developed in -- at Los Alamos. There's another one, you know, we called equivalent porous media -- or equivalent continuum model. So last couple years, we compared two approaches whether we show if those two approaches can be comparable, so we can use both, you know, approaches to do flow and -- flow transport in fracture media.

And to -- now to those fracture models, we collaborated with Japanese, Mizunami -- Mizunami underground facility and lab through DECOVALEX, the international collaboration platform.

So we got -- so after at that side, they have a very -- a comprehensive set of site, characterization data. Especially the data -- like, the data information about the fracture and distribution around the panel and around the borehole. And so we use those set of data to parameterize our discrete fracture network models. And then we converted that discrete fracture network model into a continuum -- equivalent continuum model. And then we use reactive transport model to do flow and transport calculations.

This just shows the model prediction of inflow, the water inflow into this tunnel as the tunnel is -- excavated. So this -- and the time. And so we did multiple realizations. As you can see, these are the two data point. Actual observations. So, the model prediction seems -- I mean, provided in reasonable magnitude of -- magnitude of measurement. So, this is the way we validate our transport models. Also, as you can see, we did some 20 survey realizations, but you can see a lot of scattering among the different realizations. So the one issue was -- could -- been looking at is how many realizations do we needed to get a stable statics for fracture network. So that issue was -- we are still in -- we are currently working on.

And so just switch gear a little bit toward -- about technology development. Here I just wanted to show two examples. So, as we know, the disturbed rock zone in the tunnel. I mean, that's a very important region we need to be concerned because those -- the DRZS directly -- is a direct linkage between the EBS and the far field, the natural system.

So, at Lawrence Berkeley, they developed this tri-axial rock testing system that can be -- for example, can be used to measure the flow rate or the permeability of a core sample as a function of the stress imposed. So that's very useful information to evaluate, the development or the evolution of DRZ.

Then in parallel, they also developed so-called rigid-body-spring network models to simulate fracture pattern formation in -- along the path, internal. So, we --

so the combination of experimental test and model -- modelling, I think we will be able to get a much better evaluation for DRZ and development in the rock. In -- yeah, in the crystalline rock repository.

And then also because of -- due to the fracturing -- fracture in nature of the rock, the one thing is -- it is not unexpected. In this crystal -- in this fracture of the rock, the transport or the release pathway is very heterogeneous as shown here. This is -- we use the data from Mizunami, and then we put like 500 particles inside of the panel and then that is just moving around. This is to show the transport pathway of those 500 particles. So, the contaminant plume released from the tasks – not as uniform as in other media, it is very heterogeneous, it's very sparse. So, the question is how can we design and monitor it well that can capture the release of the radionuclides from a repository that highly relied on high resolution characterization of fracture network.

So, the one technique looked at Lawrence Berkeley is called SIMFIP, which can help to differentiate active fractures versus inactive. Active meaning these fractures can percolate wastewater. So, I think -- so this kind of technology will be very useful in characterizing fractures in rocks.

And just to summarize, this slide to show the current status of process model development and the part of system integration. So, in these green boxes, that means we have made significant level of understanding for the relevant processing models. So those -- in those boxes, I said we -- and I would say we have at least one process model available that can -- that are -- that is ready to be integrated into a GDSA model. And then the blue boxes, we made some significant understanding but there is still a lot of work needed to be done. And then for this box, it's only one box. As Dave have mentioned, it is about the biosphere, because the biosphere is more or less dependent, it is site-specific, we do not have much work in this area. But recently at the GDSA side, they are -- they have issued some work in -- for -- on this box -- on this box.

So the ultimate goal of this process model, as I mentioned earlier, will be integrated into a total system performance assessment model, GDSA model, and then to predict thermal, hydrological, mechanical, chemical evolution of a generic repository system in crystalline rock up to -- yeah, for a time scale up to one million years. And we haven't been there yet, but I think we have made a lot of progress already.

So, in the next step -- I mean, actually, the work for this year or maybe next FY. So, the priority is we'll be developing a sensible GDSA model for sensitivity analysis. So, from the process model development side, we will provide, kind of in a minimal set of process model to GDSA teams. And that's the first goal.

And then the second goal is we try -- we will try to move -- to do more model validation with real data as -- for example, as the ones we show and we use the data from Japanese Mizunami site to do -- to validate far field transport model. So, we will do this kind of model validation more down the road.

And then some of this process models are very computationally intensive. For example, like the discrete fracture networks and models. And then another example is fuel matrix degradation models which have involved a lot of chemical reaction. Yeah, so those models are very computationally intensive. So, we are looking at a possibility to develop and reduce the older model. So -- and that can be integrated into GDSA.

And again, as I mentioned earlier, so in crystalline disposal system, engineered barrier system is very important. So, we will continue work on development of new buffer materials.

And then, as I mentioned earlier, currently in the process model in the GDSA model, we don't have -- we only have kind of like a very stochastic model for waste package degradation, so we try to move toward -- a more mechanistic based in waste package -- in degradation models.

So -- and, finally, I want to emphasize. So, for -- our overall process for this performance assessment is to move toward -- to aim more realistic representations of actual systems. This is very important for crystalline rock. So, in general, crystalline rocks are very impermeable, so a sensible GDSA model needed to -- somehow needed to reflect this reality. I think this is my last -- let's see. Slide.

And then this is just a list of the reference. There's more information there. You'll see this disclaimer earlier. And then this is the list of people who did actual work I would say, so I send them for their hard work. And now I'm happy to take any questions.

BAHR: Okay. So, we only have about five minutes for questions, but I see Tissa's hand up. So, let's bring him on.

ILLANGASEKARE : Thank you very much. That was very useful. This maybe a little more technical details but I think -- my first question is a general question. So, people have worked on fractured media for various applications. So in the knowledge gaps, in your case, seems to be -- has to do -- more to do with the fracture interaction with the -- with, basically, the storage system, because now you -- there are people working (inaudible) problems. But my question more have to do with the issue of uncertainty. So what can you (inaudible) methods for the fracture -- in finding the fractures. And also you basically use a equivalent porous medium idea, so my question is that when you developed your statistical method, you look at the fracture network for the disturbed system. So how do -- in a natural system, people use your statistics, they assume various situationality conditions, et cetera, but in your engineered system, the engineering itself changed the rock. So how do you incorporate those uncertainties into your model, to your stochastic models, the uncertainties associated with disturbance itself?

WANG: yeah. And so that's a very good question. So, let's choose two ways we can kind of minimize kind of the perturbation -- I mean, surely an excavation being processed. One is when we synthesize the data, we usually -- not just the use data for internal characterization. We also look at like the alter -- like the outcrop in rock. And so, we have the fracture distribution data in -- from outcrop and also we -- also look at the data from boreholes. I think that maybe less disturbed rock. So -- and then -- as well as the data from the tunnels. And then for different fracture, like the tunnels, maybe there are some way you can tell, use new formula in fracture, all those kind of -- that order in fracture, which one is active and which one is not active. So, based on all those data, I think we can then construct some kind of sensible fracture network model, yes.

BAHR: Okay. Thanks, Tissa. Let's see. We have -- we have -- I see Paul Turinsky.

TURINSKY: Yeah. Thank you. Two questions. One is related to what Tissa was just asking about. I'm not a geologist. So maybe there's a very simple answer to this question, but if you think about a real repository and the depth and all the paths to the biosphere, how do you characterize -- really know what the fractures are so that you can set up a model because materials can be very heterogeneous?

WANG: Yeah, yeah, yeah. It's a very challenging to characterize fracture distributions in this kind of rock. So, yes, there's some kind of like, let's say so. The first think you can get in a site, you can kind of look at the outcrop and then you can get a general kind of like fracture system, distribution. And then, of course, you need a kind of borehole. And then -- from the tunnel. And then kind of ideally, if there are some kind of like geophysical technique you can use, kind of like -- you detect that the fracture remotely. That being ideal. Maybe there are some technique available.

TURINSKY: Okay. Are there, like, acoustic techniques and all?

WANG: We're acoustic -- or some kind of like -- maybe, it's kind of like -- what's that called? Penetration radar or something. Yeah. Yeah. Some kind of geophysical technique can be used to detect fractures, but -- I mean, larger fracture. Not small fractures.

TURINSKY: Okay. And the second question is -- relates to uncertainties. Are faults -- is there enough data on specific processes that Bayesian techniques can be used to not only get the mean value of parameters and models but also their distributions, so that when you do uncertainty analysis, it's got some basis rather than just, you know, expert judgment?

WANG: Oh, yeah. I mean, for the fractures, we basically use fracture characterization data from the field, yeah.

TURINSKY: Okay. I am talking about the overall assessment model with many other pieces of physics that are involved?

WANG: yeah.

TURINSKY: I mean, Bayesian being used throughout in developing the overall model.

WANG: Yes. Yeah, yeah, yeah. We use those kind of approaches yeah.

TURINSKY: Okay. Thank you.

BAHR: Okay. Next up, I see a question from Nigel.

MOTE: Yeah. Thanks, Jean. On your slide six, you identified that you looked at two sizes of packages for disposal of 4-PWR assembly and the 12-PWR assembly. You didn't indicate the burn up for fuel that was being assumed. I ask two questions. Are you looking at high burn up fuel and the impact of high burn fuel? Have you looked at the effects of larger packages and the higher heat load?

WANG: So I couldn't -- I didn't catch your second question. So, let me answer -- your first question, yes, we are looking at a high burnup fuel. Actually, we just started some work at Argonne to look at -- I mean, to synthesize some fuel and that -- to represent high burn fuel. And then look at the degradation rate of -- in those. So, we are looking at that potential impact of high burn fuel degradation, yes. Yeah. And you're second question, something kind of cut off.

MOTE: Okay. As Dave Sussani indicated, one of the possibilities for the US program is to dispose of canisters, the type of storage utilities, without opening the fuel out of the canisters. (inaudible)

WANG: Are you -- are you talking --

MOTE: Are you looking at your disposal of dual-purpose canisters of spent fuel?

WANG: Oh, yes. Yeah. Yeah. So let's say the one -- those two configurations I meant -- yeah, on this slide is for the reference case we are going to view this year. But, of course, DPZ is another important configuration we need to consider, I mean, especially for this crystalline rock because, as I mentioned earlier, because of its high mechanical strength and thermal range so crystalline rock is a -- yeah. Yeah. So maybe a suitable media for disposal DPCs, yes. Yeah.

MOTE: Okay. Thank you.

BAHR: Okay. And then Bret Leslie?

LESLIE: Hi, Jean. Thanks. And thanks, Yifeng. I think I'd like to add to what Nigel was saying, and I'll put it in a different way. Your disposal concept for crystalline rock includes repackaging from spent -- from currently spent fuel packages into smaller packages because that's -- that's your reference case. That's what your just viable disposal option, is that correct?

WANG: This is just for that -- listen, so we wanted to start in sensible GDSA model. So that's the way we start. So, after we develop this model for the reference case I just mentioned, like for these waste packages, and then after that, of course, we wanted to look at larger waste packages. But after we got that kind of computation of capability there, I think it gets, it will be quite straightforward to expand that waste packages to include into -- to include DPCs.

LESLIE: Okay. Thank you.

BAHR: Okay. I think we have -- oh, we're getting feedback. One last question if I can. The -- in the Swedish conceptual model, the waste package longevity is very critical to the safety component. To what extent are you relying on long-lived packages?

WANG: Your voice cut off in the last couple sentences. It's longevity you're talking about?

