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Nuclear Waste Technical Review Board (NWTRB)

Transcript

Fall 2020 Board Meeting

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VIRTUAL PUBLIC MEETING - DAY TWO

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BAHR: Okay. Well, I think that I'm live. Yes. Okay.

Good morning everyone and welcome back to the U.S. Nuclear Waste Technical Review Board Fall Meeting. I'm Jean Bahr, chair of the Board. And yesterday I described the Board's mission and introduced the other Board members. So, to save time, today I'll just direct you to our website www.nwtrb.gov, where you can find information on our mission, our members, our Board correspondence, reports, testimony, and meeting materials, including webcasts of our public meetings.

So, this slide shows yesterday's agenda. Tim Gunter of the DOE Office of Nuclear Energy described DOE's disposal research and development program. And this was followed by presentations on DOE's technical approach and prioritization of its research and development activities and on its crystalline host rock, salt host rock, and argillite host rock disposal concept activities. Today, we'll have additional presentations on ongoing DOE research and development activities. But first, we'll begin with a session highlighting two European disposal research strategies. And we're especially pleased that Lucy Bailey from the United Kingdom and Irina Gaus from Switzerland are able to join us today.

Following their presentations and discussion with them, question and answer, the meeting will focus on DOE's prioritization of cross-cutting research activities. The first presentation on cross-cutting activities will focus on an unsaturated alluvium reference case, dual disposal of canisters, and -- or disposal of dual-purpose canisters, and DOE's geologic disposal safety assessment efforts. Then there will be a presentation including two presentations on engineered barrier systems.

The first speaker will provide an overview of DOE's research and development activities related to engineered barrier systems. And the second speaker will update us on the HotBENT experimental project.

The final session will foke on -- focus on prioritization of international activities and DOE's disposal research, R&D five-year plan.

We'll -- we'll take a 30-minute break starting at 2:05 p.m. Eastern Time and we will have a public comment period at the end of the day. As a reminder, we can only accommodate written comments because of the virtual format of this meeting. When you joined the meeting today, on the right of the screen is a comment for the record section where you can submit your comment. If you're viewing the presentation in full screen mode, you can access the comment for the record section by pressing your escape key. Comments we receive before the end of today's break period will be read online by Board staff member Bret Leslie in the order that they were received. Time for each comment maybe limited depending on the number of comments we receive, but the entirety of submitted comments, whether they're read during the meeting or not, will be included as part of the meeting record. And the meeting will end at approximately 5:00 p.m. Eastern time.

So, without further ado, let's start with today's first presentation by Irina Gaus. So, we need to switch Irina and her slides. And I will go away.

GAUS: Okay. So first, thanks a lot for inviting me to participate in this virtual meeting. My name is Irina Gaus. I'm head of Research and Development at Nagra, which is the Swiss implementer for disposal of radioactive waste.

For this presentation, I'm actually talking -- taking on another head as I'm carrying the IGD-TP which is the Implementing Geological Disposal of radioactive waste Technology Platform and bring the feedback from the platform regarding the topic at hand for this hearing -- in -- in this presentation.

My presentation has two parts, the first part focuses on a bit what is the IGD-TP, where do we stand for, or who do we cover. The second part then focuses on the feedback from the IGD-TP to the topic basically being the priorities for early stage waste management programs.

So, the IGD-TP, it's dedicated to initiating and carrying out European strategic initiatives to -- for the -- to facilitate the stepwise development and implementation of disposal projects, spent fuel, high-level waste, but also other long-lived radioactive waste. It was grant -- launched in 2009 by the European Commission and several waste management organizations in Europe. After a while, the European Commission thought that we should make it on our own and now it's solely funded by 12 waste management organizations in Europe who form the executive group.

We welcome membership of all interested parties who endorse our vision as IGD -- IGD-TP and are willing to positively and constructively contribute to our goals. Currently, we have a hundred and forty-two members across twenty-nine countries.

So, what do we stand for? When it was granted in 2009, our vision was to have the first geological disposal facilities for spent fuel, high-level waste and other long-lived radioactive waste in operation by 2025. This was called towards our Vision 2025.

Now, as quite a long time has passed since 2009 and we're actually approaching this vision. POSIVA in Finland has a -- a construction license in their hands and plan to submit their operational license in 20 -- I supposed it's going to be in '21. So, they will have an operating facility before 2025. SKB in Sweden has submitted its construction license in 2011 and hopes to make good progress in obtaining this next year in '21. ANDRA, the French waste implementing organization, will submit its construction license also next year and are working very hard to get the documents together.

So, as we are closing -- moving closer towards reaching this Vision '25, last year we updated our vision and to be -- have another level of ambition and set our target for 2040. We enhanced our vision towards in the -- stating that we are going towards industrialization of radioactive waste disposal in Europe which has three pillars. On one hand, to safely operate these disposal facilities that are already working, Finland, Sweden, also France, maybe others.

Optimize and industrialize. We realized that one -- also when you have a construction license there's still RD&D need to do, optimization is a process which goes along the whole repository implementation program, but also tailored solutions because not every country has a huge inventory. And for very diverse waste and small inventories also, solutions need to be developed. So, we broadened our scope a bit.

So, what do we provide with the IGD-TP? It's a form for discussion of RD&D issues and priorities. It's a means of sharing information results, also experience, and a -- it's also a mechanism for coordinating RD&D on various topics where we see -- we see a shared interest. Therefore, we bring -- have different ways of doing that, it's a pooling of European resources. We try to secure finances for implementation, foster knowledge management, contribute to the availability and maintenance of critical masses or resources for RD&D, identify areas and strategic knowledge or knowhow that we -- that can be covered by specific actions, and create synergies with other international organizations and European initiatives. And I think the activity today is one of this.

As we have shared research interests, it's also good to try to bring these together in a document. We had a research agenda in 2009 when we started with the IGD-TP. And we could actually see which is a very good thing that we -- that we make progress and a -- and an important part of this research agenda was -- was materialized when we formulated our second vision. So, this year we went through the formulation of a second strategic research agenda, also taking into account the needs of smaller programs, and not only those of more advanced programs. So, it's -- we see that there is a sufficient and appropriate robust knowledge available for the construction of geological disposal facilities. However, it is partly important to maintain, enhance, and increase the knowledge throughout this incremental development. And this is what is written in the strategic research agenda where we agreed on the research priorities. It can be downloaded from our website, it's publicly available.

So, this agenda highlights these main topics. It supports the Vision 2040 and it will also serve for the next 10 to 15 years as input to identify topics for future EURATOM calls. EURATOM is the European program for -- scientific program for co-financing research in radioactive waste disposal in Europe. It comprises nine key topics and various cross-cutting activities. And as you could see in different generic stages of repository development, you have different types of RD&D activities in the different domains, whether this is technology, geology, or inventory.

So how do -- do we go forward now with our -- with strategic research agenda? The topics in there which are described there, what needs to -- the broad description, what needs to be done, what the gap is, are good candidates for future research efforts and funds. There is a shared interest to -- to -- to tackle these together. It's not -- definitely not an exhaustive list of RD&D topics. One has to acknowledge that almost 50% to 80% of the RD&D is very program-specific because it's specific to the safety case, which is specific to a certain geology, to a certain legal context. So, a big part of the RD&D is not shared but there are part can be shared, good opportunities to work together. And so, we will work based on this agenda to launch some of the topics in the next years either through EURATOM, European way of co-funding research, or through own initiatives.

So, this is how we go forward. We recognize that despite significant steps already made, sustained RD&D is needed to ensure that all the countries at various stages of advancement continue to progress towards implementation. It's -- the IGD-TP is focused on deep geological disposal but you cannot see this to isolate it. There are also aspects of pre-disposal which have an important impact finally on geological disposal, such as waste acceptance criteria, or waste conditioning. And there is also a need to cover a smaller inventories, which might need specific solutions which has borehole disposal. So, we cover -- we try to influence both the European landscape in which projects are being tackled. We also have our own initiatives.

So, looking forward, with the inclusivity of all WMOs and Europe, we have reached this to promote collaboration and knowledge transfer within the geological disposal community. As I said, we have a strong focus on Europe but despite that, it doesn't hinder other countries for instance, Canada, U.S., Japan to join the specific initiatives which we are undertaking. And this is already happening for certain initiatives. We think that that we are a key instrument in ensuring this continuity in research and development over this very long-time scales.

And we also assure that a geological disposal program or research for geological program -- disposal program needs a very strong implementer voice and collaborative action. And this is together with the research institutes and then also the regulators. So, you only need the implementer to state clearly what is needed to make progress in the implementation of the disposal program. And then the -- of course, the Vision 2040 and the SRA are intended to guide this focus for the next 10 to 15 years by highlighting the research areas that are of common interest.

So, this was a bit general introduction to what we do at the IGD-TP, how we plan to move forward also within the next decade.

And then as we got to the invitation from the Board to provide input to this -- to this topic, we want -- we came together and put together a short lessons learned on generic disposal RD&D programs and the transition to siting a repository. And therefore, we invited these countries in a -- well, also in the virtual call of course because there's nothing else at the moment. And we invited all the RD&D directors or people who are responsible for the RD&D at these specific implementers to have a short discussion and think about what is important in this early stage, or when you just enter site selection for an RD&D program.

And there is quite a bit of experience available of course. I mean, when you look at the countries, we could -- that are participating. We look at Spain, they're restarting site selection after almost 15 years of politically determined hold phase. The Netherlands has decided to stay in the generic stage and they plan to go for a longer term of intermediate storage. In Belgium, they have focused very strongly on the Boom Clay which is a clay host rock for the last decades. And now they are required by the regulator to -- to look at the whole map of Belgium which also includes then, other rocks. In Hungary, they focused initially on clay host rock, went through a whole kind of selection for different host rocks, Hungary-wide, but ended up with a clay host rock again. In Germany, after a very strong focus on salt, now they recently restarted a country-wide site selection process. And finally, U.K., after a step back and a long generic stage, they are now entering the site selection. And it's for the U.K. example we have the second presentation which is going to be given by Lucy Bailey, who will focus very much on this U.K. case. So, I will not too much talk about the -- about the U.K. but try to bring together the messages that we could get from these countries and to identify what -- what they really did, the -- the key points that have been learned for generic or early stage programs.

And these have been centralized along key messages and this was in the discussion very clear that this came on top. Whether it's not immediately -- you cannot influence it by doing RD&D solely, but it is a key factor for success.

So, it's the successful repository implementation, needs the legal framework with the roles of each part clearly described, we have examples of that in Switzerland, now also Germany. So, each role needs to be very clearly described in the process that of the implementer and of the regulator, and of the society. For the site selection, how to implement the repository program, it needs to be set out and accepted by all parties before actually starting it. Each party should be aware of the role it has to play and where it does not play can -- cannot influence or cannot contribute. It was very clear also that you need a very -- a long-term political commitment. And without these three points actually, it has proven extremely difficult if one of these three is missing, extremely difficult to develop and maintain, a needs driven and focused well-funded RD&D

program. It's really this framework that needs to be in place. And also, you might have budget and good research institutes but to get it focused and get on the rails you really need these three points to be in place. When you don't have these three points in place, what has happened, as I kind of gave the examples in the previous slides, is that your program gets on hold, you -- you -- you come into restart phase, you have to reorient and this puts, of course, challenges for the RD&D program and where to put the priorities in the RD&D program. And international collaboration is an instrument to bridge these difficult barriers where there might be a political impasse. But the loss of knowledge is -- is almost inevitable and this was shared by many people in this discussion we had.

What was also shared by many people is that while the RD&D is an important part of a repository program, it is probably not the most challenging part anymore. We have made a lot of progress in the last 30 to 40 years. So, the people who we discussed it with were convinced that the success, you know, of implementing a program is now in mastering the societal challenges and having the framework in place. Having said that, this doesn't mean that there is not RD&D, there is optimization will continue through the whole repository program implant -- implementation and will be a driver for RD&D activities.

The role of the implementer is to bring the focus to the RD&D in the generic stage based on generic safety cases, as there cannot be site-specific safety case. Focus is needed because when RD&D topics mature, they become bigger and bigger and going more and more detail. And at a certain point, the knowledge which is being added to a certain topic is no longer the best way to support the program. The program needs to be agile and able to change, kind of, addressing the various aspects of the safety case. And this is very important that the implant -- the role of the implementer is really to bring focus to the RD&D program.