BAHR: Do you -- I'm sorry. I'm getting feedback. Maybe -- can you cut off your mic for a second?

WANG: Okay. So -- yeah, yeah. Let -- so let me --

BAHR: Yeah. Maybe, we won't get feedback now but you can hear me. The Swedish concept relies on very long-lived waste packages as a critical part of their safety analysis. To what extent do your reference cases require similar longevity of the waste package or are you assuming that there will be waste package degradation over much more rapid time scales?

WANG: So, I would say, we are looking -- we're -- we are not just sticking with what the Swedish program used, like relied on -- copper layer. So, what we tried to do, we look at the whole range of waste package longevities, including like a copper layer. That maybe one extreme. And then we also look -- and then for this time, we also look at the other materials like lead as an alternative material. That may be also provided in a very long -- I mean, longevity. So, we are not just sticking with the -- in KBS concept. We look kind of more -- kind of in a range of possibility.

BAHR: Okay. Well, thank you, Yifeng. I think, we need to move on to the next speaker at this point, and that's Kris Kuhlman, who's going to talk about salt host rocks. So, we can bring Kris on and I will go away.

KUHLMAN: Okay. Loading. Thank you. So while this is loading -- oh, okay. There we go. So, yeah, thank you. My name is Kris Kuhlman. I work at Sandia. I'm a Earth scientist with a background in hydrology. I worked at the Waste Isolation Pilot Plant as the lead hydrologist for a few years when I first came to Sandia. And then I was also the characterization lead for the Deep Borehole Disposal Project. It's been mentioned a few times in the past. And now I am the lead for the Salt R&D work package, which includes what I'm going to talk about here. So here we go.

Overview of the -- of the presentation. The presentation is basically three main parts. I’m going to introduce some of the same topics that are discussed for the media but kind of show how salt is slightly different. I'm going to discuss the knowledge gaps that have been observed or are known in salt. And then lastly, I'm going to talk about the DOE research that's being done to address those gaps, and basically how we prioritize our research.

So, to introduce all of these, I'm going to give kind of right up front a key factor what makes salt different from crystalline or argillite. So, salt is mainly focused on the Brine Availability Test in Salt, which this photo over here shows an image of it. And I'll talk a little more about it later in my talk. But in a, you know, really high-level overview, it's field test ongoing at the waste -- underground at the Waste Isolation Pilot Plant.

Like I said, it's the focus of our program. And, in fact, most of the laboratory and modeling work that's being done as part of the -- is being done in a way to support the field test. So that's kind of a key difference between salt and the other media. While the other media are more centered around -- they get their field data from, say, an international underground research lab like Mont Terri or Grimsel, we have what is essentially an underground research lab here in the United States at the Waste Isolation Pilot Plant.

But we do still have mature international collaborations. I'm not going to read through all of them here, but I list some of the collaborations that have been funded partially or fully by this work. And some of them are kind of new here at the bottom, just starting this year or last year. And some of them are -- have been going on for a better part of the decade, including an ongoing US-German workshop which has been pretty popular and the

Nuclear Energy Agency Salt Club. And these -- this work is -- primarily, our main international partner is Germany but we do have collaborations with Netherlands and United Kingdom, and there are other minor players who are in the NEA Salt Club and come to the US-German workshop. But most of our work is with our German colleagues.

So, a little bit about what makes salt different or what makes salt special. Why would we choose to put radioactive waste in a salt repository? So, salt has some great benefits at the long term. You know, at the repository, at a million-year timescale and the kilometer scale. Salt has incredibly -- basically un-measurably low porosity and permeability, and sense, you know, advection of -- dissolved radionuclides is the main transport path. This is -- this basically reduces this to almost zero. Salt has a high thermal conductivity for a rock. It's five watts per meter-Kelvin. You know, bentonite has one, maybe two watts per meter-Kelvin. So, it's significantly high thermal conductivity, which contributes partially to its high peak temperature you would expect in a salt repository. It's partially due to the high thermal conductivity but it's also due to the chemical make-up of the rock. It doesn't degrade at a low temperature or change into another mineral. And the mining -- or the openings themselves, be them drifts, hallways, rooms, fractures, they will creep close due to -- they'll creep close and heal themselves over the course of, you know, one to hundreds of years.

And run-of-mine salt, which is -- can be shown here -- so this is a -- this is a miner operating underground at the Waste Isolation Pilot Plant. And you see this head turns and it breaks the rock up in this pile of salt gravel, I guess you could call it. It's like a salt, sand, and gravel is what we call run-of-mine salt. It's literally from the miner. No work is done to clean, separate, or sort it. And this salt, even though it's about 30% porosity when it comes off the mining head because it's all broken up, will heal back to the same properties of intact salt if you apply enough pressure to it and obviously give it enough time.

So, this is basically some of the great benefits of salt. And then some of the additional benefits come from the brine. The first benefit you could say is the fact that there's not a lot of brine. There's typically less than five weight percent water in the salt, and there's definitely no flowing groundwater. The -- and what water there is, is hypersaline. The chlorine content is enormous. And this really reduces or even eliminates criticality concerns you might have in a salt repository. And this hypersalinity also will reduce colloid mobility because basically the electric double layer in pores goes to about zero at high salinity. And so we don't really have to worry about colloids. And the low water activity, what water there is in the excavation is saturated with sodium chloride and other -- and other species. And so basically no life can exist. I mean, you put salt on meat, to preserve it. So, you don't get a lot of microbes in a salt repository. Now, all of these great benefits are tempered by kind of near-field short-term complexities.

This figure on the right here shows kind of -- the dark blue would be an excavation. This is like a cross-section through a drift. And the lighter blue circle around it kind of shows this halo of excavation damage zone around it. And this zone is sort of -- is anisotropic. You have this kind of onion skin fractures that go around it. And so, this region of increased permeability, and porosity, and directionally-dependent properties is basically the main complexity we deal with. And I'll spend a lot of -- more time discussing that.

I want to -- I want to dive into one further detail, and that is the brine itself. This is part of what makes salt special, but the brine -- first of all, there's not much of it, and, second of all, it's mostly connate brine. It is brine from the Permian that was, you know, in the rocks when they were deposited 250 million years ago. This is not water that has flowed through the rocks recently. The water is mostly associated with disseminated clay.

Over on the right, these two figures are X-ray CT images of salt course we collected a couple years ago. And they -- you see this darker gray that's a little darker than the background color is disseminated clay. And so, it's -- you can get continuous clay layers but mostly there are little bits of it is spread throughout the salt. And they aren't large amount by volume, but the brine -- the clay itself can be about 25% brine by volume.

Then there is an intergranular fluid inclusion. Here's a microscopic image of a piece of salt. This is a two-millimeter scale bar here. So, you see a fairly large kind of -- sometimes they're called inverse crystals. It's basically a hollow spot. And that's just filled with Permian seawater. So, this kind of brine is obviously trapped inside the rock, but it can be liberated. Sometimes those fluid inclusions will move when they -- under a temperature grade or they can explode if they're heated high enough.

And we also have hydrous minerals. So, in this lighter shade of gray up here, we have polyhalite, which is you can see in its chemical formula here, it's a sulfate which has two water molecules, you know, built into the chemical structure. So, the water is not directly available to flow to the excavation, but if you heat it up hot enough, you can liberate that water.

And then there is intergranular brine. This here shows -- this is a scan electron microscope image where a salt crystal has been plucked out and what you're seeing is basically the two planes that goes in and not out. It sometimes can be kind of an optical illusion, but this is where crystals are removed and you could see this kind of wormy pattern on here, these are intra -- intergranular fluid inclusions that were created when they took granular salt and heated it and recompressed it into solid. And you could see how the brine is trapped in between the two salt crystals. This is intergranular brine. So these are rated in terms of, you know, high -- most to least, you know, this is the most significant form of water in the -- in the salt and this is the least significant form of water in the salt. And the reason we delve into all of these nitty-gritty details is because each one of these types of brine responds differently to heat and pressure. So when you're designing the repository or when you're trying to understand how much brine there is or where it's coming from or how it's going to evolve, you have to -- you have to be able to partition the brine among all of these different populations.

Now, taking a step back and looking at the -- kind of the general strategy. So, we have this cartoon on the left here, so with the repository system with the dashed line going around it and the biosphere up -- with the tree above. Our main strategy in salt is containment. We have minimal reliance on the waste package itself, on the metal waste package that we put into the repository because we see say that the salt is the container, really, it's self-healing, it's essentially impermeable. And so therefore, there is limited transport, there's really -- there's limited free water, and water is -- essentially is the solvent, it's the corroder, and it's the transporter. So if you -- if you don't have very much water, the only -- the -- you know, the -- if you don't have any water, there's no way to bring waste to the surface aside from a human intrusion drilling right through a waste package and bringing it to the surface. But obviously, there is some water and it can be highly corrosive because it's a salt brine. But there's a -- there's a minimal amount of free water in the system. The host rock itself is essentially impermeable. And not only is it impermeable to advection, but it essentially has zero diffusion free -- has a zero effective diffusion coefficient because you have fluid inclusions next to each other or you have brine in the salt and you can test fluid inclusions centimeters apart and they have been next to each other for hundreds of millions of years and they have completely different chemical compositions. So essentially, diffusion is not even happening through the salt.

So really, the main pathway to the biosphere is through the shaft seals, you know, sealing the pathways we use to get down into the repository. And these are designed to reduce or eliminate advection. They're engineered -- they're engineered structures, and they're typically engineered here as a multi-barrier concept, your belt and suspenders. We -- we don't -- we don't hang our hat on just one type of seal, cement seal and asphalt seal, crushed salt seal, we put them all in and you would have to -- basically they would have to fail in order to see a failure in the shaft seal. But this is still a focus of one of our new collaborations win salt, RANGERS U.S.-German collaboration.

So the idea for the disposal concept in salt, we -- is pretty broad. Salt -- a salt repository would be great for a glass high-level waste. You know, I think you can put glass leg -- glass logs on the floor and then just cover them with run-of-mine salt backfill. The high-level glass waste tends to be not very high temperature. The commercial spent nuclear fuel also works well in a salt repository, you know, going from 12 all the way up to 37 PWR size. This kind of falls in the range of the large heavy waste packages, you know, from the dual-purpose canisters. And these kind of -- you would have an in-drift disposal. And you -- if you can see in this drawing there's a notch made floor where you put the waste baggage it's because the thermal conductivity of the intact salt is very high while the thermal conductivity of granular salt is lower. So, you're basically trying to increase the thermal contact between the waste package and the -- and the intact salt by making these notches. And then you would cover them with run-of-mine salt for, you know, to bolster for its -- the -- because of that run-of-mine salt will eventually turn into intact salt, but also for shielding in the -- when the repository is still open. And the salt can handle pretty high, power levels and doesn't really require a lot of -- a lot of storage. You're can have high burn-up fuel with relatively short out-of-reactor times. So, salt is pretty accommodating here, and I think dual-purpose canisters or, you know, large heavy waste packages are definitely viable in salt. But I'm going to say now that it's not a -- it's not an active area of research in salt because -- because of some of the benefits I talked about on the previous slide, the main research areas in dual-purpose canisters are in criticality, understanding and controlling criticality, and also looking at thermal management. And as I said, you know, chloride-rich brines basically don't have criticality concerns that a freshwater would, and the high thermal conductivity of salt helps us manage thermal problem. So, being said, I'm not -- we're not going to really talk much about these dual-purpose canisters and because they're not really a research topic in salt right now but I want to say that they're definitely a -- they're definitely viable concept in salt.