Other lessons learned, what are the aspects of priority setting at an early stage? So, in RD&D program is generally revised after safety case. The results are assessed against program drivers and the new RD&D prioritization is defined. So, you will constantly work with the set of RD&D priorities based on safety cases and drivers, which are generally costs, safety, and also, kind of, how far you are in the program. In the early stages, the -- it's logical to focus on geology, waste conditioning, rather than late stage aspects such as technology development for example.

It's very important that when you start -- or in the -- in the generic stage, you avoid doing work that has been done elsewhere. It's -- it has proven very efficient for European programs if they could connect to topics, research topics that are being tackled by advanced programs who are actually in the stage where they start to construct the repository rather than doing -- repeating what -- what they have done in an early stage.

Some aspects can be tackled conclusively in an early stage, such as packaging strategies, the whole question of spent fuel integrity, which has become very much into focus in the last years.

Various countries were convinced that the main reason to have an RD&D program and this -- of one of the main reasons to have an RD&D program in this early generic stage is basically to ensure the competence. You need to have a technical competence within -- within the organization or within a wider group. And generally, within the implementer, you need to generalize competence. These are the people who have a wider overview of various topics who see the connections between the disciplines. The expert competence -- competence are generally with the supply chain.

What we also see 30 years ago, people didn't think a lot about costs. Now, this is becoming increasingly more important, where in the past, we had huge input and effort towards optimization for safety. Optimization for technical and economical reasons has become also a major -- a major driver for conducting RD&D.

What came out to the discussion is -- what's interesting to see is that one should not forget the role of social and economic RD&D developments. In various programs this might not be with the implementer, it can be with the government but it's really important to keep an eye on who is responsible for this process because there have been certain examples wherein in the absence of any work on that in the site selection has been felt as a shortcoming and then affected the success of the site selection process.

So, here we have an example -- a very recent example, the system from COVRA, the Dutch implementer who has reissued it's -- who is in the generic stage, they have a small inventory but the approach is generally applicable, who completed the generic safety case at one or two years ago and now have brought out their RD&D program. Based on that identifying drivers as confidence in long term safety, disposability, and costing, and then attribute it to the various topics according to the components. This is also available on the web, of course.

So, then we asked the -- in the discussion how important is international collaboration and why? And then the overwhelming feeling was that especially in the early stages, international collaboration with the programs in a more advanced stage is key. These -- these are all -- they are also the objectives of the IGD-TP. It's not only at the detailed technical level that collaboration is very important. It's also the strategic program level because some programs have made a good progress and there are reasons for that. And how they tackle certain issues, like, for example retrieval, like, also other aspects, safeguards and there are -- there are various, various aspects which are not purely scientific work but benefit from international collaboration to discuss how to tackle the issues, criticality is another one.

A lot of the topics we include in our safety cases are highly specialized, for example bentonite expertise. And people have -- or countries have two, three experts maybe in each this -- in each focused discipline, at least in Europe, maybe in the U.S. But it's all big -- bigger, you have more. But it's really needed that you bring together the experts from the different countries and as they are so specialized and they have such a deep knowledge, and need to be able to exchange at their level to stay at the top of science. Of course, I mean, international collaboration is also budget sharing, right? I think the HotBENT experiment in the GTS, where so many international groups came together to launch one of these large-scale one-to-one experiments, which are hardly ever been done at the moment, is a real achievement.

International collaboration has also increased confidence because you get international consensus, and this also brings stakeholder buy-in at home. If people see, well, this is now internationally accepted, it has a better chance of surviving at home as well. A good input came also from the German program, and they say when you give up the site selection there's such a strong reliance on the international development and reinforcement of the link with academia because you have to mobilize suddenly quite a big RD&D group to -- to get the focus to the site selection program.

So, what are the challenges of the program in an early stage? It's -- the challenge one of the major challenge is as the budget is always limited. It's finding the balance between keeping the focus in the RD&D program but still being broad enough to cover all the potential developments for the future.

Generational changes, I mean, we are in these long-term endeavours with disposal programs and especially when you have generational changes with stops in the program for five or ten years, this can lead to a loss of knowledge.

The agility and long-term collaboration with academia, often the -- the purpose of academia is to do excellent science and also to publish papers. But in terms of bringing a repository program forward, it's addressing the needs of the safety case and these change when a repository program advances. So, it needs to -- to be able -- the research program needs to be able to -- to -- to -- it needs to be agile and able to say, "Okay. We know enough about this topic. Now, we're going to focus on another topic." It needs to be open as well to embrace new topics where maybe that the research groups are not so well-established but they should also get a chance to have their say. A good safety case really focuses the RD&D program.

Recruiting excellent staff, in some countries is not always easy. It's keeping the momentum, which is the essence and if you give this enough attention, has shown to work in -- oh, again, international collaboration is -- is -- an essential pillar in that we had examples from Spain and Hungary.

When you have a program like Belgium, who focused very much on this clay host rock Boom Clay or also Germany where they focused so much on salt, and then suddenly it has to widen up. There is a challenge of actually losing the detailed knowledge you had as people retire, as we are in these long timeframes.

But it's clear that one specific geological environment are selected, a strong refocus will occur and you really need to anticipate this transition. In some countries, maybe have been caught by surprise but they're.

So, I think this concludes the messages we could bring together on early stage programs and programs which are going toward site selection. There was a lot of experience in the -- in this virtual room when we discussed this. And these are just the key points that we could bring out. So, I hope this is -- this is value also for the -- for this. Thank you for the attention.

BAHR: Thank you so much Irina. And thank you for your efforts in bringing that group together. I'm sure there's lots of questions from the Board for Irina but before we have questions for her, we're going to hear from Lucy Bailey. Hello, Lucy.

BAILEY: Hello. Hi. Oh, I think for most of you it's good afternoon. Hello. For most of you, I think it's good afternoon.

I would like to introduce myself. I'm Lucy Bailey. I'm a physicist. I work for the UK implementing body Radioactive Waste Management. I've actually been working with -- and for RWM and its predecessor organizations for over 25 years in the geological disposal area. My main expertise is in developing the long-term environmental safety cases. And I have been a peer reviewer of a number of international safety cases, particularly in the Swedish program. And I'm currently the chair of the integration group for the safety case, the OECD, NEA, IGSC group.

But my current role as of about a year is to head up the Research Support Office at RWM. We established the Research Support Office to bring together and to integrate a network, universities across the U.K. and academic institutions, and also relevant international borders to really develop our understanding of what is required to underpin a safety case for geological disposal.

So, my talk -- my talk today will focus on the -- give a brief overview of the UK program, we're currently at the GDF siting stage. So, very similar to the -- to the U.S. The -- the early stages, although we do have some exciting news recently to announce in that.

And are particularly focused on our research strategy during this -- this early siting stage, and fulfilling importance of building understanding, how we present that understanding. Introduce you to a new tool that we have developed that we're very excited about and that we can help with that particularly how we can identify knowledge gaps and research priorities.

I will then explain a little bit about this new Research Support Office and how that operates and how we can increase that value to our GDF program.

And last, but no means least, I will say a little bit about the value of international collaboration, and particularly how I think it's so important that we work together to build trust across a whole range of stakeholder communities.

Okay. An overview of where we are in the U.K. So, as Irina already alluded. In fact when I first joined what was then Nirex back in 1995, we were far more advanced than we've ever been since then. Back in 1995, we were about to excavate an underground research rock characterization facility at a site that we then hoped to go forward and construct with GDR.

And that one fell through and we've gone backwards since then. But we've learned an awful lot. We've learned a lot about the process. We've learned a lot about the importance of building trust with communities and with stakeholders. And we now have what we very much hope is a successful siting process.

And literally, last month we had the exciting announcement that Copeland Borough Council, this is an area in the Northwest of England. It's actually the borough in which the Sellafield site is located, has publicly announced their intention to work with us and form a working group. This gets us from that first stage and that interested party stage where we are talking to communities. We're providing information into the stage where we actually start to form an active working group, a group of people in the community working with us to identify whether there is the possibility within their area, both from the scientific site suitability but was also from the community acceptability.

And I should say in the U.K. we need both a suitable site and a willing volunteer community. They're both equally important. We -- we cannot proceed without both of those. It's got so much more fluid process than our previous processes and very much goes at the pace of the community stakeholders. So, we're certainly not forcing anything on anyone. We're working at their pace.

And so, I just mentioned we have established a working group. Who's in the working group? We have a number of people involved, in particular -- if I can get my pointer. There are two key people from RWM full-time dedicated to each working group and the regional manager, who is managing the process. This is a communications and a society engagement expert. And the siting manager who brings the technical expertise and manages the site evaluation process at that site. And the group is -- has an independent chair appointed by the group to facilitate the communications, supported by a facilitation expert. And also by communications lead. It's also important to note that the working group is -- is open to other members. Any interested party, council group, other maybe representatives of a particular community groups, anyone who considers that they would like to be involved in the process.

And so, the working group has been formed. And one of its main aims is to communicate, to communicate publicly with those in the area. And these are some screenshots here from the website that is available for this particular community group. This website provides key facts and generic facts about the Geological Disposal Facility, the GDF, and who to contact on the working group. It produces -- we'll be producing newsletters on a regular basis. And they'll be available on the website as long as -- as well as various events and any frequently asked questions that are raised.

A really important responsibility of the working group stage is to identify what we termed the search area. This is the area that we will be investigating for its geological suitability for a site. And, hence, because I said it goes hand-in-hand with the community. There's also the need to help identify a willing community associated with that research area and, hence, to engage with the relevant principal local authorities.

So, we are at this early stage during siting. And we -- although we have an interested working group, we don't, by any means, have a site for a GDF. We are very much hoping and expecting all the other working groups coming forward. So, the majority of our research is still very much at the generic stage.

And our focus, as Irina said, that the generic stage is all about building confidence, confidence and safety. And we do that primarily through developing or understanding, developing and integrating our understanding. What do we need to understand? We need to understand the way the various barriers along with accepted international approaches, we have a multi barrier approach to providing safety in our GDF. And we need to understand the safety functions of those barriers and how those safety functions evolve under different conditions under a very-long timescales.

We need to understand what features, events and processes, FEPs, could affect those safety functions and again how those could evolve under different conditions, what FEPs might be helpful to long-term safety and what might become a hindrance and how we might need to mitigate about that -- mitigate against those.

Of course, in the safety pace whilst demonstrating that our concept will be safe. In order to do that, we need to think about the what if's. We need to think about how radionuclides from our inventory perhaps could be released and transported back to the environment, in order to ensure that our barriers are mitigated that happening in any significant way.

In the U.K., that leads us to look at groundwater, migration and also migration as a gas phase. There are also, obviously, other pathways, natural disruptive events and -- and human intrusion, those we looked at as various scenarios.

It's important for us to understand the engineering design in order to optimize that for safety and for -- and also for efficiency.

The research also feeds into our operations, researching the construction techniques, how we identify and mitigate potential hazards.

And also, we need to recognize that we all need to transport waste to the facility. We need to consider our transport containers. We need to consider their robustness, the various accident scenarios, and particularly looking at research on particulates, how those transport containers are sealed and how particulates from the waste perhaps could migrate through those seals and what we can do to prevent that.

So, our research strategy covers the whole range of activities that are required in order to deliver a GDF.

Now, one of the things that's -- is very important in terms of managing a research portfolio particularly at the generic stage, is identifying, you know, what are your priorities of the research? What are the important things to do? And given that we don't have a bottomless pit of funds, there will always be a need to ensure that we are getting the best value for our research funding.

Previously, we looked at a concept called technology readiness levels. This was something that NASA developed in the 1970s and has been widely used across the defense technology sectors including in our U.K. nuclear decommissioning industry.

The aim is to identify the technology readiness from a basic principle that might be observed and reported right up to technology level nine which is a system that is actually ready for operation.

The focus of these TRLs was very much on understanding the technology status as a key driver for risk management. It would recognize that projects -- technology projects often went over budget or were subject to delays because of immature technology. And hence this was identified as a driver for risk management and used to make decisions about technology funding.

However, when we tried to apply the concept of these technology level -- readiness levels to geological disposal, particularly at the early stages, we found there were some issues. Whilst they may be a very useful tool where -- where you have a site, where you have a design that is as agreed, the disposal concept, and you're really just looking at optimizing that design once the site has been characterized. So, it is about the technology of waste and placements. Then they can be very helpful.

However, at this early stage that many of us are at the moment, the siting stage, readiness is not so much about technology. But it is much more about our understanding. And really, I think that's the main take way point of my talk is I need to develop understanding. If we don't have a site, if we have purely illustrative concepts and designs, we need to understand how those designs may evolve under different conditions, in different scenarios, under different sites. And that's really what is driving our research program. So, it's not so much about the technology readiness but about our level of understanding.

And, hence, we’ve developed a concept called Scientific Readiness Levels™. This was developed by the U.K.'s National Nuclear Labs and was used as part of our generation for a new build program. And we believe that it's a very useful tool for assessing our current level of understanding, for identifying what understanding is required, and what actually is sensible. It's not -- in this -- in this -- on this -- on this scale, it is not necessarily appropriate at every stage to get right up to the top -- the top level.

So, it supports our developmental policy. It helps us to challenge the adequacy of our current plans. But it also, perhaps most importantly, helps to defend the waste management organization from the idea that you have to understand absolutely everything. That is not the case, particularly given the long timescales and the uncertainties involved with the deep geological repository. But you need to know what is important. What is important in terms of safety and you need to have a very high confidence level that the way that your system will evolve over these long-time timescales will still lead to safety.

So, we found that this has been an important tool to help us focus on the real needs of examining our level of understanding and how that understanding relates to safety.

So, in the U.K., we moved primarily to presenting our understanding and confidence in terms of the safety claims that we make. These are based on our regulatory requirements and the arguments that we make to support those claims and the evidence that we need to back up those claims. So, we have a claims-argument evidence-approach to thinking about safety adding into constructing our safety case. The safety claims come straight from our regulatory guidance on requirements for authorization which sets out a set of principles and requirements that we need to meet in order to demonstrate the post-closure environmental safety of a GDF.

This approach has been reflected in our most recent -- in our safety case, it's published in 2016, and includes safety cases for the long-term environmental safety case, for the operational safety case, and the transport safety case.

And we've developed a tool that very much links into this, to help us to actually visualize and categorize these claims, arguments, and evidence.

At the top level are environmental safety case, has a number of high-level claims. And this is a snapshot of the top-level of our vision tool, which I will explain in more detail. So, we missed the high-level claims. And so, for example, this one we will show that the assessed risks from the disposal facility after the period of authorization are consistent with our environmental safety standards. We also have a claim about human intrusion, about the accessible environment being adequately protected from radiological effects and also from non-radiological effects and also showing that the site used and the facility we designed and construction will not lead to any unacceptable risks.

We can then -- unfortunately, this isn't a live tool. But you can then link and expand each of these claims to identify sub-claims and then safety arguments, and then right down to the evidence and actually right linking into the -- to the very documents, the reports where that evidence is cite. So, you will not be able to read this, but there's an expansion to show what it -- what it looks like. So, this is a visualized tool that brings together all of our information.

So, ViSI or Visualization of System Information does exactly what it says on the screen, it enables us to bring together all our information about our disposal system. So, in that sense, it's a digital safety case management system. I think the important thing though is that it connects relevant information. So, when we have a piece of research coming through, we can identify that that's a piece of evidence that supports a particular safety claim that feeds into our one of our high-level claims.

This will actually enable us to access all our safety case and supporting documents. So, it also a front-end portal into our safety case documents. And our regulators really like that because it enables them to trace through the reason -- the logical reason from a safety claim, future safety argument, down to the safety evidence.

And we also received interest when we presented it internationally to sister organizations. And I'm particularly excited about this tool because it enables us to identify those areas where we have a lot of evidence to support our safety arguments, and perhaps more importantly those arguments where the evidence is perhaps a bit thin or -- or maybe not even there. And that therefore enables us to identify knowledge gaps and requirements and hence to enable us to prioritize our research and development program.

We have, as some of you may be aware, a science and technology plan at REM and in the U.K. that lists what we've identified as our research priorities and needs. And every single task in that science and technology plan is linked into this ViSI tool. So, it enables us to identify a -- a map on those task that we've already identified, and also going forward as we expand our understanding, as we gather more information it will enable us to identify new gaps that's emerged.

It's particularly helpful at the generic stage, because the way it's structured it has sections with different geological environments and different disposal concepts that might be relevant to those environments. And so, you can see where information actually feeds into multiple the concepts or to multiple environments and perhaps those areas that are very specific to a specific site or a specific disposal concept that you may want to wait until you -- to know where you are. So again, it enables you to identify the real value that you're getting from your research and how it will link in to build that stuff, understanding of your safety case.

Then a very valuable tool for our research office, our Research Support Office has been established to drive our research strategy, to actually have a coordinated approach, recognizing that the activities that we need to deliver in the U.K. at the current stage are around community engagement, around our ongoing waste management activities. We have a huge decommissioning program, waste is, as we speak, packaged, prepared suitable for -- suitably for disposal, we need to support those ongoing activities.

We will need to characterize the sites that are being considered for GDF and we will then eventually need to obtain the permits and license in order to go ahead and construct the GDF.

These are all key strands of our GDF program. They represent the needs of RWM. And the aim of the Research Support Office, I like to think of it as a hub and spoke model. So, the Research Support Office is the hub but the most important part, I think, really are the spokes that represent each of the different disciplines and recognizing, of course, that this is a very multidisciplinary project. And recommend -- recognizing the academic experts in those disciplines, working very much alongside the RWM research managers to ensure that our research is targeted within those areas that we needed to deliver the GDF program. And the -- the wheel or the tire are the universities, the research institutions, the international bodies, the people that can actually do the work.

So, in the hub side, I sit in the hub, along with our key academic leads, we're collaborating particularly with the University of Manchester and the University of Sheffield. Who won the -- the contract, to help us set-up and deliver the -- the Research Support Office. We have spokes in all the relevant disciplines. And you can see the material science, advanced manufacturing, radiochemistry, geosciences, social sciences, environmental sciences, public communication, and also a spoke dedicated to training as well, a cross-cutting discipline, recognizing that a key part of the RSO is to build capability and skills for the future.

And in each of those spokes, we have an academic discipline linked typically a professor from one of our universities. And our key subject matter expert from RWM who will, typically be, the research manager in that area. And one of the real delights is to see the way they are working closely together. And it's -- the research manager's feedback to me that is giving more visibility to their work and they're enjoying actually being able to get into some of the -- the nuts and bolts and interacting with -- with their academic peers. And for the academics, it's really helpful because they can actually understand with much more clearly the impact of their research and ensure that their research is tailored and directed very much to our needs.

And so, it really is about working together, working together to deliver understanding, to underpin our GDF safety cases, and in the process developing, and engage, and inform the academic network.

And that's really what the objective is -- of the RSO is all about. It's about building these long-term strategic relationships to -- so that the research is better aligned. And we obviously in the past we have been doing a lot of research, sponsor Ph.D.s and post docs and that they haven't always been as focused as perhaps we would ideally like. And the people doing them perhaps haven't been as connected into the program as perhaps they would have ideally liked. And so, it's about increasing that engagement so that we create a network of -- of researchers who understand the context of their research. And also, given where we are with need to engage the communities and to build public confidence, I think it's also a very important that we have a network of respected, independent academics that understands the GDF program and can be advocates for that. Can -- can speak out and they're active on social media. I think it's important that everyone is better communicated, that we actually develop -- develop a sense of community of -- of those being funded by RWM and their research. And by -- by sponsoring particularly Ph.D. projects, we are developing the next generation of researchers. And developing them in a way where it is not just funding for that Ph.D. project and maybe meet with them once or twice a year and then get a thesis at the end of it and say thank you very much and put it on the shelf. But we're actually engaging with them and they're working alongside the RWM research managers. They are networking with -- with other students working on related areas. And they understand because they have access to our -- to our safety case and particularly on the visualization of that. Their -- when they produce their research, whether that's a paper or the final thesis, the key evidence from that will be linked to the relevant safety arguments in our safety case. So, they will be aware how their work is actually supporting particular part of the safety case. And their work will then form -- it's actually will form part of the safety case that will become the evidence that supports that safety argument and will be linked into -- into our business tools. So, that's a really exciting way forward of capturing research and ensuring that it really is -- is integrated.

So, the management of the RSO, we have a strategy board and that is just the strategy and supported by a program executive and then the core team. The core team is the sort of day-to-day operation, setting the budget control, deciding on the research priorities, and -- and feeding upwards into -- into the program executive and -- and the strategy board. And we think that this -- which is, we are very much in our first year of operation and the core team and the program executive are up and running and we are due to have our first strategy board meeting in the new year. So, we'll not talk too much about that but I think the core team and the program executive are -- are working well.

Finally, I wanted to talk about the value of international collaboration. Although the RSO is primary -- primarily focused on U.K universities, we do recognize that we don't have all the facilities that we need in the U.K.

For example, we don't have an underground rock laboratory. So, along with a lot of our physical organizations, we collaborate with shared URL facilities, and so we're collaborating on research projects in Grimsel and Aspö, et cetera.

We also find particularly at our current siting stage that is enormously helpful to be able to take some of our stakeholders on visits to these underground facilities to show them what an underground facility actually looks like. We find that's enormously helpful in building confidence. And actually, I think that is a key value for international collaboration. If we can share and demonstrate that there is international consensus, particularly regarding common methodologies, that particularly relevant at this generic stage, that there is a huge common consensus internationally that geological disposal is safe, that we have the ability to make a robust safety case. If we're sharing common tolls, for example the NEA International FEP database is widely used across safety cases and that again gives confidence to stakeholders that there is a commonality and an international agreement on what the state-of-the-art looks like.

And Irina mentioned, and I would strongly endorse, that I think most of us are now recognizing that actually the real challenge is perhaps not so much the technology development but more of a social science aspects. That we actually need to be able to communicate our scientific understanding, we need to be able to build trust and confidence with stakeholders, particularly community stakeholders. And so the IGSC group that I chair, one of our key ends at the moment is working very closely with our sister organization, the Forum for Stakeholder Confidence to look at ways of how we communicate the safety case, how we deal with issues of uncertainty over long-time scales, how we can build trust. And I would go as far to say that our safety cases really only as powerful as our ability to communicate it.

So, finally, I think the key messages that I would like people to remember that building understanding is the most important focus for research during early siting. Communicating that understanding to all stakeholders is vital if we're going to build trust. To support that, we need to integrate and visualize the system information. Information remains just information until it is integrated, until it's linked, until we put pieces of the jigsaw together, until we identify how or what that actually means. To building understanding and it's only through building that understanding by integrating our information that we can identify where we do have gaps in knowledge, and hence, we can then develop a focused, needs-driven research program.

We're very excited by the RWM Research Support Office, we think that it's an innovative way of building a collaborative network of researchers and promoting thorough engagement with our own expert staff.

And we also believe that international collaboration can be very cost-effective and valuable way for building that stakeholder confidence, particularly demonstrating where there is international consensus on state-of-the-art methodologies and tools. So, on that note, I'd like to thank you all very much for your attention.

BAHR: Thanks both to Lucy and Irina for very stimulating presentations. I will use my chairs prerogative to just make a couple of comments while the IGD-TP is clearly a European Union focused activity, I was encouraged to hear that you welcome participation from other countries. And I -- I hope that the Department of Energy is participating as appropriate in some of the projects that are generic and -- so, I would like to encourage that.

Lucy, I -- I think your visualization of the -- of the safety case is a really useful tool. And I -- I think we'd be, in the United States, be well suited to -- to try to think about our disposal concepts in a -- in a similar sort of manner.

One specific question for Irina. You mentioned that there are some aspects that you think can be fully tackled in the early stages and one of those that you mentioned was packaging strategies. That contrasts with what we hear in the United States, that without a particular site it's difficult to make firm decisions about sizes of containers, and materials that they are composed of, maybe you can comment on why that is different in Europe.