So, yeah -- is a salt repository susceptible to climate change? This is a question -- a valid question. So, I think you can boil that down maybe to what are the impacts of freshwater on a salt repository?

So, this cartoon on the right here shows the salt would be this kind of yellowish-orangish layer and you can have a freshwater aquifer maybe in green underneath it. And so, salt is very soluble in freshwater, so you wonder how could that -- how could climate change possibly influence repository. But if you have -- you have to think about it from a density point of view, the freshwater from above, it's a stable arrangement, you basically have light above heavy. And so, it might get a little -- if you have -- if you have a, you know, water being pushed against the salt by advection, you might have some erosion, but it's not going to be a runaway process. It's density limited. It's only if you have freshwater under the salt, which you can have runaway dissolution process. And in the Delaware Basin in Southeastern New Mexico, they've spotted these breccia pipes, where basically freshwater has come in contact with the -- high-pressure freshwater has come in contact to the bottom of the salt and it -- and it erodes through the salt because of the runaway process. But this arrangement where you have a high -- where you have an aquifer directly under the salt can basically be avoided in the siting process of a repository as was done with WIPP. So, based on this analysis, I think you quickly -- or this reasoning, I think you can say that there's no direct impact to the increased precipitation or temperature on a salt repository directly or the effects of glaciation and deglaciation because you can basically avoid the cases where you might have these units juxtaposed.

So, the status of monitoring characterization of salt is similar to many other media but there are few differences here. Unlike crystalline, we don't really worry about open fractures. We don't worry about mapping fractures in the salt because the salt cannot support open fractures. Fractures always heal in salt. And so, there aren't far-field fractures or faults to map. And really, the siting process or the characterization process to avoid these fatal flaws like I mentioned in the previous slide, you want to avoid these deep high-pressure formations that are right up against the salt because they might lead to breccia pipes. And you would also want to avoid, you know, leftover human boreholes from, you know, oil exploration or solution mining.

There is one catch, you know, it's you don't have to do a lot of characterization in salt. Maybe you have to characterize fracture networks, but the salt itself is difficult to characterize. You can't really characterize it in boreholes from the surface. It's basically immeasurably low permeability and porosity and you need to be in the repository or you need to be in the underground where you can measure from tens of meters away, not hundreds of meters away. Just the rock is -- the permeability of the rock is on the order of permeability of the tools you're using. So, oil and gas typical exploration methods are basically ineffective in salt. And even in the laboratory, precipitation and dissolution of brines and salt makes lab testing difficult even when you collect the sample and bring it back to the lab. And to add insult to injury, you know, brine is corrosive and it destroys thermocouples, destroys pressure transducers and it can make -- it can make it difficult to characterize some of these formations.

Going as a flashback to the slide from Dave's talk about the high-priority R&D activities from the 2019 Roadmap Update and I've highlighted in red here the ones that apply to the salt. And they include engineered barrier activities, and international activities, and salt-specific activities. And I will talk about these, but I just wanted to show kind of how the overall high-level activities and the work we're doing still kind of flange up.

Now, to -- I'm going to step back and make a couple definitions and give you, kind of, a description of the processes going on that we're most interested in in salt. So, a salt repository can be kind of broken down into -- if this is the drift and this is the cartoon showing the area around it, one is the backfill drift, so that's the drift, we backfill it with the run-of-mine salt. Two is the excavation damage zone with the big "D". That is the area around the excavation where the properties of the rock had been modified. And then you have excavation-disturbed zone, which is the halo around that with the little "d" that describes we're just a state, you know, just a pressure or the stress had been modified. And so, the -- this is at early time, right after the excavation. This will all eventually heal, but at early time, we have this perturbation we have to deal with. And the perturbation comes essentially from this.

If you look over on the right, you see this is basically time going down. But the moment you -- if you could imagine -- you can imagine instantly making a drift, you -- you -- at that moment, the -- the radial stress has nothing pushing back on it. You only have air in the drift pushing back. So, the radial stress goes to zero as you approach the drift wall. So, therefore the "hoop stress" or the circumferential stress has to get very high, higher than the strength of the rock and the rock fails plastically. And you develop these damages on there, accumulates around the drift where you've exceeded the strength of the rock, basically. And so, you see this red curve showing porosity developing around the excavation. And this is basically the evolution of the excavation-damaged zone and excavation-disturbed zone where just stresses are different.

You can also relate this -- you also have permeability dropping off rapidly as you leave the excavation. And you have liquid saturation going up, you know, the far-field desaturated, the near-field is dry, you have the liquid pressure going up to a very high value in the far-field and its, you know, atmospheric pressure at the drift. And then, you can have the perturbation of the waste on there, too, where temperature drops going away. And you can even have some thermal pressurization effects in the near-field. So, we have all of these processes going on kind of in the halo around the drift and this is what we're interested in right now, because -- and with time we know this will go away. We know that the far-field conditions will prevail again in the near-field. You know, the salt backfill in the drift will become intact and the disturbance will go away. But understanding this. is kind of the key of our -- the main focus of our research right now.

So, like I said we have steep gradients across the damaged and disturbed zones in both material properties like permeability and porosity, and in the state variables like liquid pressure, brine saturation, and stress.

Here's a -- some data from the Waste Isolation Pilot Plant showing the x-axis is distance, so this is radial distance from the excavation and the y-axis is formation pore pressure and you see that pore pressure goes from basically zero at the drift to fifteen megapascals, which is a hundred and fifty atmospheres in about five excavation radii. So, you see there's incredible pressure gradient across the salt, which is only possible because the permeability of the salt is fantastically low.

So, we look at these gradients. We look at the non-linear effects going on. We have mechanical, thermal, and hydrological perturbations. We have two-phase flow going on in -- in fractures around the -- around the drift. We have ventilation dry-out during the -- during the operational period of the repository. We have dissolution and precipitation of the rocks, which affect the -- both the transport properties and the mechanical properties of the rock. And we can get what's called the heat pipe.

So, this is a cross-section. The -- the gray at the bottom shows intact salt, stippled area around it is run-of-mine salt over it and this “hot” would be a waste package. You basically have boiling right at the waste package surface, which deposits a low porosity brine of the -- of the salt which was dissolved to the water. You have high -- you have steam traveling out to the point where the isotherm gets below boiling and then you get condensation. Now, condensed steam will dissolve salt again so then you'll have -- you'll create brine again so you increase porosity in the far-field and you decrease porosity in the near-field, so we're actually reducing the porosity and drying out the salt right around the waste package. And also, convection is a very efficient heat conduction mechanism, so basically this region, this -- this pale orange region around the waste package is basically constant temperature. It's not -- if it was conduction only, it would be very steep temperature gradient, but because of convection, you can actually have a very smooth temperature gradient, and this lowers your peak temperature. Also, another thing that's observed in salt is thermal expansion will close the fractures in the disturbed rock zone and/or the excavation damage zone and this would decrease permeability. At Avery Island they observed, you know, three to four order of magnitude decrease of permeability as they approached a heater showing that the disturbed zone around the --

associated with the drift was closing up around the heater. So, you can actually get this in salt. You know, the heat will dry out the salt and precipitates salt, but it will also reduce the permeability of the salt itself.

So, now how do we put that into our numerical models because these are complex processes? You know, in the -- in the GDSA modeling, in the Generic Disposal Safety System modeling, we're typically worried about larger distances, longer times. But in the near-field, we're worried about short distances, short times, and we -- the -- Berkeley has the powerful tool called TOUGH-FLAC, which includes all the thermal, hydro, mechanical, chemical processes. You can have deforming salt. And they -- Jonny from Berkeley's put a lot of effort into making this a physically realistic model, but it's a very computationally expensive model. So, we've wonder, are there appropriate simplifications that can be made? Can we -- can we simply it to a single-phase flow? Can we -- can we assume that salt is a porous medium -- the equivalent porous medium rather than a discrete fracture network? Can we uncouple slow and fast processes? Some processes happen in the scan -- in the course of minutes, hours, and days, can we uncouple those from processes that take months and years? And can we -- can we get by and predict some things of relevance using simpler thermal hydrologic compared to a hydrochemical models like PFLOTRAN, FEHM, and TOUGH? So those are -- those are important questions that we're -- and maybe gaps that we're trying to address in our research.

So, I -- one of the things is we need more work on constitutive laws. These complex models have complex constitutive laws. Here's some examples.

This is a mechanical constitutive law showing creep rate as a function of effective stress, and most laboratory tests are over here where we have a high differential stress that's applied in the laboratory. And you have -- when you extrapolate these rates to the field, you'll vastly underpredict what's going on because salt has a -- has this funny knee in its behavior where it actually has a -- you have -- you have a different micromechanical mechanism kicks in at the field scale and at field -- and so, you can actually have much higher creep rates at low deviatoric stress. And this is honestly a relatively recent realization. You know, salt underground -- work has been going on on salt repositories for decades but this is a relatively new development. And we're trying to incorporate this in our models, but as you can see it means we have to do more complicated lab tests that emulate field tests and we have to incorporate these complex nonlinear constitutive laws in our -- in our models. And also, even the -- even the thermal conductivity is the function of temperature in salt. And we'd like to incorporate chemo-mechanical coupling, looking at how dissolution and precipitation make the change of physical properties of the rock.

So, taking a step back after introducing all this complexity and asking the question, do we really need to make accurate predictions in this excavation-damaged zone that's this halo around the drift? You know, it's a -- it's a near-field short term thing, do we need to make good predictions there? One option and which I think is being relied on by some organizations is to rely entirely on the geology and avoid these complex near-field processes. You just say, you know, we're going to -- we're going to assume that there's plenty of brine available for lots of corrosion in the metals. We're going to assume that there's enough brine to dissolve all the radionuclides. We're going to assume that there's a large microbial community which is going to generate a lot of gas, which is going to create more driving force, which is going to drive advection. We're going to assume that there's only heat conduction in the repository. And these are conservative simplifications because you say, well, these processes might not be going on, but I don't even need to take credit for them because the salt -- the salt itself is such a great seal.

But I think another option is to actually drill down and start accounting for these complex processes. Like I said, the heat dries out the waste. That limits corrosion in transport. The thermal expansion and excavation damage zone reduces the permeability around the waste packages. There are very few halophilic microbes, which creates a very small amount of microbial gas generation. And these granular heat pipes which can set up around a waste package could create a very uniform area of constant temperature rather than a steep gradient where you have very high temperature at the waste package, to reduce the max temperature of the repository. And we can investigate and more fully understand the timing of this return of backfill and EDZ through the state of the intact salt rather than saying, "Well, it's g take somewhere between one and a thousand years." What if we -- you know, we know the complex processes that interplay and we can say, you know, under these conditions, it should take 50 years or it should take 500 years.

And really what the US program is doing is kind of a hybrid of these two. We're falling back on the geology, but we're trying to investigate these processes to take as much credit for them as we can and bolster our case and not rely entirely on conservative assumptions.

Now, what we're doing, the current R&D in salt, like I said, is focused on the Brine Availability Test in Salt or BATS we like to call it.