GAUS: Yes, of course. I mean, one of those about classical packaging, a lot of this packaging is not RD&D, this is packaging. But when it comes to new ways and new ways of waste characterization and -- and then trying to have more generic waste acceptance criteria, there I think still quite a lot of work that can be done, also, looking at difficult -- difficult to package waste, like organic liquids, this type of stuff. So, there is at the fundamental research level, because this is mostly where you are in the generic stage. There is still quite a bit of work that can be done. But with classical packaging of low-level waste, for example, this can be -- this is under control, I think. But there are difference -- yeah. Then another aspect is the spent fuel characterization and how to deal with that. The impact of dry storage. There are very -- there are couple of questions there, which can be tackled or contribute because it's not one country that's going to solve it, but there are -- there are different questions which can be tackled on multiple countries in an early stage.

BAHR: Okay. Thanks for that clarification.

So, I'm going to go to Board questions in the order that I see them. So first is Lee Kenneth Peddicord. And we need your microphone and camera on, Lee. Here we go. Mic.

PEDDICORD: There we go. Yes. Yeah, I'd be so flummoxed by Lee Kenneth, I'd never been called that before. So --

BAHR: We're just trying to make sure that the moderator knew who you were.

PEDDICORD: Thank you. So, first of all, thank you to both of you, these are just phenomenal presentations, and that I thought were so informative and so valuable, so, you know, a whole range of questions come to mind, but let me just focus on a couple because I know everybody else will have many things they want to ask.

Well, first, Irina, to you, with the organization you mentioned, the participation in some of the projects, for example, but I wanted to ask a little more broader question about participation beyond the members, and that is, when do you have meetings, for example, do observers come in to hear the deliberations, to hear the discussions? And in terms of that, or if you are linking to the regulators in the various countries, and might they be some of the observers, if that's allowed, on the meetings.

GAUS: Uh-hmm. Well, the IGD-TP is very much a waste management organization, and we also try to organize it like that. We do have observers. I mean, the IAEA comes in regularly as an observer to our meeting, but we also want to keep a platform, not all of them-- I mean, are research projects, which are pure research, I mean, like, how the climate change affects our scenario definition, which is a pure research topic. But then, there are also topics like retrievability, like criticality, which are maybe not research-research, but kind of how to tackle the issue, and at certain points, we prefer to discuss between implementer first before we go outside. And therefore, in Europe, we have an implementer network, which is the IGD-TP, but there is also a regulator network, which is called SITEX.

PEDDICORD: Yeah.

GAUS: So, it's -- and, of course, we -- within these networks or so -- between the networks, there's also a communication, but I think it's in -- it's really important also that implementers can come together and exchange, and -- because there are different views on how to tackle things, and there should be an open forum. And also research institutes, they also contribute a lot to what we do, but they also have a slightly other focus. I mean, research institutes are interested in progressing science and delivering excellent science in writing papers. But bringing a repository program forward is still slightly different, but you -- so you need a very good dialogue, but you also need places where different implementers can discuss, and different regulators can discuss.

PEDDICORD: Uh-hmm. So, if I understand, you keep it kind of within the community, but you do have the crosstalk incorporated.

GAUS: Yes.

PEDDICORD: Okay.

GAUS: Yes.

PEDDICORD: Well, that sounds like an excellent approach.

And then, to Lucy, I really -- I think it's excellent. I really commend you all for developing the concept of the scientific readiness levels. I think that's a great contribution because I could see where that really lends a lot more credibility as an organization tries to develop priorities of where the work is going to go. And if you can put this in the context of scientific readiness levels, I think it strengthens the case of why you are prioritizing, and what's going to come first. But my question to that then is -- well, how to ask? So, is this becoming a more internationally recognized and accepted approach, and are you gaining some traction within Irina's organization and so on, really institutionalizing this -- certainly TRLs, as you know that, have become exactly that.

BAILEY: Uh-hmm. Yes, I may ask Irina to comment on this as well. We -- I think the important difference is that you're not aiming to get everything out to your top, scientific readiness level at that time, so we -- in our science and technology plan, for example, in the UK, we have a -- sort of a target SRL for each task, and that doesn't necessarily have to be the top level 6, so it's a generic stage, it maybe quite acceptable to have some of our understanding about some of the issues at a SRL of 3 or 4, or even lower. And so that's important. And it enables us to see where -- if we are commissioning a piece of research, what we expect to gain from that in terms of the increase of understanding, and what that would relate to. But I think we're also linking much more into ViSI and to this identification of where we have knowledge gaps to support our safety arguments, particularly for the -- for the environmental safety case, and that's important, too. That lends it -- lends itself much more to thinking about the understanding, and it isn't always easy to quantify understanding, in perhaps the same way that it is to quantify technology readiness, so I wouldn't -- I wouldn't say it is as quantified and as hard and fast as perhaps the TRLS, but we find it a useful concept.

PEDDICORD: Okay. Good. I'll probably take the discussion offline in the interest of time, Jean, but I'd like to come back and understand more about your involving universities, and I think that is superb. But let me defer to other questioners now, Jean.

BAHR: Okay. So, let's next go to Tissa.

ILLANGASEKARE: Informative, and I also like the idea that you emphasized the importance of international corporation. So, I think what I -- my questions are related to at least question about academic collaborations. I think it's important that -- to learn from your lessons, to do things better here. The US has, you know, has a very good academic collaboration, national labs, if that.

So, Irina -- so Lucy mentioned the academic network, so are there any ideas you could share on how improve it here? Because I can -- I can appreciate what you're saying because we are in academia, and then, we do research our goals, sort of sometimes, you know, we --we do other things, like publish in journals but before I finish that, I also want to emphasize the -- another value of academic collaboration, is the issue of training the future scientists.

BAILEY: Uh-hmm.

ILLANGASEKARE: And this becomes important, and you may -- if you measure the academic productivity just based on the fact that what you produce, one of the products is the future generation of scientists, so I assume that's what you meant. I don't think I need to comment on that, I was just emphasizing what you said.

But my question is, Irina, you mentioned in your slide 15, the early stages, you want to give higher priority or -- early stage in the geology, and the later stages in technology. But I think in a particular case of monitoring, I believe that, you know, once you understand the processes, I believe in that the -- at all stages, the technology has to evolve and develop, especially in the case of monitoring. I can understand certain technologies, you can break, so I want you to comment on that, your thoughts on that.

GAUS: I think, yes. I mean, there, you picked on the one part of the technology development that goes through the whole repository program. I mean, monitoring starts with the URL experiments, and this happened in an early stage also. Like, for example, for the HotBENT experiment, we're looking in -- very much into fiber optics, which is new technology. But monitoring starts with the URLs, and then, goes to field monitoring for geology, then goes into monitoring in the -- in the onsite URL if you have it or within the repository. So that is an activity which goes right up to the closure of the repository.

Now, when you think about emplacement technology, then in the early stage, very often, the operation of the repositories is likely to be a generation away. So there -- for developing emplacement retrievabilities, the technology, also kind of excavation technology, you really want to think, "Is this something we want to tackle in this early stage?" Because by the time you will need it, it will be obsolete. If you have technological development over one generation, it's -- are you really going to use it? It's good for maintaining competence, but -- as we need something to gather result, that will be -- keep its value over this long period development for this purpose, retrievability and placement tunneling, is probably not the investment you want to go for in an early stage.

ILLANGASEKARE: Thank you.

BAHR: Okay. Thanks, Tissa. Next to Steve Becker.

BECKER: I want to begin by echoing Lee's comment that these were both phenomenal presentations. They were extremely informative, so thank you. So, I have one question for each of you.

Irina, I was intrigued by your comments about the need to consider the role of social and economic RD&D developments in the process. And I also noticed that on slide 16, this was actually listed as the second highest priority. Could you say a bit more about the kinds of social and economic issues that are important to consider?

And should I put the second question out there as well or should I wait for the first answer?

GAUS: I can start with this one.

BECKER: Cool.

GAUS: What we see is that how people perceive what a repository will be in the area, is an -- and what they see as kind of what will be the big disadvantage of having a repository in the area, is very much an issue which needs to be looked at. Now, in Europe, at least, the socioeconomic aspect or the science related to that, is not part of the -- of the -- not within the merit of the waste management organization. Often, this can be with the government. And we had an example in the discussion where one of the country said, "Well, it is -- has to be taken care of by the government, the social economic issues also impact on values of houses, and how it is being perceived, has to be taken on by the government, but they don't -- they don't do a proper job." So it's for the implementer then to keep an eye on that, and make sure this is being taken along, because once you go into a site selection, it can backfire, it -- people say, "Well, you won't do this technical stuff, and -- but what is it going to mean now? And what is the impact, and how will people think about their region?" And so, it needs -- it also has its place in the whole site selection, and the RD&D. And it's often, it's not with the technical organization who develops the solution, but it's somewhere, and -- but it needs to be taken along.

BECKER: Thank you.

And, Lucy, I thought your comments about communication were very compelling. I was particularly struck by the following three things that you said. Building understanding is the most important focus for research during early siting.

BAILEY: Uh-hmm.

BECKER: Communicating understanding to all stakeholders is important for building trust. And this one really, really impressed me, if you will. Our safety case is only as powerful as our ability to communicate it. Given those statements, what lessons about how to communicate do you see is the most important? What kinds of things have really struck you as being the key lessons in terms of how we do communication?

BAILEY: Okay. Thank you very much for those comments. I think that I have learned a huge amount from how we communicate the safety case by working with Pascal (inaudible) the chair of Forum for Stakeholder Confidence and her colleagues on the FSC. And we've had a couple of workshops now with -- between the IGSC and the FSC. And just bringing together the technical experts from the IGSC and the social science and communication experts from the FSC, and understanding each other, that's the first thing. So we've had some really exciting workshops where we've used this sort of world cafe approach to share ideas, to -- not just sort of sitting, having a power point presentation, but actually going around in groups, sort of scribbling on flipcharts, even on tablecloths, just to build a message of what that understanding is.

And so, by understanding one another, because actually you understand where people are coming from, people's ideas of, "What does safety mean?" That is not a straightforward question. A lot of people have different views on that. We may think as a technical expert that we've done all these rigorous mathematical analyses, and we can present that, and we've taken to convince ourselves with its idea, but to a non-mathematician, that probably doesn't mean a thing. You know, they are more worried about what's going to happen to their local community over the next 20 years, and to their children, and to their grandchild. And when we present results of what's happening thousands of years into the future, it just sort of washes over them. So, I would say the most important thing is to understand what your stakeholders, where they are now, and, you know, what they want to understand. So, communication is all about the person you're communicating to, not about the information that you want to convey, but about actually understanding where they're at, and how you can help improve their understanding.

BECKER: Thank you. And I'm assuming that both of you -- it seems that both of you believe that the social economic and communication issues need to be incorporated in the process from the very -- from the very start.

BAILEY: Yes, I would definitely say that. I don't think it's a matter of in your safety case, and then, give it to your comms teams to work out how to communicate it. I think what you need to be doing is training your technical experts to be aware of their duty to communicate more widely to people. And actually, if you can train your technical experts to communicate and send them out into the communities, I think you'll get a much better response than sending a communication expert that doesn't have that detailed understanding. I think when people realize that you understand -- the true component to trust, there's a trust in somebody's technical competence, and there's a trust in their integrity as a person, and their desire to do the right thing. And you need both of those as a waste management organization. So, a community needs to respect that you have that technical competence, that you have that technical understanding, but also you have the integrity to do the right thing and to deliver. And when you could bring those two together, I think you could then have a really meaningful engagement with your stakeholders.

BECKER: Thank you both.

BAHR: Okay. Thanks, Steve. Let's go to Mary Lou. And I think this will be the last question in this session, just in order to keep us on time. So, Mary Lou.

ZOBACK: Okay. Thank you, Irina and Lucy, so much. I don't need to say you gave wonderful presentations because everyone said it already, but I will say, it's wonderful to see smart and articulate women in charge of rational programs. So, thank you both for your service. And I just want to hit on some of the same points that Steve hit on.

But I also have a question for both of you. And I think, Lucy, you covered part of the answer. And Irina, first, I liked the way that you broke out the whole approach to waste management, having three parts, implementers, regulators, and the public. So, it says from the beginning, all three components are essential to success.

But the question is to both of you, in the US, we have no requirement for a safety case, a 9500-page performance assessment is considered, describing the safety. Now, I couldn't read that and understand it, and whether my neighbors could, I'm sure they couldn't. So how -- how does -- how do you -- how do you see the public, let's just say, in your understanding, the term safety case, understanding the types of safety cases that are presented. And maybe more importantly, how much is the public involved in the brainstorming part of what could go wrong? You know, these FEPs, I guess, that's features, events and processes. In any large endeavor, we always -- it always turns out a lack of imagination was the weak point, and that's what led the Twin Towers getting hit by airplanes and -- and collapsing. So, do the public get engaged down to that level? You know, we're trying to think, all of the things that could go wrong. You could help us with this.