So, it's basically two arrays. There's a set of boreholes that are around -- centered around the heater, and then there's another set of boreholes over here that are similar to it but don't have a heater. And we're -- there's a heater about two -- two and three-quarters meters deep. We're measuring borehole closure, we're measuring water production and isotopic composition, we have cement seals -- in these boreholes and we're monitoring cement-salt-brine interactions, we're going -- we're -- we have complex geophysical methods going on, we're mapping the electrical resistivity of the salt, which is being done by Berkeley, and it's fantastic. We're actually being able to see the brine move around in the salt, which is very difficult to do. And we're monitoring acoustic emissions and listening to the popping of the salt when it -- when the permeability closes and the permeability opens, when you turn on, and shut off the heater. And we've completed Phase one or Phase 1a of the test that was earlier this year.

And here, you could see some temperature data where you turn on the heater and then you turn off the heater, and you can see the thermal response of the -- some thermocouples embedded in the salt. But we also have a tracer test which we're hoping to start in early in 2021 but, you know, the -- it's a COVID world we're dealing with, and it is hard to start new experiments. We're hoping that in late next year, we're going to be drilling new boreholes and we'll be able to take -- build on the lessons learned from this first experiment and create an even better one.

And BATS is the focus of DECOVALEX Task E and we've -- it's -- it's just starting but it's been a fantastic collaboration. We're learning lots about our own data from what the German, Dutch, and British colleagues are -- are teaching us by our data and it's fantastic.

So, one of the main focus, as I said, is engineer barriers, because that's really the only pathway out of the repository. So, the RANGERS U.S.-German collaboration is looking at drift and shaft seals in -- as a whole and trying to understand the best way to design those. Now, KOMPASS is specific to the run-of-mine salt.

So, we -- this is a sample here of reconsolidated granular salt. And this is a microscopic image of it. And you can see these planes of fluid inclusions that are pointed out with arrows show where grains have sutured and you have intergranular fluid inclusions between them. We're trying to understand, you know, all these inputs, you know, it's -- the salt reconsolidation is a function of temperature, stress, moisture, and how do we take -- how do we take laboratory tests that have to be run in days and weeks and make them representative of processes that might happen over tens of thousands of years? How do we speed it up without changing physical mechanism? This is the point of this research.

And we're also looking at cementitious seals. Both Sorel cement, which is a magnesium oxide-based -- salt-based cement, rather than a calcium oxide-based cement, and typical salt concrete made from furnace slag.

And these plugs are -- have been then placed in boreholes and we're looking at them interact with the brine and the salt. And we're also collaborating with GRS in Germany, where they're basically recreating our borehole experiment in the laboratory, and we're trying to synthesize, you know, modeling, field, and laboratory data to understand the complex hydro, chemical, mechanical reaction going on between salt and cement. Since salt -- cement is a likely repository sealing material.

And lastly, obviously, we have model development. We're looking at improving the GDSA model itself. That's PFLOTRAN. We've recently introduced temperature-dependent thermal conductivity because as I said, that's an important thing in salt. And we're trying to utilize cool -- high-tech meshing tools because meshing around all these boreholes, we've drilled in the EDZ. We have to -- it's a complicated problem. Just the meshing itself can be a complicated problem. And anybody that's done modeling knows that if you have a bad mesh, you're never going to get good results from it.

So, we're also trying to improve the process models themselves. Here's some work by Berkeley being done to do multi-continuum approach to fluid inclusions so that we don't have to make the matrix ridiculously tiny, but we can still include the effects of fluid inclusions. And here's some work being done by Los Alamos to include the effects of dehydration of hydrous minerals and clays, and include the evolution of porosity in our models. And we're also looking at the effect of two-phase flow in salt, which is complex and there's very little data to characterize it.

And as I already said, we have a lot of international benchmarking activities going on. Here are some, right here. We're looking at, you know, the BATS heater test, looking at improving mechanical constitutive models, looking at granular salt reconsolidation, and we're looking at validating thermomechanical models.

So, all of that being said, kind of the question of this talk is, really, where does our work have the greatest impact? There are definitely -- you know, as Dave pointed out earlier, you have both things that are well known or not well known, but you have -- you know, how important are they to the safety case? And so, you have to take both those things into account. So, some things that are very important to the safety case which have a low priority are far-field salt behavior, how does salt behave on -- you know, in the undamaged state? We're not really researching that, even though it's got a whole safety assessment hangs on it, because it's relatively well known. And we're not investigating large hot waste packages because salt has such great properties, that I think a lot of the things are currently investigating, that's kind of -- it's not a big deal in salt. So, these are important things, but they're not current priorities.

Our priorities are centered around drift and shaft sealing and that's the RANGERS and KOMPASS projects and, I mean, I love the -- collaborating with the Germans is great. You get these great project acronyms, like, we're never going to get lost if we have rangers and compass. It's great. So -- but these projects are looking at timing of return to far-field conditions and also modeling the salt and engineer barrier evolution in these interactions because, as I said, they're complicated. And these greyed out numbers over on the right here kind of link back to that table on slide nine with all the high priority things from the 2019 Roadmap Update. And we're also trying to investigate coupled EDZ processes. You know, these processes in this near-field damage zone right around the drift, and the BATS field test at WIPP, which you see in this photo over there, there's a -- there's a lot going on, but we're -- we're learning a lot about salt and the behavior in this near-field because, really, that damage zone, it's complex, but if you can understand salt in this complicated region, it further bolsters your understanding of it in the far field.

So as I -- as I -- as I said before, I'm going to reiterate, our safety assessment really relies on the salt geology. It provides a great container. But we're trying to bolster it with this EDZ understanding.

And I'm going to leave at this. And obviously, this is a team effort and we have a team across several national labs including a great team that works underground at the Waste Isolation Pilot Plant. You have to give credit to all these guys and ladies that's -- it's a great team. So, thank you. I'm ready for questions.

BAHR: Okay. Thanks, Kris. Looks like we have about 15 minutes for questions before the break. And just before I go to the people with their hands up, you talked about the fact that characterizing salt is not nearly as complex as crystalline rocks because you don't have to worry about fracture mapping and fracture networks and those sorts of things. But you do have to worry to some extent about the salt heterogeneity, particularly the abundance and distribution of clay beds. Do you want to say anything about that?

KUHLMAN: Oh, that's absolutely correct. Yeah, you can't escape heterogeneity. I mean, it's -- any time you work with, you know, natural materials, you have heterogeneity. Yeah, the -- like I said, the -- I showed that X-ray CT imagery had little blebs of -- of clay distributed. Obviously if you -- that's on -- that's on the centimeter scale. You know, that's a core, like a four-inch core. You zoom out to the drift scale, and you'll see little layers in the drift where you have slightly more clay and slightly less clay. And right now, we're trying to understand it, we're trying zoom in and understand the components but you're right, you have to then map those components out in your repository and understand where they are and how much of each one you have. Because you can actually -- if you go down into a drift at WIPP that's been recently mined, you'll see this little -- they call pop corn, little efflorescence on the wall of the drift and it's basically everywhere you have some clay, the high-pressure brine in the clay is now leaking out because it's not confined anymore, and then it evaporates and you have these little -- and you can map -- you can basically map the salt -- I mean, map the clay amount in the salt by looking for those efflorescences. And you're right, it's a multi-scale problem. You know, you worry about it at the centimeter scale, you worry about it at the meter scale. When you get to the, you know, tens of meters and kilometers scale, it kind of averages out because the bedded salt is relatively homogeneous over, say, kilometer scale. These -- at least in southeastern New Mexico, the units are pretty continuous over the whole over, you know, kilometers but you're right, there's a -- there can be significant complexity at the small scale.

BAHR: Okay. Thanks. I see that Tissa has his hand up, so let's bring him on.

ILLANGASEKARE: Thanks, Kris. So -- so you mentioned that the most important area is the disturbed area, because the fractures are forming in there. So eventually, the process of healing is thermomechanical. So, do you -- are you -- question number one, how is it modeled or how do you -- in your experiments, are you looking at that process, also?

KUHLMAN: That's a -- that's a great point. And the -- that's the ultimate -- the ultimate point we're trying to seek is, you know, when everything heals back up. And typically, these type of healing experiments are done in the laboratory on a, you know, triaxial test where you can apply a significant load, you know, you know -- many megapascals to force the rock together and you get pressure solution, you get lots of small-scale processes which basically allow the rock to just heal.

You definitely -- the TOUGH-FLAC model that I pointed out that's being -- that's been created by Jonny Rutqvist at Berkeley, does include some healing. There -- they used the Lux/Walters mechanical model which includes a lot of processes and healing is one of them, but when you start to -- when you -- when you flip that on in your numerical model, it -- it makes the model very complex. Because you have this -- now this feedback loop where the -- you know, the mechanical problem is changing the hydraulic which can cause thermal pressurization which can hydrofract the rock and -- it's a -- is possible to simulate it. It is -- it is not a trivial problem to simulate, though, but yeah, we're -- you have to have a very complex model to include it explicitly. I think in some of the simpler models, we try to include it implicitly by just changing the permeability as -- as a knob, kind of like, you know, we change it, we don't have an explicit mechanical coupling. But you're right. There -- that work is being done and there -- there are other groups doing it with different numerical models but, yeah, the -- the understanding healing and calibrating those models, I would say it's basically on the cutting edge of salt mechanics work. There are tests being done and there are lots of groups working on that, but it is not a trivial problem at all.

BAHR: Thank you. We have other questions from Board members -- Nigel Mote, staff?

MOTE: Yeah, thanks, Jean. Thanks, Kris, for the presentation. You will remember, I believe, that in March

2014 the Board had a meeting on salt disposal. The meeting was in Albuquerque. One of the points the Board raised after that was the potential for the presence of brine pockets and the human intrusion potential comes into play particularly with salt in that -- in -- in that instance. To what extent are you -- to what extent can you take account of that in looking at potential disposal in salt?

KUHLMAN: Yeah. So, I didn't really -- I mean, I mentioned human intrusion in passing on one slide, yeah. Human intrusion, obviously, you know, you -- the WIPP is our main example, you know, it's the operating salt repository for defense transuranic waste, so not for the kind of waste we're talking about here but obviously WIPP is what we do our experiments. WIPP is our main -- you know, it's where most of our experience comes from in salt in the United States, and -- and at WIPP, human intrusion is -- drives everything because the regulations have laid down that they have to consider the series of human intrusions which -- it's -- it's a complicated system of human intrusions. But you're right. That's -- salt is often associated with other resources that people are interested in, like petroleum. And so it tends -- you know, your salt domes often have petroleum associated with them, even bedded salts can sometimes -- like at -- at WIPP, it has petroleum underneath it and so you have to consider all those factors, including human intrusion, when you're doing your safety assessment. But you'd say that right now, we're mostly focused on the nominal case and we're -- or the undisturbed case, or the natural evolution case, because our experiences -- well, not our experience, but we -- human intrusion is largely dictated by law or by the regulator. And I guess it seems maybe it's not our place to say what we think it should be or maybe we should, but it's -- but that's -- it's not an active area of research, even though you're right, it can significantly drive releases or the performance assessment process.

MOTE: Okay.

BAHR: Okay. Thanks. Bobby Pabalan?

PABALAN: Kris, in your BATS test, were you able to retrieve enough volume of water to analyze the isotopic composition and distinguish between the different water sources?

KUHLMAN: We are working on that. We -- we have several -- we -- we have cores that we're trying to sample the brine from and obviously, you know, there's not a lot of water in the cores, but there are fluid inclusions that can be tested, and those are -- you know, we're taking cores into the laboratory, because work is going on at Los Alamos where they are heating cores. And basically, in the thermogravimetric analysis, where you heat them up, and then the -- but the vapor goes into a cavity ring-down spectrometer and you look at the water isotopes that come off the salt. That work is being done. But as you kind of indicated, there's not a lot of water, so you're struggling for microliters of water.