GAUS: Maybe I can start. Do we involve the public in our FEP analysis? Honestly speaking, no. We go -- the FEP analysis, we see more or less, as a completion check on our safety case. So, at this, we --

ZOBACK: Oh, completion check, okay.

GAUS: We do develop a understanding of how the repository is evolving, and there, we do involve the public because for all the aspects. We have to -- in Switzerland, we have a huge regional parliament, they're called. They are in the different areas, so we have exchanges with them. They have their experts. They -- also -- but also non-experts can participate there. So, there we talk about all aspects of the safety case, but not in the structurized way. It's -- it's more on pragmatic topics then. What does it means low-permeability? What does it mean if you have radionuclide transport? But not kind of very structural FEP analysis, and this would more used as -- as a -- as a control mechanism, to check if our understanding is complete.

And how to involve the public is, basically, getting them as Lucy said, with the experts, and get them in touch with the rock, get them to the drilling site, get them to the URLS, get them to an evening, talking about the subject, and talk about real things, not about structures, and not --and --and arrows, and -- and trees, and branches. Because this -- this, for a lot of people, this -- this is something -- first of all, they think it's boring. And then, it's -- it's not what -- what they know. So -- and -- and why would they have to step into this -- this kind of complex way of thinking? If they want to talk about, why do I think this rock is -- is -- is -- is low-permeability? It doesn't let the radionuclide through? Why do I think this canister is going to hold for a thousand years? And, of course, we need the -- the scientific backup, and you you need the structured checking for completeness, but this is not the front end you want to -- to show to the public, I think.

BAHR: Yeah. Okay.

BAILEY: Yes, I do agree very much with what Irina has just said. I think particularly in most -- most organizations, as I said, use the NEA international FEP database, which is -- is well-established, and includes the -- the FEPs from -- from all the -- the main international projects as -- as a checklist, or a starting point, rather than -- so, we're not so much looking about adding that anymore. We -- we think -- and actually, it's one of the --

the confidence, things that we have is that -- that, you know, we're not just suddenly discovering a whole load of new FEPs every week. So that's then stable.

I would say in the UK, RWM had an issues register, which was on -- on a website open to the public, so anyone could raise an issue. So, if there was something that they were concerned about, we did have a bit of a flurry on that, but for the last few years, there hasn't really been much interest in that, even though we're about launch siting, so we are actually shutting that -- that down, and looking much more at building things into our science and technology plan, into our R&D plan, and to be identifying the knowledge gaps. We think that that -- that is a role for -- for the -- for the experts in terms of identifying their knowledge gaps, but to do it in an open way, and in terms of, I would particularly agree with Irina, that the general public, they -- they want to be confident that, you know, competent experts are looking at these issues. They -- they don't perhaps themselves need to understand every single FEP, but they do need to have confidence in the -- in the people that are doing that. And so, getting your experts out there, your experts meeting your -- your public, talking to them, they can see, you know, we -- we don't glow in the dark. We don't have two heads, we're actually fairly normal, rational people, having a range of people, I mean, you know, some of your younger people as well, and I think that there's a diversity of people involved to this, is really important, that all helps to build confidence.

BAHR: Okay. Well, I know we could -- we could go on with this discussion for much longer. There were other Board members and staff who wanted to ask questions, but in order to keep the meeting on time, I think we're going to have to go to the next speaker, who's Emily Stein. So, thank you again, Lucy and Irina, for joining us.

GAUS: You're welcome.

BAILEY: Okay. Yes.

BAHR: Okay. So, our next speaker is Emily Stein, who's going to be discussing prioritization of cross-cutting research and development activities, and the Geological Disposal Safety Assessment as sort of a framework for that.

STEIN: Okay. My name is Emily Stein. I am an R&D manager at Sandia National Laboratories. My background is in geology and hydrogeology. I have a lot of experience in groundwater flow and reactive transport modeling. I started my career at the Waste Isolation Pilot Plant, working on performance assessment there. And for the Spent Fuel and Waste Science and Technology campaign, I have been working on the generic performance assessments in all of the different host rocks. Right now, I'm managing the group that develops the Geologic Disposal Safety Assessment framework, and I also support the -- the underground research work in the -- in salt.

So, this talk will be looking at some of the linkages between the unsaturated alluvium reference case, disposal of dual-purpose canisters, and the Geologic Disposal Safety Assessment topical area. And -- and, I guess, what I'd like you to know, starting right out, is that that unsaturated alluvium reference case is not associated with a full R&D program, like the other host rocks are. Rather it has been developed, really, just to drive understanding in a few key areas and capability development within GDSA. And that understanding and capability then translates more broadly into the rest of the program.

So, I will read you the first sentence of the disclaimer. This is a technical presentation that does not take into account contractual limitations under the standard contract.

And before I dive into that unsaturated alluvium reference case, I'm going to define Geologic Disposal Safety Assessment for you in a couple of different contexts. Then I'll move on to a description of the Reference Case. Take a quick look at some of the knowledge and capability gaps -- gaps for that unsaturated reference case exposes. And then, give you some examples of the current R&D we're doing to address those gaps. And then, finish up with a forward look, not so much at alluvium, but at integration between the GDSA and the DPC topical areas of the campaign. All right.

So, Geologic Disposal Safety Assessment, as you saw in Tim's presentation, is a topical area within the Spent Fuel and Waste Science and Technology campaign. It is also a method for evaluating the long-term performance of the deep geologic repository. Within that campaign topical area, a significant portion of the GDSA work scope is focused on development of GDSA framework, which is an open-source, high-performance computing software toolkit for simulation and analysis of the post-closure performance of deep geologic disposal systems. GDSA framework is built around PFLOTRAN, which is a massively parallel simulator from multiphase flow and reactive transport, and it includes tools for uncertainty, sampling, and sensitivity analysis, pre-and post-processing, and also visualization. Additional work scope in the GDSA topical area includes interfacing with all other areas of the program to develop reference cases and to implement process models, and also to demonstrate safety assessment methodologies through quantitative simulation and analysis in the reference cases.

And that brings me to the next slide, which is about the safety assessment process. So, now we're looking at Geologic Disposal Safety Assessment as a methodology. And this diagram represents the flow of information and iterate of development of the safety of the assessment. We're going to start up here at the safety strategy and the disposal system concept. And when I move beyond the slide, this is what I will tell you about first in terms of the unsaturated alluvium reference case, with an awareness of regulations and safety criteria.

Once you have that disposal system concept in place, you can identify the features, events, and processes that are likely to affect evolution of it. And with a knowledge of regulatory requirements, probability and consequence, you can then screen the FEPs so that you make sure you're including those that could have a significant impact on safety in your quantitative analysis, so -- and I'll give you an example of this later in the talk, screening the possibility of a criticality event in the dual-purpose canister on the basis of consequence.

So, next stop on the tour is this technical bases box. So, together with the FEP screening, the site characterization and the design of the engineered barrier system, and all of the characteristics of both of those things, together with specific process models form the technical bases for your safety assessment. And this box, I will later give you an example of the linkage between site characterization and simulation through a tool known as a Geologic Framework Model.

And then, I will also talk about process model implementation inside of GDSA framework, so how we advance capability to make sure relevant process models are included in the safety assessment.

And finally, within this loop, your last two stops are in fact performing the simulations and uncertainty and sensitivity analyses. And then, taking the results of the entire structure to direct the next round of research and development. So, the unsaturated alluvium reference case has not yet moved forward to a complete system performance simulation, so I won't be talking about that. And then, you've already heard from Dave yesterday about the process of prioritizing R&D. And somehow, I've lost my -- I've lost my next button. Ah. Thank you. Okay.

So, moving on to the unsaturated alluvium reference case. So, this is built upon the idea of putting a repository in an arid environment, deep below the surface, and well above the water table. So, this type of environment can be found in alluvial basin, where you see in dark here, an uplifted bedrock, a fault-bounded basin with a direction of movement indicated by those arrows. Precipitation would occur mainly at higher latitudes, and then, erosion creates a gradation of deposits from core grained at the foot of the mountains through to find grained toward the center of the basin.

The unsaturated alluvium reference case is characterized by complex stratigraphy and structure, a great deal of lithologic heterogeneity. There may be complicated hydrogeology with perched water tables in local aquifers. And then, geochemically, you would expect oxidizing conditions in the repository and reducing conditions that some depth below the water table. Next slide please. Thank you.

So, the post-closure safety strategy has same elements that all of the other repository concepts have. There's an element of containment, which would be achieved through an overpack with some degree of corrosion resistance, and would also depend on the low water saturation which would slow corrosion. There's an element of limited transport due to the deep water table and a low effective permeability in the unsaturated zone. And then, if radionuclides do make it to the saturated zone, dilution would be an element of the safety strategy.

Definitely climate variability would need to be considered, in this reference case, alternating between an arid environment, like the current environment in the American Southwest, where some locations have not experienced deep recharge over the last hundred thousand years. Pluvial conditions, which means increased rainfall, could be created by a global ice age. And in that case, downward liquid flex rates maybe in the range of five to ten millimeters per year. So, this is still quite low, and the saturation in that unsaturated zone would remain less than one. It would still be unsaturated, increasing only until the relative permeability balances the infiltration rate. So over here in this picture, you can see repository 250 meters below the surface, another 250 meters to what would be, a saturated zone and some kind of alluvial aquifer. Next slide please.

The waste forms and engineered barriers that we have considered in the unsaturated alluvium reference case are limited to the direct disposal of dual-purpose canisters, so these are -- would be large waste packages containing, for instance, either 24 or 37 pressurized water reactor assemblies. They could be quite hot due to that large fuel load within each package.

The overpack that the dual-purpose canister would be placed into before disposal underground would provide mechanical strength and protection against corrosion.

The tunnels will be backfilled with crushed alluvium to provide shielding during operations, and also to protect against rock fall.

And then, thermal management would be achieved through possibly specific waste package loading through aging fuel at the surface, and through spacing within the repository, with the goal of maintaining temperatures less than about a hundred degrees C, along the axes of the pillars. That's the undisturbed host rock between tunnels. And a liquid saturation greater than zero along the axes of the pillars. And those two things are important because you don't want to drive off all of the water in the host rock, which may affect the structural stability, and you'd also like to maintain a -- some degree of liquid saturation between tunnels, so that there is a path for any evaporated water to condense, and then, drain through the repository. Next slide please.

So, this reference case has allowed us to really take a good look at what is -- what would be the consequence of a criticality event in an unsaturated repository with direct disposal of DPCs. A further analysis that will happen this year will include whether the impacts to radionuclide inventory of such an event on what might be the impacts to the material properties of the disposal system itself.

Because of the complex structure and stratigraphy, this unsaturated alluvium basin reference case provides a great playground for developing expertise in geologic framework modeling, and also for developing workflows to take those geologic frameworks through meshing, and to flow and transport simulation.

And it's also offered several opportunities to develop capability that is important, both to generic, to the -- to the usual run-of-the-mill safety assessments that we do in the GDSA program, as well as safety assessments that look at direct disposal of DPCs. And I'll give you four examples of that. Next slide please.

So first, we're going to look at the FEP screening of criticality event, based on consequence, so that's the number two stop in the iterative loop of safety assessment development. Next slide. Thank you.

If you were at the Board meeting related to DPCs, you've already seen the content on the next three slides. On this slide, I would like to draw your attention to the bottom half of the list. We're looking at a post-closure scenario in which a 37 PWR waste package is placed in a backfilled drift. The top of the overpack, which is represented here as this dark blue line, breaches at 9,000 years, allowing water to enter the waste package, the turquoise area. And when that waste package fills with water, a criticality event can be initiated.

So, in these simulations, two cases were looked at. A two millimeter per year infiltration rate and also a ten millimeter per year infiltration rate. And then, on ranges of power outputs associated with those criticality events. Next slide please.

So first, we're looking at both temperature and liquid saturation before the waste package breaches. So, with time on a log scale here, we're looking at temperature from closure of the repository through to 9,000 years. And whether the infiltration rate is two millimeters or ten millimeters per year, the maximum temperature reaches just over 200 degrees. And by 9,000 years, it's dropped to about 60 degrees in the waste package. In terms of dryout, with a 10 millimeter per year infiltration rate, the maximum dryout is achieved 500 years post-closure. And you can see that it dries out the drift in some degree into the alluvium itself, this little tiny box here is the waste package. With the lower infiltration rate, maximum dryout occurs a little bit later at 750 years post-closure. And in both of these cases, a non-zero liquid saturation is maintained in the pillars, so they're both going to allow water to drain through the repository at all times. Next slide please.

So now we're looking at temperature and liquid saturation after the waste package breaches, so on the top is the two millimeter per year infiltration rate, and it takes -- with two millimeters per year, it takes from 9,000 to about 17,000 years for that waste package to fill with water, to the point where a criticality event could actually be initiated. And then, when that event is initiated, temperature rises just a few degrees, which is sufficient to drive off water. And a thousand years later, enough water has evaporated, that the criticality event would be terminated.

With the ten millimeter per year infiltration rate, it takes only about a hundred years for the waste package to fill with water, assuming that a four hundred Watt criticality event is initiated. It takes only a couple of hundred years for the water to evaporate to the point that the event would be terminated. So, the impact of those short, low temperature, low power output events is -- will continue to be analyzed this year, both in terms of radionuclide inventory and possible influence on the property simple backfill. Next slide please.

Okay. So we're moving on now, and I'd like to give you an example of how site characterization data, this is a completely generic example, but -- of how site characterization data can be gathered, formalized, and then, brought through to simulation. So, we're moving onto number three. And next slide please. Thank you.

So, a geologic framework model is a three-dimensional representation of geology. Usually, it's going to be regional geology. It's constructed from surfaces, such as stratigraphic horizons and faults that are derived in the field from borehole data and from geophysical data. It's informed by digital elevation maps, by geologic maps, by cross-sections and conceptual models, and it can also hold lithologic data and hydrologic data. And like development of the safety assessment itself, development of the geologic framework model or GFM is an iterative process that helps improve sub-surface characterizations, so you'd compile this data, characterize the sub-surface as well as you can, create your framework model, you can generate a mesh, and then, flow and maybe transport simulations will help you determine if you actually understand the system that you've created, if it matches what is observed in the field. And then, guide further data collection and iterate. Next slide please.

So this is looking at a brief overview of construction of a GFM, and the alluvial basin, because of its complexity, has turned out to be a very useful test case for developing expertise, for developing the workflow, and for figuring out how to make these complicated software toolkits work for us. In this example, the data that's input is either point cloud for surface -- for this stratigraphic surfaces and land surface, and point cloud data. And then, fault surfaces were defined by lines propagated at various depths. From the point cloud and line data, surfaces are generated, and you're seeing here depth to surface in the color coding. And then, from the surfaces, volumes are generated. These volumes are watertight, and those watertight volumes can be meshed. Next slide please.

So once you have your volumes, you can also associate lithofacies in those volumes, and this example, there are three lithofaces in the alluvial basin, and then, the gray underneath this bedrock, and you can see the faults cutting through here. You can also associate properties, rock properties in these volumes, and so, this is showing one realization of a geostatistic distribution of heterogeneous permeability in the basin. Next slide please.

And then, you can slice and dice your GFM in order to create meshes. You may elect to run a full regional flow model. You can elect to cut a piece out; and run a much smaller scale model at higher resolution. So, two meshing tools are being explored for this workflow, and the first is LaGriT, which is a long and well-established code, based out of Los Alamos. It is -- has a lot of processing tools that help with transferring information, from one piece of software to another, and that gives the user a high degree of control over the mesh that is generated. The meshing algorithm that is used is Delauney triangulation, and using that algorithm, you can see that it's not actually possible to capture the sloped surface of the fault plane here between the blue and the yellow. It's -- rather, it's stair stepped. And so, for that reason, the people who work in this meshing field are very excited about this new meshing tool, VoroCrust, which is the first provably correct algorithm for conforming Voronoi tessellation.

It's a completely automated algorithm, which simplifies meshing, and it -- it allows a nice smooth contact between complex geologic features to be implemented inside of your mesh, but also guarantees quality of each cell in that mesh. Though it's lacking at the moment, it's user-friendliness and the ability for users to specify details of the mesh. So, this is under development right now, really in that making it more user-friendly, improving its processing speed by implementing parallel processing, and also under development are advanced automated algorithms that would include the ability to mesh anisotropic cells, which is important in a geologic system, which has thin layer's that extend over many kilometers. Next slide, please.

And then, finally, I want to give you several examples of process model implementation inside of the GDSA framwork -- where we take the technical basis through to simulation assessment. Next slide, please.

Okay. So, it turns out, and this will be no surprise to the modelers among you, that -- that unsaturated reference case with the high heat load waste packages is a very complicated problem to solve numerically. It's highly nonlinear, you have phases appearing and disappearing. So, first the water evaporates, and then, when things cool down, water comes back in. And this presents a lot of problems for the traditional or default solvers inside of PFLOTRAN. The basic problem with each time step is to minimize the residual of a multidimensional function, and that is represented over here in this color contour plot, where you're looking at a starting point at this time step, we want to find the global minimum, which is indicated in dark blue. There are also some local minimums, also colored in dark blue.

On this plot, we're looking at four different iteration methods or time stepping methods. And the first is the Default Solve, which is a Newton -- it's called Newton Step and Direction here. It's a line search method. And it's going to take us all the way out here to the outer circumference of this larger circle, which you can see is a saddle between two minimums. What happens when you land here is the solution does not converge, and that -- and you're going to cut the time step, and start over again. So, this is an inefficient approach to this highly nonlinear problem.

You can improve on that by using the Newton Trust Region method. In this case, you first employ an algorithm to estimate where the extent of the region, that that -- the global minimum is likely to be found in, and that is this inner circle. Still, the Newton Trust Region method takes you in the same direction up yet over a smaller time step, and land you on the saddle. So, although, it will require fewer time step cuts than the original default method, you may still find yourself in a situation where you're redoing time steps frequently. Another method is this Cauchy Steepest Descent method. So that takes you off in a different direction, bringing you much closer to the global minimum to begin with. In this particular example, it then, took 17 iterations to finally land over here at the desired endpoint. So, the innovation here is to combine the Newton Trust Region method and the Cauchy Steepest Descent method, take information from both. And in this example, you can arrive at the global minimum, and solve your problem in a single iteration. So, although this is a more expensive method, in the end, it ends up being faster. In -- in early tests, it looks like the Newton Trust Region dogleg Cauchy method reduces computation time by a factor of approximately 35. And this is really important when you're dealing with a large model to mean of many unknowns, long periods of interest, of long simulations. And also, you want to be able to do many realizations. So, this is a big improvement in computational power, it's important to the whole program, not just the unsaturated reference case. Next slide, please.

Another -- another new implementation that was really pushed forward, both by the unsaturated reference case, and also by the BATS heater test that you heard Chris talk about yesterday, is this implementation of temperature-dependent thermal conductivity in PFLOTRAN. So, with the high heat load waste packages, you can expect temperatures in the repository to go from background, maybe at 20 or 30 degrees C, to as high as 200 degrees, or -- or -- or even higher.

And over that range of temperature, you need to consider temperature dependent processes. And some of the processes that might be affected by temperature include corrosion, mineralogical changes, aqueous speciation, including radionuclide solubilities. There will be thermal expansion of solids, affecting the local stress state, and, of course, there will be buoyancy-driven fluid flow over that type of a temperature range. And over that temperature range, most minerals will experience a decrease in thermal conductivity, as temperature increases, and that's shown here for the thermal conductivity of salt course, taken from the BATS heater tests. And so, we now have five different expressions for thermal conductivity inside the PFLOTRAN. Three of those are a temperature-dependent, and now that the structure is in there, it's relatively straightforward to continue to add desired functionality for future problems. Next slide, please.

Another feature that has recently been added is a criticality submodule. And this is a capability added to PFLOTRAN's waste form process model. The waste form process model is responsible for keeping track of degradation of the canister, degradation of the waste form, the radionuclide inventory, and release of radionuclides from the waste form. And it's also coupled with a heat source term, related to radioactive decay within the waste form. So, the criticality submodule then, layers on top of that, radionuclide inventory changes, related to a criticality event, and also, the heat source related to the criticality event. At the moment, that heat source turn and radionuclide inventory associated with criticality are read from external files. But in the future, this calculation will be integrated with the neutronics code, so that the criticality power output can be modeled as a function of water saturation. Next slide, please.

So, the Fuel Matrix Degradation Model is another example of a mechanistic model being implemented inside the PFLOTRAN for use in safety assessment, and you saw this yesterday in Yifeng's talk. It's a 1-D reactive transport model that really only deals with a few microns away from the fuel surface. It's looking at -- on dissolution of spent nuclear fuels, the function of radiolysis, diffusion of reactants through a growing alteration layer, and the interfacial corrosion potential. And then, it takes its input things about bulk chemistry, including hydrogen concentration, which could be generated by corrosion of elements within the waste package, iron concentrations, silica concentrations, et cetera in the bulk liquid. Within GDSA framework, we're working on more efficient numerical methods, so that it can be coupled in, mechanistically, without slowing computation time too much. We're also looking at speeding computation time using machine-learned surrogate models for the full mechanistic model. And in the future, we expect to couple this small scale 1-D model with evolution of in-package chemistry, given specific groundwater conditions, and also to validate the model against SNF dissolution experiments, which Dave will talk about a little bit more later today. Next slide.

So just to summarize, the unsaturated alluvium reference case has driven a lot of capability development. It's helped us understand the consequence of a criticality event in an unsaturated repository, and it will continue to drive capability developments over the next couple of years.

In terms of integration between the GDSA and the DPC topical areas, in this next year, we'll be headed -- we will be focusing more on looking at a high temperature shale reference case, and that would be a saturated repository. Some of the aspects that will be looked at there are improving our representation of waste package loading, by using actual data of spent fuel that is housed at Oak Ridge National Laboratory. We will begin to implement temperature-dependent reactions, including a look, both at how bentonite mineralogy and porewater chemistry change with temperature, and looking at the influence of temperature on radionuclides solubility and sorption.

Corrosion models are under development, and these will become more mechanistic in the future. They can include a temperature-dependence. They will be specific for different materials. And those materials include the waste package overpack, the waste package internals, they may include fuel cladding, and also the neutron absorbers that are in DPCs. I think Chandrika brought this point up as well, that there's also a thermal-hydro-mechanical coupling that happens with these high heat load waste packages. And that is another point of interest, how does that affect the hydrologic properties and the evolution of the near field. And then, next slide.

And as with all other talks you've seen, this is, of course, the work of many people, more than are listed here. But these are some of the people who contributed most directly to the research shown in these slides. And with that, I'm -- I'm happy to take questions.

BAHR: Okay. Thank you very much, Emily. Emily started a little bit late. So, my plan is to continue the questions if needed until about 2:15, which would cut our break to 20 minutes. So, I see Tissa with his hand up. And then, after that will be Paul.

ILLANGASEKARE: Emily, as always, enjoyed your talk. So, actually, I like sort of -- recognize the fact that you are made -- you are making some really important advancements here, you mentioned two. I think the people who are doing this type of modeling recognize the importance of what you talked in slide number 20, and you talked about this to get in the -- looking -- looking for the most efficient of getting the optimum solution. So, the reason for that, you've mentioned is that the - the models that would be used for very large long time periods. And if you don't, the nonlinear issues become very, very important, and then if you go.

And then a second thing, is actually your work on time depends on -- on the -- on the properties of the -- the -- the material the -- I'm sorry, the temperature-dependence on the -- on the models. So, these are important because --

especially because you don't need the type of temperature in, just in this traditional hydrogeological problems, so you are making really good contribution there.

So, my -- my question is that, in the -- in the reference case, you are basically using -- you are not going to do any calibration per se because you are basically looking at two scenarios of high and low. But then said that, then in your -- in your geologic model, used your statistical parameters to define your stratigraphic field. But then, you must be using certain geostatistical parameters to define that field. Now my question is that have you done any sensitivity analysis because in the generic site, you can have different geostatistics. So, have you done any sensitive analysis, not calibration that can be done. A sensitive analysis on what is the sensitivity of your model in a way to this geostatistical parameters, I assume, in your reference run?