In the field test, we -- we have gotten more water. And, as you might know, it's difficult to collect a sample of brine in the field that has undisturbed isotopic signatures. So, the field data are less -- they're more easily contaminated than the lab tests. And we're working on all of it but it's one of the avenues we're looking at, is trying and get the isotopic signature of fluid inclusions, the isotopic signature of -- I'm sorry, water and fluid inclusions and the water in -- that's in clay -- associated with clay minerals, and maybe the water that's associated with a hydrous mineral, trying to tease those apart. We don't have that question answered, but it's one of the questions we're looking into.

PABALAN: Is it possible to design your future tests, for example, the ones for next year. So you can --

KUHLMAN: Yeah.

PABALAN: -- get more data to -- to analyze this?

KUHLMAN: This is one of our -- kind of lessons learned or hopes that we -- you know, we learned that the approach we took first is not getting us the data we wanted. We're revising how we're doing it and, yes, that is one of the -- that is one of the goals of our upcoming test, correct.

PABALAN: Okay. Thank you.

BAHR: Okay. Thanks, Bobby. Any other questions from Board members or others? Okay, well, thank you for an informative presentation, Kris. I think you articulate nicely some of the advantages of salt, so that goes well to providing a case that -- oh, we've got Chandrika, with a question.

MANEPALLY: Hey, Kris. Thank you for the nice presentation. My question was can you speak a little bit more about how much information you were leveraging from the German work, especially the PA models that have done a lot of work in the past? I know you're collaborating with them on current experiments, but have you looked at the work they have done in the past?

KUHLMAN: Definitely. The -- the BATS test is, you know, kind of standing on the shoulders of -- I -- I gave a talk in 2014 at the -- at a Board meeting and I talked about the long history of testing in salt, because salt does have -- you know, it goes back to the late '50s. So, salt for radioactive waste disposal has a long history. And we have tried to draw as much understanding as we can from, you know, what's been done, trying to not reinvent the wheel, but there's also been significant advances in geophysical techniques, sampling methods, and now, you know, the BATS test, I didn't really go into it but, you know, we have a quadra-pole mass spec in the underground and we have the gas stream flowing through it. We're -- we're monitoring these things in real time and that saves us some of the complications of collecting samples and transporting them, and getting contamination and we're -- we're trying to -- we're trying to do learn -- you know, use what was learned in the past, bring new techniques to bear, and also kind of train the next generation of salt scientists, because there was a lot of work, like I said, done in the '60s and '70s and '80s at -- in Germany, in the U.S., and those people are retiring or have retired. And so, we're trying to, you know -- DOE -- we're trying not to recreate what was before, but we're trying to, you know, augment what was done before.

MANEPALLY: Thank you.

BAHR: Thanks, Chandrika. Any other questions from Board and -- and staff? Okay. Well, I think this is a good time. We have a scheduled break that will go from now until 3:55 Eastern Time, which is 12:55 West Coast Time. So, we'll see you all back in about 10 minutes, 10-12 minutes.

(Whereupon, a break was taken.)

BAHR: Okay. I'm back. I hope our speaker is ready. This is our final presentation for today. It's going to be Carlos Jové-Colón from Sandia National Laboratories and he's going to talk about the final class of host rocks that DOE is investigating and those are argillite. So, if Carlos is here, here he comes. Thank you.

JOVÉ-COLÓN: All right. Is there a pointer I can use? All right. So, let's get started. My name is Carlos Jové-Colón. I'm a principal member of technical staff at Sandia National Laboratories.

Just a little bit of my background. Like Dave Sassani, I am a geologist/geochemist but the thing that I should emphasize in the latter because that's what I've been doing for a great part of my professional career. I have worked in the Yuca Mountain and mainly on the development of thermodynamic database is used to actually use in models for -- or, your chemical models of fluid-mineral interactions. Anyway, I'm going to actually be talking today about argillite host rock. Some of the work done in terms of assessment -- assessing disposal concepts and, of course, the R&D activities related to this.

Just a quick outline here, basically, I'm going to talk a little bit about the argillite repository concepts. Some examples from the European counterparts, and actually some of these clay-rock repository concepts that have been studied for a while. And then, we actually have partnerships with this group because number one, they have underground research labs, et cetera. So, we can actually leverage on that. I'm also going to talk briefly about argillaceous host rock characteristics and the types of, you know, there are argillites and there are argillites and -- but, overall, I mean, I'm not going to be talking too much about it except just to say one of the main characteristics and also a little bit about the pore water chemistry from databases developed on water chemistry, you know, water -- gas producing wells. I'm going to talk a little bit about argillite post-closure safety strategy, some of the considerations taken there. Similarly, I'm going be talking about waste form and engineered barrier, you know, argillites and some of the considerations. I mean, what I mean consideration is what actually I've been considering, models and simulations, particularly in the geologic disposal safety assessment. I'm going to briefly mention the argillite reference case, something that we are still working on, particularly in terms of some of the deterministic, GDSA type modeling for argillaceous host rock. I'm going to talk about some of the knowledge gaps and R&D priorities, that's these argillite work package, actually encompasses, some of the repository relevant processes in the chronology of this, in regards to argillite. And actually, these repository relevant processes, they actually apply to crystalline, and in some cases, salt in well. And then, I'm going to be talking about some highlights of disposal R&D in argillite. And then, I will end up with a summary.

So, the argillite repository concept, it's something that has been considered by other countries. This is just an example from Switzerland, France, and Belgium. I should also emphasize -- and Japan also has considered argillite as a host rock.

And for example, here on the left, actually we have the high-level radioactive waste disposal, or what's called the French concept here, which you have intermediate level waste disposal. And also, you can see panels here for high level waste disposal in the underground facilities. For the Opalinus Clay, this is a Swiss repository concept. Basically, we have the -- similarly, we have the intermediate level waste, and also, high level waste disposal facilities. And then, we also have -- this is actually the Belgian repository concept, which is the -- actually Hades in this -- into the Boom Clay formation, Belgium.

So, one of the -- what are the argillite host rock characteristics? I mean -- and Kris and -- talked about salt, et cetera, and similarly Yifeng talked about also some of the characteristics, and then -- in crystalline rock. Well, argillite -- well, one of the main important characteristics is the low permeability. And this is something pretty well-known and actually pretty well-recognized in many argillaceous formations. With that, you also have low hydraulic gradients. You have low diffusion, or basically low effective diffusivities. Argillite, being -- mainly, a clay rock, I mean, has a good sorption capacity. They are widespread in terms of their geological occurrence. I mean, it can be found almost -- I would say not everywhere, but actually, they exist, I mean, in whenever you have in kind of the sedimentary sequence. They exist in the appropriate thickness, at depth, and actually appropriate host for nuclear waste disposal concepts. They are found in -- for example, basinal environments, which means they can be found in stable geologic settings. And also, they have self-sealing properties.

The bulk mineralogy of argillaceous rocks is mainly made illitic clay. But, also can have a large quartz component. Then you can have minor -- or --or minor components, for example, kaolinite, chlorite, some carbonate, minor feldspar, and also pyrite. In terms of, let's say, you know, categorizing the argillaceous rocks, I mean, in terms of their sealing properties, Ian Bourg in 2015 actually, they were studying, for example, what will be the sealing properties of, for example, cap rock, in carbon sequestration. And one of the things that Ian actually observed was that basically, if you actually look at the unconfined strength of many argillaceous rocks, and then, you map that to their clay content, you have, basically, you know, this commonality, which is a one-third clay fraction. And actually, this is a turning diagram, basically separating the argillite, you know, components in there. And actually, what he's telling you is that if you have a higher than a one-third of a clay fraction, you end up having a sealing of argillite material. So, Ian is -- Ian Bourg uses this for many of the -- or several of argillaceous formations in the US, and also, those that actually are marked as radioactive waste storage actually that those are from existing underground research laboratories in argillite in -- in Europe.

So, in terms of how that actually matches some of the argillites in the -- in the US, for whatever -- you know, from the data that actually we can get, in terms of mineral fractions, we can actually have the eastern -- interior Paelozoic shales plotting here -- I mean, again, close to these, actually one-third fraction. Here we have the Boom Clay. We have the Opalinus Clay. These are actually from Europe and, of course, the COx argillite in France. But also, we'll have the Pierre here, which is actually a pretty extensive clay shale formation in the Midwest. And actually, it's also considered what they call a soft clay, and just because of the high clay component into it. But this is actually, in my opinion, an interesting way of looking at the characterization of argillaceous rocks, particularly when we are just considering deep geological disposal.

So, a little bit -- we'll talk here about the porewater chemistry, getting porewater out of the argillite formation, just because of the low permeability, and it's -- it's very, very difficult. But in many cases, you will always get produce -- production water, something -- especially in hydrocarbon extraction operations. And some of those shale porewaters have been collected and analyzed. The main take-home message in here, you know, versus here, a Piper diagram, actually showing the distribution of all the chemistry of these Paleozoic shales. And this is actually for US Paleozoic shales. I mean, they actually tend to overlap in terms of the bulk cation and anion concentrations.

On the diagram on the right actually, it's essentially the chloride concentration. It's a function of that. And the take-home message in here is, like, the variability that exists in this porewater chemistry is huge. And I also emphasized that shale formations are not very homogeneous. I mean, they are heterogeneous. It can be intercorrelation with sandstones, et cetera or, you know, limestone formation. So, there could be a lot of water mixing in here. But overall, the chloride concentration tends to be, you know, from -- ranging from like average seawater to a -- up to three molal. I mean, particularly at the depths of interest in the repository, in most disposal concepts, particularly for nuclear waste repositories.

Here, for example, I'm showing just the argillite post-closure safety strategy. And as with others, I mean, containment, it's going to be again a waste package isolated by depth. And it's going to be a repository, will be in between 400, 500 meters below the surface. It is going to be surrounded by a buffered/backfill material, say, bentonite. It's going to be a diffusion-dominated environment. Conditions, at this depth -- I mean, tends to be reducing. And our consideration is that the overpack integrity goes from a hundred years to higher than ten thousand years. And some of the other packing materials that have been considered are stainless steel, and -- but there are actually been other disposal concepts, some of them, for example, in Europe that consider actually carbon steel. Limited release, fuel degradation and corrosion is slow in reducing environment. I mean, that's actually a good attribute, deep geological environments particularly, in areas in which you don't have much of a fluid flow. The -- there is again highly retardation factors in the host rock, and again, low permeability, low effective diffusivity, and, of course, a high sorption capacity.

And here in the -- in the right actually showing just a generic stratigraphic column for the argillite reference case, I'm going to be showing you a couple of slides later, some of the results of this. And this is mainly based on the deterministic model, but actually, the whole point here is that here, we have the repository depth, and this is the host rock. Again, we also want to capture some of the heterogeneities that might be present in such a geologic sequence, in such a geological setting, in where you can have permeable -- or more permeable units below and above the repository.

In terms of waste form and engineered barrier in argillite, I'm just going to mention the cases in -- for, at least, the type of waste that have been considered in the development of the argillite reference case. For example, glass high-level waste. This is actually vitrified glass log in waste package. In all this context, we are considering horizontal emplacement in boreholes, and again surrounded by a bentonite backfill. Spent nuclear fuel. And then, this is like, for example, we have considered a 4-PWR waste package. And when I mention about, let's say, 4-PWR or 12-PWR, or 21-PWR, it's basically the nuclear fuel capacity. And the higher the number, the higher the thermal load. And again, horizontal emplacement in boreholes, and then, we consider -- we have to consider with or without actually a bentonite buffer present. And this is actually for studying the thermal management considerations, in terms of the repository layout, according to a particular thermal load. The same we have done for 12-PWR and actually, waste package in-drift axial emplacement, similar to what I just mentioned before, and again, with and without bentonite buffer. And then, we go into higher capacity. So, just for example, 21 to 37-PWR, those are actually into the DPC, or at least touching with the DPC type of capacity. And similarly, in the study of, you know, looking at in-drift axial emplacement, waste package separation, drift spacing, et cetera, and mainly to actually study the thermal management considerations, when actually we are talking about high thermal loads.

And here on the -- on the -- here on the right actually is, just shows, some of the configuration that also have been considered. For example, the canister laying on top of a, either crushed rock or cementitious ground support. But also, we also consider more a concentric type of geometry, which we have the same, you know, a canister -- just kind of lining up in the center of the drift, mounted in a pedestal of bentonite blocks.

Here, this is an example of the argillite reference case simulation that has been done in terms of the GDSA work for this host rock as, you know.

Here on the left, actually we had generic stratigraphic column for the argillite reference case. And, again, you know, all the considerations that I just previously mentioned with all the stratigraphic, and really, you know, stratigraphic consideration of the permeability of each formation, et cetera.

And this is just a quick example of the 24-PWR case. We have, for example, you know, the near-field model domain, the waste package in here. We have a space here in between. And then, here, this is time evolution of the thermal of -- you know, from the canister. And actually, sorry, that the print for the marks scale here is going to be pretty small. I think the -- more this becomes red, I think that the peak temperature is actually 280 degrees C. But basically, just to show that we are actually doing this kind of work in terms of the, you know, simulation of this particular concept in the safety assessment.

Here is actually a 2019 Roadmap Update in terms of high impact topic groups with high and medium high-priority R&D Activities. So -- and just basically want to show here is that the red arrows are pointed to some of the high impact R&D topics that the argillite work package is working on. For example, high temperature impacts, something that actually we are emphasizing right now, but also looking at buffer and seal studies. You know, or international collaboration, we look at gas flow in the engineered barrier system. Waste package degradation, I think you find the crystalline work package thoughts about this. We also look a little bit into in-package chemistry in crosscutting with the engineered barrier systems. Again, generic PA Models, something that I already showed previously. And, of course, THC processes the EBS, something that I'm going to be showing you in the next slides.

In terms of the Roadmap Update, and looking at the high-priority R&D Activities, again the arrows actually show those high-priority R&D Activities in which the argillite work packages is working on. And these are actually, for example, evaluation of ordinary Portland cement, design of improved backfill and seal materials. Again, you know, interaction with cementitious materials and absorber degradation, et cetera. So -- but also, we are actually crosscutting with some international activities. For example, experiments in bentonite EBS, and the high temperatures, HotBENT, which was mentioned before. And I think -- and Matteo from Sandia and Zheng Liange from Lawrence Berkeley are going to be talking in more detail about it tomorrow. The Mont Terri fault slip experiment. Again, Mont Terri is another underground research lab in which it's an -- the host rock is actually, Opalinus Clay, an argillaceous type of rock. And then, looking at also the gas flow in bentonite. And these are experiments conducted as part of the DECOVALEX international collaboration work.

This -- I'm going to be going quickly through this, basically looking at a high priority activities, and I just want to give an examples of what, you know, the argillite R&D work package actually is doing in terms of disposal research. For example, an evaluation of Ordinary Portland cements, cement plug/liner degradation, those activities that I mentioned before, and actually the purpose of this is to evaluate the mineralogical alteration evolution in seals and liners. It crosscuts with the crystalline work package and EBS. And the way we're tackling this is to look at an experimentally verified cement-geomaterial 3D reactive transport developed in PFLOTRAN. That is thermal-hydrological and chemical coupling, using this simulation code. But also, we use experimental studies of barrier material interactions. For example, cement-bentonite-metal, and I'm going to be showing those later.

The international ties is actually DECOVALEX 2019 Task C. And, for example, the EBS Task Force, which is actually the -- looking at all these interactions as well.

Another important aspect of the high priority argillite activities is EBS high temperature geochemistry/mineralogy, and also buffer material by design, evaluation of mineralogical alteration at buffer/waste package interface. I mean, this is actually key, because basically a lot of thermodynamics and the activity will -- let's put it this way, a lot of things happen at the interface. And again, crosscuts with other work packages, and again actually is conducting experiments, and under certain conditions do actually address this. And one of the future activities in international that is going to be tied into it is going to be a HotBENT.

And again, you know, these are actually mostly international activities. For example, evaluation of transport effect, evaluation in seals and bentonite backfill, and one of the -- for example, a lot of the stuff

-- a lot of the -- actually, our lead work, most of these is done in Lawrence Berkeley National Labs, along with multiphase flow and bentonite studies at various scales.

Another activity that actually I'm going to be showing some aspect of it is the experiments on bentonite under high temperatures. And just because, you know, not only the consideration of DPCs, or dual-purpose canisters disposal, I mean, the -- you're expected to have a much higher thermal loads. We need to understand the feedbacks from thermal into the bentonite barrier surrounding the canister. So, we have done -- I'm going to be showing some of that information later, but basically the purpose is to evaluate barrier alteration, transport, and chemical effects in backfill and canister materials. So, we also look at in-package chemistry as well. Again, crosscutting with crystalline, we actually look at benchtop high temperature column experiments, and also laboratory experiments.

And in terms of in-package material interaction, modeling experiments, Yifeng talked about a lot of the electrochemical method that Argonne National Lab has been conducting as part of that, Sandia have been conducting first principle simulations of corrosion products of UO_2, or in mimicking the spike in metal corrosion products, for example, and schoepite and metastudtite which are actually uranium hydroxide phases. And we have been conducting a lot of simulations in those with the purpose of retrieving thermal high properties at higher temperatures. There is no international tie to this, but in terms of the high temperature experiments, we have the HotBENT column test and the EBS test for experiments.

And here, just to show quickly a schematic. For example, the chronology of a repository evolution, and actually how that ties to some of the process models. For example, here is just a red curve showing the thermal period, which is basically you start at environmental conditions, and then, the temperature goes up to peak, depending on the PWR capacity that you -- that is considered. In this case is actually for 12-PWR heat load, that actually gets a canister surface temperature of about a hundred and sixty degrees C. And then, after a peak, there is a period in which it goes down. I mean, it starts actually going back to ambient. But during the thermal period, there is actually a lot of disequilibrium, in terms of thermal hydrologic mechanical and chemical processes.

And one of the key challenges in here is the modeling of these particular non-isothermal process, and actually that copies on the feedback. So that's actually a very active part in terms of all the research that we're doing. And these are actually the collaboration partners. I mean, a lot of acronyms here. Sorry for that. There's a little legend in here actually tells you what do they mean. But basically the point in here to show is like we have international activities that actually cover a lot of these processes, I mean, from, you know, environmental conditions and the repository towards thermal period, and so on.

So, I'm going to just jump into some of the highlights in here for the disposal in argillite R&D. And most of this is going to be giving you an idea of the high temperature experiments that we have been conducting, and studied bentonite interactions with barrier materials and host rock. Particularly today, I'm going to show Opalinus Clay. The reason for that is basically we don't know much about what happens, and depending on the host rock composition, and that will determine, of course, the resulting mineral assemblage for those interactions, especially at high temperatures. Development of preliminary

GDSA reference case, actually, I already mentioned that, so I'm not going to go over in the following slides. Advances in THMC modeling approaches, a lot of this, its work has been conducted, Lawrence Berkeley Labs, and also at Sandia. Thermodynamic modeling of bentonite-barrier material interactions. And I'm going to be showing just one example of how actually we're doing this.

Oops. For some reason, my slides flipped back, and I don't know why.

Also, I'm going to talk about non-isothermal 1D-3D thermo-hydrological-chemical reactive transport modeling. This is actually, again, a challenging aspect of the modeling because, you know, capturing all the feedbacks, I mean, especially when, you know, you have a heated canister and basically having all the chemical reactions, yeah, feedback and -- plus, all the changes that might've occurred to the rock, et cetera.

So I'm going to be showing you a little bit of that, and also I'm going to be showing some of the results of reactive transport modeling done for cement, material interaction, which is actually part of an international collaboration that just ended, which is DECOVALEX19. And

I'm not going to be saying about DECOVALEX2023 gas transport in clays, and other TH modeling, et cetera, because it just basically started.

Here, these are past experiments, and I think I have shown this slide in the past at NWTRB meetings. And basically just to show surface of stainless steel 304, and this is an experiment conducted at 300 degrees C, using -- and the solution is actually a STRIPA brine and using Wyoming bentonite, and essentially the mat of iron-saponite corrosion products that occurs actually at the interface of the stainless steel surface.

So basically, we have the stainless steel here. We have the iron-saponite growth actually in the corroding surfaces. And then, over here in this grayish area, it is all actually Wyoming bentonite, which still, not pristine. There's some level of recrystallization, but it's still stable, even at those high temperatures. And actually another thing to consider here is the occurrence of sulfides, you have pentlandite and millerite. And the sulfur source for this is actually the pyrite degradation from the mined bentonite, and some of the sulfur actually in the -- in the -- sorry, reacting solution. And then, we actually can do a thermodynamic modeling.

Gosh, I mean, I don't understand this. My apologies. I don't know why this is going on.

So, essentially here doing a Pourbaix diagram, and this is basically to correlate what we observed experimentally. Using thermodynamic modeling of those temperatures, and essentially looking at the inner oxides and the outer oxide occurrence, which actually matches what we observed in the experiment. So, this is a good mapping tool, you can say, in terms of understanding what's going on at the interfaces of these barrier materials.

Another thing that we're looking at is for example Opalinus Clay with Wyoming bentonite. And we're also doing hydrothermal experiments, 300 degrees C, and we can actually extend those up to six months. And essentially, we have actually zeolite formation in clay on cracks, and this is basically doing a lot of -- this is actually doing a lot of XRD -- Quantitative XRD in the run products.

And one thing about this is here on the right, we can see the rock, the Opalinus Clay with cracks, et cetera. And one thing that is typical, you know, on the Opalinus

Clay is that the formation of analcime right at the cracks, but we don't see much analcime actually within the rock. When you go temperatures below 200 degrees C, basically 200 degrees C, we don't see any zeolites or any feldspars, but in both cases actually, the weight percent of clay increases.

And then, we actually go to more extreme conditions in which we actually react the Opalinus Clay with Wyoming bentonite and Portland cement. And for example, the formation of calcium-silicate-hydrate materials, and for example, tobermorite, et cetera, which is typical cement phase. And in this case here, we can see the Opalinus Clay. We also see here the smectite, but we also see the occurrence of zeolites, analcime, also the occurrence of garronite, which is a calcium-silicate that occurs -- has been observed in hydrothermal wells, and also -- yeah, I see that. I think that's actually it. And one thing that we see, of course, is the clay degradation. We just want to see some reductions in the clay swelling, but also formation of most material. And just want to reiterate that these are conditions that are fairly alkaline, in which the silicate minerals is going to be dissolving. And let's see, I think that's going to be everything in the slide.