STEIN: The answer is, no, we haven't done that yet. So, so far, we have been really focused, I think, on the underlying numerical issues that turn up when you put the hot waste package into this unsaturated system. Over the next couple of years, we expect to develop the geostatistics more to start running larger simulations, including more waste packages. And at that point, we would be doing multiple realizations and doing exactly what you suggested, looking at sensitivity of the repository behavior to the geostatistical distribution.

ILLANGASEKARE: Especially -- the reason I'm saying this is that when you go to higher variances, then heterogeneities become more dominant, become highly heterogeneous, then you may find that some of the unsaturated soil processes you created in this capillary barrier effect and all that will become --

STEIN: Uh-hmm.

ILLANGASEKARE: So -- so this next question --

STEIN: Yeah.

ILLANGASEKARE: -- is a general question. So, you are using PFLOTRAN, and I am familiar with PFLOTRAN but I have worked with other DOE models such as FEHM and then worked with TOUGH. So my question is that you are basically using this as a -- as a primary code, but there are a lot of -- the other models have been valid -- process validated, like TOUGH who had been process validated than FEHM I have done some validation of both this codes. So are you capitalizing on some of those algorithms in improving PFLOTRAN so some of these knowledge you gained from these other models can incorporate either into PFLOTRAN or even look at some of the area PFLOTRAN process models can be replaced with some of these other -- other codes?

STEIN: Yeah. So, I think it's an -- in terms of the safety assessment, PFLOTRAN is really the target code to get all of the capabilities that we need in there. And the reason for that is because it works -- well, I know TOUGH has been parallelized as well, but it is because of its parallel capability. But we definitely keep in touch with the modelers at Berkeley who are primarily using TOUGH and also Los Alamos who are primarily using FEHM. And particularly in the fields of capillary pressure curves, I think there's a lot we can draw from TOUGH to implement those same more sophisticated models into PFLOTRAN to give it the same capability. And then when you think more about FEP screening or simply process model development, some of that work is being done in -- with TOUGH or with FEHM, and then lessons learned from there can be transferred to the safety assessment that is then simulated with PFLOTRAN. So, yes, we are very aware of what the other code capabilities.

ILLANGASEKARE: Yeah. Thank you very much.

BAHR: Thank you. Okay. Next is Paul.

TURINSKY: Okay. One is a point of clarification. When you were doing the high flow case and criticality, there was a power level you went to. Was that in its total value or was it really a balance -- a real criticality value of k_{eff} equal to one

STEIN: No. That was an assumed power output that allowed the criticality event to be sustained for some amount of time. If you assumed a higher power output, then your critically event would be --

TURINSKY: Okay. I get it now.

STEIN: -- would be terminated almost immediately.

TURINSKY: Yeah. I mean --

STEIN: Yeah, so it was just -- yeah.

TURINSKY: Yeah. The real situation is you go to k_{eff} of one. Because you're going to get Doppler feedback and you're going to decrease the density of the water, and --

STEIN: Yeah, we don't have that bubbling in there. This is -- this is just --

TURINSKY: Okay. But then -- this -- when you integrated the criticality capability, you talked about later, then you will have that capability?

STEIN: I believe so. I'm actually not familiar with the details of that plan, but that -- what you are saying has definitely been discussed.

TURINSKY: Okay. And what -- where did those assumed power levels come from? What's their basis?

STEIN: The -- I suspect that they were really calibrated to drive off the water. It was kind of looking for what is the highest output you could in fact sustain a critically event at. And if the -- if the power output is high enough that all the water is driven up instantly, then we're not so interested in -- in that event.

TURINSKY: Okay. And following up on Tissa in the uncertainty, where do you get your probability distributions from when you're running the code doing sampling?

STEIN: So, the answer is it depends. But in terms of the geostatistical distributions in the alluvial basin, that comes from a literature search of -- of existing alluvial basin.

TURINSKY: Okay. I'm thinking of model -- model uncertainties either introduced by the model itself or the parameters that go in the model.

STEIN: Yeah. So, parameters uncertainties are what we have dealt with the most. And those all at this point come from literature circles. From looking and saying, "What is a reasonable range of values reported into literature for, hmm, permeability of a shale and, you know, these types of characteristics."

TURINSKY: Okay. And -- and my last question is related to uncertainties also. You've indicated you are adding a whole bunch of new features. How do you evaluate what new features really have to be added given their -- given the current probably significant uncertainty in your predictions? You know, you had -- you know, you shouldn't be spending time on adding a feature that's lost basically in the current uncertainty of the model. Now, do you go through a process?

STEIN: Yeah. But -- I think you raised a good point there, and I also think to some extent, you need to run the model to know the answer. So -- so to bound --

TURINSKY: So, yeah, many time -- yeah. Yeah. Many times, you can just go in and change thermal conductivity event. Well, Tissa mentioned earlier, just do sensitivity on something and say, "Well, we really don't have to model that in detail 'cause it -- it -- the change was much smaller than all of the other uncertainties that are inherent in this sort of modeling."

STEIN: Yeah, yeah, yeah. That -- that is true.

TURINSKY: Okay.

STEIN: I mean, that can be done.

TURINSKY: I mean, I know -- I know we love to add things to our models but --

STEIN: Yeah.

TURINSKY: -- somewhere you have to say that that feature really isn't that important to include.

STEIN: Yeah. I don't know that we're there yet though. I mean, at some point, you need to design your safety assessment that -- yes, that hits the most important things that you can run in an efficient manner. But, at this point, when you're still doing screening arguments or you're really trying to understand processes, then you -- you do want to model those things in order to figure out whether they matter.

TURINSKY: Okay. Okay. Thank you very much. It was an interesting talk.

BAHR: Okay. We have several questions from staff. Andy Jung first.

JUNG: Hi. This is Andy Jung. I have two questions. First was clarification related to the degradation models for fuel matrix and the waste pack corrosion, especially for the disposal of your proposed canisters. Are you considering those two models can be applicable for both unsaturated and the saturated conditions or only for like unsaturated as you just include for the saturate on all of it?

STEIN: So, really mechanistic corrosion models are in the future for the program. And they would be developed in a site or design -- or somewhat -- in a targeted manner. So -- so they will vary depending on the repository that you're modeling and the -- and the material that you are assuming the waste package is constructed of. So, I don't imagine that you would be using the same model for a saturated and an unsaturated repository. It would be two different models.

JUNG: Hmm. Okay. It's possible. The second one is for the corrosion model of waste package. You say the model will be temperature -dependent. It's very reasonable. But also, you said that it will be applicable to up to maybe 200 Celsius degree -- 200 Celsius degree, you said that. So, my comment is that below the -- the 100 Celsius, like below the boiling point, you can maybe apply for the current temperature-dependent model. But over than -- above the 100, the conditions for corrosion will not be any more accurate, could be very humid and salt deliquescent, depending on the host type. So, you have to consider a different type of mechanism corrosion model. So, I want to just make sure if you have a plan developed temperature-dependent model up to 200 Celsius, in that case you may have to separate those two mechanisms for your model.

STEIN: Yes. Like, you are saying like there would be a -- a humid corrosion model that would not be saturated and there would be a -- this is a saturated system corrosion model?

JUNG: It doesn't -- I mean, it doesn't matter. Like, probably the high temperature humid condition will be in maybe early stage rather than later stage because it could be above 100 Celsius degrees of the waste package temperature. So, if the case for the unsaturated condition, it may have high temperature corrosion, but in the later low temperature case, have to consider like a current temperature-dependent as corrosion model. That is my comment.

STEIN: Okay.

BAHR: Thanks, Andy. I think we have time for a -- a question from Chandrika.

MANEPALLY: Hi, Emily. Thank you for a nice presentation. My question was more about the future outlook for your alluvium reference case. I didn't see that mentioned too much in the five-year R&D plan. Maybe -- is that an area you will be focusing more on in the future, or what -- what work do you think should go in to building more on that reference case?

And, secondly, the question was about, unlike the shale reference case or the crystalline rock reference case that you have so much of detail, process modeling, and experiments, you know, kind of supporting that, the unsaturated alluvium reference case, you don't see that in the DOE work. So, I just wanted to see what your thoughts were or what do you think we'll be doing -- will be done in the future.

STEIN: So, I -- I really think I'm -- I am you, to some extent, my personal thoughts on the alluvium reference case. For a more programmatic answer, I would -- I would ask you to ask that same question to David or Tim. But the unsaturated alluvium reference case is somewhat unique to the US --it -- I don't want to say -- the US has a lot of options for disposal. I don't know that this would necessarily be one that would be pursued as much as some of the others would be. It is, however, very useful in pushing our models to the limit and really driving capability development. So, it has -- it has gotten to -- us to a place where we can, for instance, model those unsaturated -- the multiphase flow problems more efficiently than we could before. It is a really great challenge for the geologic framework and for geologic meshing software. So, it's very useful in that respect. I don't know that it has a lot of value in developing the really strong technical basis or very complete disposal concepts for it like the other host rocks do.

BAHR: So, we're gonna bring David onstage for just a quick response. And then I think after that we're going to have to take a break so that people can have a -- a bio break. David, can you -- yeah.

SASSANI: Oh, yes. Thank you, Jean. And, Chandrika, nice questions. And so a number of the past few questions -- one of the things that I would have people keep in mind with the unsaturated system is we have a very large program in the US that did an enormous amount of research on unsaturated tuff and behaviors of waste package corrosion above and below the boiling point, et cetera, and actually developed models for spent fuel degradation in an oxidizing unsaturated environment. And so those are all available for us to utilize similar to utilizing the expertise and the work developed in other international programs. So those can be applied from a technical standpoint. They can be picked up and then utilize in this -- in this fashion as a baseline of data sets and models, so we wouldn't be necessarily starting from scratch. From a programmatic aspect, Tim would have to comment more on that if he would like to.

BAHR: Okay. Well, I don't think we have time to do that and also have time for a break. So, we're going to have a quick 20-minute break. Now, we'll reconvene at 2:35 Eastern Time, 11:35 Pacific. And, Emily, again, thank you for a stimulating presentation.

(Whereupon, a break was taken.)

BAHR: Okay. I'm giving people about one minute to -- to get back from the break.

Okay. Well, it's 2:35 by my clock, so we're -- we're gonna get started again.

And the next, we're going to have a pair of presentations, a -- a tag team, as we did this morning with Irina and Emily. The next two speakers are going to be talking about engineered barrier systems, and it's going to start with Ed Matteo from Sandia National Labs and then LianGe Zheng from Lawrence Berkeley National Lab. And we'll let them do their presentations in sequence, and then we'll have a period for questions for both of them at the end of that. So, if we can get Ed on the screen, we can get started.

MATTEO: Okay. Can you hear me? Okay. Hello, I'm Ed Matteo from Sandia National Lab. And we'll be talking to you about this crosscutting research area in engineered barriers, and I'll be talking in broad brushstrokes about some of the overall activities in the EBS work package, and then I'll be passing over, as -- as Jean mentioned, to LianGe for -- for an in-depth deep dive at the -- looking at the HotBENT experiment.

So, I've been at Sandia for about 10 years. I did my dissertation research in subsurface seals, specifically in wellbore integrity during geologic storage of carbon dioxide. And then I came to Sandia as a postdoc and worked on geo-materials, reactive transport and mineralization of geo-materials, and -- and then started to move into the -- this area of nuclear waste disposal. I worked at EBS -- EBS in thermal analysis for the defense waste repository for -- for a couple years until the --those programs were suspended. And then that's when I became the --the lead here at Sandia for the engineered barrier system.

I do need to advance to the next slide. Okay. So first --

BAHR: Hover over the bottom of the slide, you could be able to see the advance.

MATTEO: Oh, yeah. There it is. Thank you. Let me test that out. Okay. So just to give you a quick overview of the topics that I'll cover

So, I'll talk about the knowledge and capability gaps related to the engineered barrier systems, and that will tie in to -- to some of the prioritization activities that were spoken to at lengths by -- by David Sassani and -- and Tim Gunter yesterday. I'll talk about what our research priorities currently are.

I'll -- I'll talk a lot about the crosscuts between EBS work package, and the three hosts lithology disposable concepts that you heard at length about yesterday. And then I'll -- I'll give sort of a summary and a -- and a look-ahead to what are sort of the future directions for the EBS work package. And then I'll -- I'll pass the -- the baton, so to speak, over to LianGe for -- for his deep dive into the HotBENT.