So, again, this is actually models developed at Berkeley, and in terms of looking at THM processes in clay formations. For example, the -- this is actually Mont Terri experimenting on Opalinus Clay, and this is the code TOUGH-FLAC 3D, something that Kris mentioned before. These are usually in salt, but also is used in actually, you know, argillaceous rocks. And essentially just to do the modeling of the thermal conditions, and, for example, close to the tunnel wall, and some distance from the heater, et cetera. And you can see that the modeling and, of course, I mean, there has -- there's some calibration exercise involved here, but going from a heater surface to the tunnel walls, the model actually represents the data fairly well.

This is actually non-isothermal 1D-3D thermo-hydrological and chemical reactive transport modeling that I've been conducting for a single waste package. And essentially, the -- one of the emphases in here is actually on the chemistry, and making sure that actually we're having reasonable results in terms of the chemistry. For example, here, even within this thermal loads, a differing distance from the -- from the canister center, or the waste package center, temperatures are actually close to a hundred and sixty degrees, but also we can actually -- those same conditions, we can actually predict the pore solution pH as part of the model. And also another challenge in here, even at full saturation, I mean, it's basically having, you know, overcoming convergence issues, et cetera, something that actually working, you know, do at this point. Of course, more work is needed, but we can actually represent very well chemical reaction, you know, the solution precipitation, changes in bulk mineralogy, and the evolution of changes in porosity and permeability. But again, we need to actually go and see how we can evaluate these scenarios with higher thermal loads. And, of course, also evaluate mesh resolution effects.

Here, FEBEX-DP was an international activity that also already ended, but I just want to actually just talk about some of the recent work that we have been doing in terms of thermal analysis and testing of bentonite. In this case, it's a FEBEX bentonite, so we have been conducting thermogravimetric analysis and differential scanning calorimetry on the controlled relative humidity and temperature. And as we all know, one of the attributes of the bentonite and montmorillonite is actually, swelling. I mean, an expansion, but to actually take a good sealing performance. So, swelling depends in the amount of moisture that is actually encountered with the montmorillonite. So here we have the two layer, you know, montmorillonites. I mean, there is silicates, we have the typical POT layers. And in between -- sandwiched between them, there are two exchange cations, for example. And basically, the hydration of those cations as water comes in, and the clay started taking water, basically start expanding. So, the distance between these two layers expand, expand until it reaches a maximum. So, there is swelling in this direction.

But if you drop the humidity or you dry out your environment, it's going to be shrinkage in the opposite direction. So, the FEBEX experiment is we focus on Heater 2, because number one, it was probably the longest -- the long last -- the longest lasting heater test to my knowledge. I mean, it was 18 plus year of continuous heating. Peak temperatures were a hundred degrees C, and the dismantling phase, basically, what they did is just dismantle the heater, excavated through the tunnel, and excavate different sections of the heater, just some little slices.

So basically, I'm going to show you then -- the study that I'm going to be showing you here is from Section 49, which is actually close to the center of the Heater #2. And this is kind of a mouthful here for a figure, but this is a thermogram. Just -- I just want you to focus on the TGA, or thermogram image part, which is basically telling you what happens to the sample in terms of its weight. All this were conducted at constant temperature of 60 degrees C and an RH of about 50%, so it's not fully saturated. And these are going to be the conditions, the event that I will be experiencing on a real repository. So, here, we dehydrate the Bentonite, and then, here, at this point, we actually start flooding the chamber with RH of about 50%. So, the sample start off taking water, start gaining weight, as you can see, by the green line. The blue line is the differential scanning calorimetry. Water absorption is an exothermic process, so it's a downward pit. And then, the sample equilibrates with this RH up to some point, and then, we purge the moisture by flooding the sample with the things, nitrogen gas. And then, when the sample dries up, it loses weight, and there's an endothermic peak here, upward. And then, we have this little shoulder in here, and then, it goes down to a baseline here.

There is a blowup of this particular process in here. Again, hydration, we keep it here at the RH of about 50%, and then, we dehydrate, and then, we have this little shoulder in here. And you can see that this shoulder appears every time we do this in cycles. And that is the advantage of this technique. We can do this in cycles, and see how the sample behaves. But this shoulder tells you that, number one, you know, it's -- it is asymmetric to the whole process, and this actually tells you about the hysteretic behavior of bentonite, which is actually -- it's well known, it has been observed before. But at least this process gives us not only a testing of the material, but also, it tells about the energetics of hydration, dehydration, particularly when you have hysteresis. So we're going to actually do this type of methodology again in bentonite with other materials, et cetera, we are actually going to do experiments at high temperatures, at a hundred C, we're thinking about hundred twenty-five, hundred fifty degrees C, and see how it goes. But it's actually a pretty neat technique to understand in this particular behavior in bentonite.

Here, we have the DECOVALEX19, this is the GREET experiment, Mizunami underground research lab, and this is called a closure test drift. And basically, what they did is, like, in this particular tunnel at 500 meters below the surface, they actually flooded part of the tunnel and, well, firstly sealed the tunnel, and then, they flood it with groundwater. And the flooding experiments, it's actually has a lot of boreholes, I mean, and these boreholes actually are a lot of sensors, and also water collection -- for water collection and sensor operations. So, basically, in the way we modeled this, we have the tunnel here. This is the filled CTD with water, and then, the red line here is the shotcrete layer, a liner around the tunnel.

So, we develop a reactive transport code for this, and so, a reactive transport model for this using PFLOTRAN, and essentially, this was all isothermal. And we basically actually sample observation points from the code -- code predications, and compared to what was measured in the field. As you can see, this is, for example, near to the shotcrete wall, and this is actually pH predictions with time, as you actually move away from that structured wall. As you can see, the predictions are actually -- the trends conform very well with the data, and the same goes for the sodium concentration with time. So, there is -- it is actually very good to study, for example, length scale effects, shotcrete thickness, et cetera, and in terms of these experiments. So, these international activities offer a unique opportunity to do this.

And this is my summary. So again, developing a high temperature argillite reference case. I mean, and this is, of course, it's needed for, you know, study disposal concept for dual-purpose canisters, and, of course, in any other heat-generating thermo -- concept -- or sorry, heat-generating waste. And this is actually needed for studying on EBS design options, and that is, for example, thickness, you know, what type of EBS requirements, or not requirements, but, what would be the optimal condition for the EBS in terms of thermal management, et cetera, canister spacing, drift spacing, etc. And this is, of course, part of this post closure strategies. Again, bentonite metal cement, Opalinus Clay interactions and basically, at high temperatures, invariably this actually produce zeolites, and degradation of the clay. And in some cases, you can see some swelling reduction in smectite, so those things has to actually -- had to be very well studied. If I mention, for example, saponite, which is a type of smectite, and more stable in the alkaline solution, so we are actually crosscutting with them though in this particular work. So, also, basically study the effects of host rock composition or materials that actually is being currently done experimentally. And, of course, expand the work that we have been doing in terms of modeling non-isothermal heating, in terms of thermal, hydrological, and chemical aspect of the simulation, and understand, you know, the -- basically the coupling of those process at high temperatures. DECOVALEX, you know, hydrological, chemical, the green modeling that I just showed you is actually a good success story, in terms of modeling shotcrete interactions in the CDT experiment. Cyclic thermal analysis to better understanding bentonite behavior under various conditions, we -- basically, we can do this in different -- differing RHs, that's going to be a prevalent or the predominant conditions on which the bentonite's going to be exposed. So, in terms of looking at potential face transformations or transitions, I mean, material, phase mineral transitions, I think this is actually a very good technique. And, of course, the official work is actually look into more into these hydro-chemical model sensitivities to, for example, shotcrete thickness, something that actually we discovered in doing this work for that CTD closure test -- modeling test. And also looking at extrapolation to high temperature effects, and, of course, we engage with international programs, you know, in DECOVALEX2023, HotBENT, and the EBS task force. These are actually very key to many of the activities that we are conducting right now.

And this is actually acknowledging, it's a team of people from three labs. I hope I captured everybody here, but again, this is of course a team effort.

And these are the reference for using this presentation. So, thank you very much, and I'm open to questions.

BAHR: Okay, thank you. Carlos, we have a few more minutes for questions. We're a little bit over time, but we don't have too many public comments, so I think we have enough time for some questions. I wanted to start with sort of going back to the disposal concepts themselves, and you showed pictures of the three different argillite disposal concepts that are being employed in Europe. The -- those differ significantly in -- in some of the construction and engineered barrier details because the argillites are quite different in France, and in Belgium, and in Switzerland. Are you -- in your reference case, are there -- are you doing all three of those reference cases? Or are you focusing on one set of assumptions about the argillite mechanical properties that may constrain that?

JOVÉ-COLÓN: I think it's going to be more so the latter. We are focusing on disposal concepts that -- yeah, we're not trying to -- we -- we look at the results of what the Europeans have done, but they usually -- I mean, the heater test and all that is actually to represent heat loads that are much lower than the ones that we're going to be considering. So for that matter, we are actually looking more into what we -- I mean, in terms of canister material, the bentonite, and also some of the properties in the argillite -- will be -- I mean --

BAHR: If you -- all of these, do you have a specific reference case at this point or you're -- you're working on developing your reference case work, for all of these?

JOVÉ-COLÓN: Yeah. We have actually a particular reference case for high temperature. The -- it's actually -- it's --it's --it's being published as a Sandia report recently. It's going to be a backfield -- typical backfill concept. I don't have --

BAHR: With (inaudible)

JOVÉ-COLÓN: Yeah. In terms of the difference, I mean, more specifically, you're talking about, for example, canister material, what kind of Bentonite material, and, for example, some of the rock properties, or --

BAHR: Right. And what kind of liners are you going to need, you know what the -- the drifts stay open by themselves, or do you have to put cement in them? Or, you know, the -- the Belgian concept is a very weak clay, and so, you have to do a lot of stabilization. Have you built those kinds of things into your reference at this point?

JOVÉ-COLÓN: Yeah. Well, not to the -- it's going to be more like a sealing clay. It's not going to be a Boom clay, as soft as that, it's going to be more like a typical argillite formation, I mean, something that you find typically here in the U.S., I mean -- and -- but for example, there is the Pierre -- you know, for example, we have here in the U.S., a Pierre shale, which is not quite equivalent to the Boom clay, but it it's a Soft clay, it's a ceiling clay. But we are actually -- mostly not too much into the mechanical aspects of the disposal concepts, more so into the hydrological characteristics of that shale that we are actually considering. In terms of liner, cement liners, right now, on the top of my head, I can get back to you, it's going to be more like an OPC cement. But most, this -- like, for example, European concept and many other concepts, is -- they are considering low pH cement, for example. Something that we probably might change in the future, as a -- as a consideration. And in terms of the bentonite, I mean, we basically are looking into, for example, bentonite without additives and bentonite with additives, for example, thermal management, thermal connectivity, et cetera. So we -- we have a whole array of these ideas, I mean, this is like -- almost like a matrix, I mean, in terms of consideration. But it's all driven by how much the thermal load is going to be within the concept. And we basically are limiting that at this point, not going about 200 degrees C, for example, at the canister surface.

BAHR: Okay. Well, I better get to questions from Board members. So, the first Board member who I see with a hand raised is Tissa.

ILLANGASEKARE: I have a general question. So, this is related to the modeling, but so heterogeneity is not -- never an issue because you are -- you know, any type of natural formation, I mean, your whole idea of this material is because it is very, very low permeability, all the good things. But in any scenario where you may have to deal with heterogeneity, for example, maybe some sort of other material getting in there, and then, suddenly, that becomes a high permeable pathway. Is it ever possible in this material?

JOVÉ-COLÓN: Well, again, lower permeability is an attribute of argillite or argillaceous formation. Now, it depends, for example, at the scale for -- of the whole repository concept, for example, we have formations that have low -- higher permeability, I mean -- and you're right, I mean, the shale -- the shale formations -- and actually, as I said before, they basically are not very homogeneous. I mean, their intercalations with more permeable formations. And we tried to capture that, you know, the deterministic model, but in a fairly simple way that it can actually see what could be the effects and the safety assessment. So, yeah, you have, for example, below the repository, you can have a formation with a higher permeability and higher flow, and the same actually goes on top. So -- but that's kind of a repository scale. I don't know if you are referring to, for example, the scale of the -- the scale of the near field, far field.

ILLANGASEKARE: Yeah. I was referring to more near field, because, like, I mean, your figures showed that you're looking at other formations. My question has to do with any possible scenarios in this natural formation that you may have heterogeneity issues, that's my question, in the near future.

JOVÉ-COLÓN: Yeah. And a lot of that heterogeneity, I mean, it could be, for example, the excavator disturb zone, I mean, you can have actually cracks in there. And in shale, it's something that actually has been, for example, in some of the underground research labs in Europe, have been studied, but one of the attributes of shale is actually the self-sealing. But the question is how long it's going to take. So that's a -- that's a -- there is a big question mark in there. The other thing is that some argillite formations have fracture fillings, and -- and things like that. I mean, for example Opalinus Clay could have actually fractured fillings, silicate minerals, for example. And that actually could be a distribution of those within the repository could be quite heterogeneous, where those actually has implication in terms of the mechanics and the, you know, and -- and also interactions in the near-field; far-field is still a question.

ILLANGASEKARE: Yeah. Second, briefly, so you -- in your -- in your -- in your action list, you had multiphase flow. Is that a scenario of multiphase flow? Is it possible because gas formation, and you may result in multiphase flow?

JOVÉ-COLÓN: When I say multiphase flow is mainly to capture the effects of partial saturation in the bentonite. And, of course, in the liner -- and of course, and also in the -- in the host rock. It's mostly in terms of the water movement or transfer. And that's actually the targets that we have right now in terms of the modeling. Yeah. I mean, but mainly to study the dynamics of partially saturation media, especially in the non-isothermal conditions and that is becoming a challenge, I have to admit.

ILLANGASEKARE: Okay. Thank you.

BAHR: Okay. Next we have Paul Turinsky.

TURINSKY: Yeah. I was wondering about bentonite, and that is aging. Did the -- did the properties continue to change over the long term?

JOVÉ-COLÓN: Good question. Well, the bentonites, number one -- like for example, the FEBEX bentonite if I'm not mistaken, the geological formations around there -- I mean, volcanic formations around there, are ten to eleven million years old. And we have done cyclical thermal studies on this bentonite, and in the course of that experiment, which, of course, is lab scale, I mean, it's very relatively short period of time, as you can see the -- when we actually do the same hydration intervals. That is the hydration in which we actually allow the Bentonite to hydrate and dehydrate, the -- we noticed that it is boring, I mean, it's the same. So, the Bentonite, in terms of aging, and basically hydrating and dehydrating back that mineral, or rock, in this case, seems to be no problem. We didn't see aging effects. However, we are doing these experiments at a temperature that is below a hundred degrees C.

TURINSKY: Yeah.

JOVÉ-COLÓN: We don't know if that will be -- that behavior will persist at temperatures of about a hundred degrees C, and that is our next step in those experiments.

TURINSKY: Yeah, that's what I was thinking of, specifically, was the chemical, just at 300 degrees.

JOVÉ-COLÓN: Yeah. And let me tell you, for example, in those experiments that I showed, the hydrothermal ones at 300 degrees C, there is dissolution, recrystallization of that swelling material in the bentonite. And they actually did, you know, some X-ray -- you know, X-ray diffraction studies before and after. And, yes, in some cases that causes swelling reduction, so there's probably some effect because of the interaction. But whether aging per se is going be, you know -- you know, aging of the interaction can actually do have an effect, yes, that could be possible. But again, that's why we're doing these experiments at high temperature to really understand what other changes in the material.

TURINSKY: Okay. Thank you.

BAHR: Next, we have Lee Peddicord -- Kenneth Peddicord for the conveners there?

PEDDICORD: Thank you. Interesting presentation. Appreciate it. I think you may have kind of answered my question in your discussion with Jean, and Tissa -- but let me ask it anyway. So, you reported on the models you developed around Opalinus Clay, you have an opportunity, I assume for good data coming out of Mont Terri to benchmark that against, and have confidence in your models. So, as you were discussing with Jean, of course, there's a lot of variations. So, do you have an opportunity to see how generic your models are by, say, going to Belgium in their HADES facility in the Boom clay, which you know it's quite different, and get an -- get an idea of the confidence in your models. And then, kind of a second question, both those facilities are relatively near surface. So, how much different would conditions look, if, say, 700 meters, and Nagra is getting -- is taking a lot of samples, borings in the Benken Marthalen region in, I guess, that's the Nordost site. So, do those help you understand what might be happening with your models at depth?

JOVÉ-COLÓN: Yeah. The first question, in terms of getting confidence, I mean, you have -- like, you're totally right. I mean, there are Boom clay. It's different from the argillite, and the COx formation, and also the Opalinus Clay. I mean -- and we can go at length in terms of what potential geologic processes that actually caused that. But, yes. I mean, we need to look at the properties of these. I mean, when you're actually implementing new models, but the models are generic, or sufficiently generic, to actually represent what we faithfully want to represent. Still a good question. And that's why when we, for example, I can talk more about the chemical aspect of it, and I mean, if we actually, for example, represent the clay behavior that correspond to that particular formation, I mean, because you can have illite, smectite, and all these clays swell differently, et cetera, and the composition et -- I think I have confidence that actually you can at least represent a key part of that behavior. We cannot represent -- there's so much more we can do with the models. But, yes, I mean, those are things that actually is going to be site-dependent, formation-dependent. And, yes, they have to be taken in consideration in the models, be -- to enhance confidence.

That -- and the second part of your question, where, you know, I have an argillite depth, I mean, it's going to be the same as those URLs I mean, in terms of behavior, et cetera. Some of these formations, actually, even if you sample at a shallower surface, I mean, their extension to depth is going to be pretty much the same. I mean, I'm talking -- I'm here as a geologist that you, of course, expect conditions, I mean, you know, the lithostatic, the hydrostatic conditions, I mean, at depth are going to be different than in shallower. But those are actually taken in as part of the mechanical model. I mean -- and then, those are actually taken in consideration when you actually model for example pore fluid pressures, et cetera. Now, in terms of the chemistry or composition of that particular, you know, rock formation that, you know, very shallow, or -- or you kind of extend that to other depths, I mean, that's basically that we geology or chemistry rely on. And I don't think there's going to be a significant difference.

PEDDICORD: Okay. Thank you.

BAHR: Okay. I see Chandrika from our staff has a question. If you can ask us quickly, Chandrika, that -- because then, we do need to go to the public comments.

MANEPALLY: Sure. Thank you, Jean. Thank you, Carlos, for the nice presentation. Quick question I had was, you are focusing most of your high temperature work on Bentonite that is basically the buffer and its interaction on the host rock. I was just curious, what is going on in the host rock itself. I'm -- in particular, I was looking at a paper by Jonny Rutqvist where he did some modeling, and they found that whatever properties that he assumed for his model, there was some really high pressures developed in the host rock, which would cause some failure. So, I was curious if that's an area for your future studies.

JOVÉ-COLÓN: Yeah. Going back to the previous question. Yeah, there could be, for example, heterogeneities in the argillite. I mean, like people for example -- I'm going to cite, or quote Chris Neuzil, which has studied shale formations for a long time. And there, for example, overpressure zones, and actually there's the opposite. There is zones that actually instead of the pressure go outwards, go inwards, so it's like there's some sort of saturation, so there's this level or this type of heterogeneities existing. Although, it's -- although it exists, whether that is going to be a -- I mean, I don't want to call it something to really dwell on, and because it is actually, I'm going to say it is rare. It happens, but I don't think we know much of it, although that it exists. But according to Chris Neuzil, it's something that it's -- first of all, it doesn't -- it's not at a scale that actually will impact the operations in our -- or, let's say, the operational level of the repository in terms of isolation. Those pressure zones actually don't translate into really long distances. So, the other aspect is for example Jonny Rutqvist talks about layering, for example. And layering can have an effect in the thermal conductivity in the host rock. And those actually or -- are things that has to be also taken into account. For example, the thermal connectivity on across the layer could be higher than the surrounding matrix. So those are things that, yes, heterogeneities. I mean, that definitely you have to take it into account.

BAHR: Okay. Thanks, Chandrika. So, now, we need to thank Carlos. And I'll turn it over to Bret Leslie, who is going to read the questions that we have from the other attendees.

PUBLIC COMMENTS

LESLIE: Okay, Jean. Thank you for that. There are a total of four comments that were made during the meeting, and I'll go through them now. And I'll provide some context. As we stated in the press release, we would read them in the order that they were received, and so, that's exactly what I'm going to do.

During Tim Gunter's presentation, our first comment is from Donna Gilmore from sanonofresafety.org, and her comment was, "Is it true the molten-salt radioactive waste doesn't even have a solution for interim storage (e.g., the Oak Ridge Molten-Salt Reactor) due to salt corrosion issues? How or where is this being addressed for disposal?"

Next in the meeting, during David Sassani's presentation, we got an -- another comment, and here it is. The comment was from Carlyn Greene from UxC, "DOE has been doing generic research from years now. Is there a date by which one or more 'preferred sites' might be identified for further site characterization like other countries have done?"

Then, the final two comments occurred during Yifeng Wang's presentation, and they're both by Donna Gilmore. So the first comment during that period of the meeting was, Donna Gilmore from sanonofresafety.org, "What is the technical basis for this statement”, and the statement is in quotes “'canister integrity is maintained for a significant portion of the regulatory time period?' Existing canisters are already at risk of and may already be cracking. Sandia Lab, December 2019, Technology Gap Report has made this priority number one problem that has not been resolved for dry storage."

Donna's second comment during that period also from sanonofresafety.org, "A number of these proposals seem to be assuming the fuel waste does not need to be retrievable from the container. Is ability to retrieve the fuel (in case things don't work as planned) being made a requirement or even a consideration? Who is the decider of this issue -- on this issue?"

And, Jean, that is the last of the comments that were submitted during the meeting.

BAHR: Okay. Thanks, Bret. Thanks to everyone who made presentations. Thanks to everyone for your attention. Everyone who's both participants in the meeting, direct participants in the meeting, and people who are watching online. And this -- and to those of you who might be watching this at a future date, because we're going to recording it and it will be posted on our website. So, we're going to reconvene on tomorrow at noon Eastern Time again.

And we have an exciting program. It will start with a couple of international speakers to give us some perspective on research strategies in other countries, and then, some additional presentations from national laboratory researchers who are working on more cross-cutting aspects of this -- of the disposal program. So, thank you again, and we'll see you tomorrow.

(Whereupon, the meeting concluded.)