So, basically, first question is, what are the -- the fundamental processes that -- that represent knowledge gaps currently? So, a big focus about -- for the engineered barrier systems is -- is looking at the integrity for the seals. This includes drift and shaft seals. And one of the main things that we're concerned with is degradation mechanisms and evolution of those seals and their integrity over time, and -- and -- especially the permeability evolution as we saw in the previous talk. Kind of alluded to by Emily, was that the -- you know, the -- in order to do -- to do a system assessment route, we need to know, in some concepts more than others -- and this was spoken to in the host lithology talks, and some systems more than others. There's high reliance on the seals and engineered barriers and then others more reliance on the -- the natural host.

And then when we -- when we really look at the integrity of those seals, these processes at material interface has become very important. This could be engineered materials, say, in contact with a disturbed rock zone. I think Kris talked a lot about that yesterday. And also waste package materials, buffer, and host rock, and other structure materials like cementitious materials.

And what this really boils down to, where -- where the big knowledge gaps are in these coupled processes -- and this could be chemical-mechanical coupling, thermal-hydrologic-mechanical-chemical -- chemical coupling which is sort of the Holy Grail of -- of process models, could be multiphase flow. Multiscale phenomena becomes very important to understanding the evolution here. And then -- then also understanding how do we make the linkage between things that we could say -- understand at a microstructural scale or the -- the very tiny scale, say, of the molecular dynamics scale up to the continuum scale so that we can -- we can make sense of -- of these key processes.

In the current program, we have particular attention given to cementitious materials and bentonite. And I don't think I need to go into the details of that. I think that was explained pretty well yesterday both by Yifeng and by Carlos.

In terms of these process models, what are of the specifics? Yesterday, Carlos showed us some very nice slides about modeling the shotcrete layers in the Mizunami tunnel and using PFLOTRAN for those models. So one thing that we really want to do is be able to -- to -- to push forward these -- these -- these capabilities to model cement and to assess the -- the evolution of plugs and liners and -- and, again, the chemo-mechanical coupling can be important, especially if you -- you have fractures created, then you're increasing the surface area of the cement, and so you're --you're thereby increasing its reactivity effectively.

And that could include finding ways -- and --and this was again talked about a lot in crystalline. Finding ways to represent these -- these fracture networks as they -- they evolve.

Another important topic area is this resaturation, saturation of cement -- cementitious materials and bentonite in the -- the near field environment, these materials close to the waste packages. And, again, Carlos talked about that and showed some very nice examples of -- of evidence that we see that --- that we need to be concerned about these processes.

And we have particular emphasis in the program on the bentonite buffer, especially THMC model refinement. LianGe and his team at LBL have done a lot of work over the years in -- in looking at different length scales and looking at these -- these THMC couplings within the -- the swelling behavior, mechanical behavior, and chemical response of -- of bentonite materials.

So, what -- what would be the -- the importance, if we were to able -- be able to fill these gaps? And, of course, we could better represent the seals in the -- the GDSA analysis; and improve confidence and permeability porosity values for engineered seals. And this, of course, can be a big driver in performance assessment when there's high reliance on seals or when -- when the -- there's a high sensitivity to the seal behavior. And overall could also improve our understanding of near field geochemistry as there could be mineral phase formation, other processes that could impact radionuclide transport from -- in the near field and then moving out into the far field.

So as we learned yesterday, we've had some -- some prioritization activities that were pretty rigorous for the program. And the EBS knowledge gaps identified, we can talk about them in -- in a broad sense, falling into a few areas that are highlighted here with the red area -- arrows. One is high temperature impacts. Another would be buffer and seal studies, which I've already spoken to a bit, gas flow in the EBS. You could have pressurization in the repository and understanding how different components of the EBS are affected by that -- that increased pressurization, could be important. And then THC processes in the EBS.

To look at this another way, we can look at some of the specific activities. These would include things like evaluation of ordinary Portland cement. This would also probably include low-pH cements, cement plug liner degradation, EBS high-temperature experimental studies to understand mineral -- mineralogic alteration. And then over to -- to I-04 here, experimental studies of bentonite high temperature, like the HotBENT, which you're about to hear more about from LianGe in a few minutes. And then some of the international activities here associated with DECOVALEX, and these were from the previous DECOVALEX, moving into new activities for the newly started activities for DECOVALEX-2023. And then the -- the field test in salt that Kris talked about in length. We have some cementitious plug materials being tested there.

The EBS crosscuts both with the - the host lithology research areas and also with international activities, as -- as Dr. Gaus spoke at length in a -- in a -- in a great talk this morning about the importance of international collaboration. I don't think I need to say more about that because that was covered in great detail.

But we have three main areas where -- where we -- where EBS work intersects with an international community. And one is in bentonite buffer performance. Another is in cement interactions. And then seal performance studies.

I would like to now talk to some specific activities that have these international crosscuts, and then also just call out how they crosscut with the particular host media. As mentioned, we have cement plug and liner degradation studies, and also evaluation of ordinary Portland cement. What is the reason for this? We want to understand mineralogical alteration. Perhaps, you know, mechanical alteration. And, ultimately, we want to know how the permeability of these materials will evolve over time in the repository. These can crosscut with argillite, as Carlos showed yesterday, and also with salt as Kris showed yesterday.

So one of the -- one of the areas with argillite that we have this -- this crosscut is -- is the PFLOTRAN model where we have very nice explicit representations of -- of cement liners and/or plugs in -- in these -- these URL field tests. An international tie-in here is there's a new EBS Task Force looking at the interactions between cementitious materials and bentonite clays, and we're participating in that. And then seals and salt, again, we have the cementitious seals and the BATS heater test.

If we go down to the next row here, the EBS high temperature mineralogy, looking at alteration at high temperatures crosscuts with some of the illitization that Yifeng showed yesterday, and then some of the high temperature hydrothermal experiment results. We saw some nice SEM images in Carlo's slides yesterday as well.

TH/THC and advective gas flow, we need to understand transport and permeability. Again, this is sort of a recurring theme of what we need to understand for the EBS. Again, some crosscuts with argillite and crystalline. We have a lot of vareid studies, too many to go into detail in terms of chemical controls, both at the molecular scale and bench -- bench scale experimental results, and then drift scale test at the URLs as mentioned. And this includes activities such as the FEBEX heater test and then DECOVALEX activities, which include gas transport in clays, THM modeling of the -- of heater tests, and then BATS tests, which was spoken to by Kris. And then some high temperature tests in -- in bentonite materials, which we're gonna hear a lot about with respect to HotBENT.

Just to summarize the international, again, we have these -- we have participation -- we have participated in the FEBEX heater test, both -- primarily in the EBS Task Force Task 9, which just wrapped up in 2020. Again, we're going to be starting up on -- on a bunch of activities in DECOVALEX 2023 Task B, which is gas transport in clay, Task C, which is a -- a -- a heater test, and Task E, which is some fracture behavior in crystalline rocks.

We are also again starting up on some EBS Task Force Cement-Bentonite Interactions that I mentioned already. We have the RANGERS study, which is shaft and drift seal performance study in collaboration with German colleagues. And then HotBENT Field Test.

Looking forward, we will continue our participation in these international EBS studies and -- and -- and bring those things to -- continue to bring those to bear -- bear fruit, and also, you know, keep an eye out for emerging collaborative URL-based activities. Another area where, as I mentioned, was this of fracture development in EBS materials, especially cementitious materials and bentonite. Perhaps, there are tools from -- from the crystalline work package or GDSA, which could be leveraged for this, meshless methods or another emerging field, which are -- which could -- could be future directions for that.

And then when we talk about next generation materials, especially cementitious materials, we just want to keep in mind some lessons learned, we've learned in the past, which is making sure that we keep an eye on emerging trends with sustainability needs and decarbonization and -- coming forward. For example, fly ashes material, that's very -- can be important in low pH cement blends, and if coal power -- coal fire power plants go offline, this material may be harder to come by. And along the same lines, new binder materials are being developed all the time, and so -- you know, we saw in the early slides the -- at the programmatic level. It could be awhile before we actually are implementing a -- a repository plan, and so we just want to keep in mind that for cementitious materials, they may be evolving over that time length as well.

With that, I'm going to transition to LianGe, but first, I'll -- as I've -- as others have said, there are many, many people that work on these different topics, and the -- and the EBS work package, we have a bunch of researchers at Lawrence Berkeley, Los Alamos, Sandia, and we also have some collaborations at Vanderbilt. With that, I will pass the baton over to LianGe.

ZHENG: Okay. Thanks, Ed. As I -- As I said -- so as Ed gave you an overview of prioritization in EBS work and also the high priority research activities in these EBS activities. So I'm going -- I'm here to give you an example how those high priority research activities carry out within the campaign for -- you know, especially, you know, the HotBENT experiment, also the supporting lab and the modeling work.

Again, I'm LianGe Zhang from Lawrence Berkeley National Lab. My background is hydrogeology and geochemistry. I've been studying -- been there for -- for -- for almost two decades. It's quite long. And, yes, since my Ph.D. time.

So, let's jump into this HotBENT project. Let's see. So, let me start with the motivation of these research activities. As we -- as Ed mentioned, there's some – knowledge gap that needs to be addressed. So, this activity addresses the understanding of fundamental processes, especially the coupled THMC processes in EBS and the -- at the interfacial area at high temperature. So just putting in -- putting it into perspective, you know, in regards to the impact -- R&D topics, it will address the high temperature impacts. You know, the buffer and seal studies. And also the THC process in the EBS. So regarding, you know, the high priority research activities, you know, it relates to the E-11, you know, the EBS high temperature experimental data collection. Also, the E-9, the cement plug and the line degradation.

So, in addition to addressing the knowledge gaps, we also have a particular motivation about this study. You know, we are trying to evaluate the thermal limit of a repository. As some of you may know, thermal limit is -- one, is an important design variable for a repository. Lower thermal limit requires longer surface storage time or smaller number of samples of, you know, waste package. In terms of repository themselves, they require a lot of spacing between -- in placement tunnels and a lot of space in between waste package within one -- you know, in placement tunnels. So allowing a higher thermal limit will significantly decrease the footprint of a repository and therefore, you know, reduce the cost of the repository. So years ago, after we review, you know, the thermal limit, most country using a hundred degree as the -- as their limit. But after starting a very extensive review, we realized that thoroughly, you know, understanding of the couple of THMC process and high temperature -- and the high temperature is needed to build a strong scientific foundation to determine what should be the thermal limit of our repository.

So that's why we started some modeling work, you know, years ago to -- using coupled THMC modeling under high temperature to study, you know, what is the generic behavior of bentonite for -- under high temperature. And -- but eventually, this work, you know, leads to this -- this HotBENT project. You know, for example, in this paper, you know, Vomvoris, you know, 2015, you know, after we reviewed all of the, you know, lab study and modern study, is very clear that at that -- at that time, a large scale field experiment is warranted to really, you know, understand this problem. So that's how, you know, the HotBENT project start -- started.

You know, this project is actually composed of three parts. Of course, the core is the field test. Those are the modeling work and those are our lab work. And there's no -- please note that some -- more lab work is not necessarily, you know, funded by this whole HotBENT project. Currently, SFWST scientists are involved in three activities, you know, the high temperature column experiment on bentonite, which is running at LBNL right now. Also, the field study, and also a modeling platform. So, in the next 10 slides or so, I will go through with you each of the three activities.

So, let's jump into the high temperature column experiment on bentonite that is now running at LBNL. So, this is the configuration of this experiment. From the inside, we have -- we have a heater, a shaft, a bentonite layer, which is about three inch in -- you know, in radius, and also have a sand layer for fluid distribution. So, the water will be injected from one end at a pressure of around -- around a hundred and twenty PSI, about 8.3 bars. And then the water will be circulating around the, you know, center layer and, you know, hydrate the bentonite bar for, hopefully, you know -- you know, access circularly and then after bentonite is flooded for one day, the heater will turn on at a hundred fifty degrees. Then one week later, the temperature was maintained at -- at two hundred degrees. So, this is -- the temperature evolution at some monitoring points -- so the heater is 200 degree, and I did the point close to the center layer, the temperature is about 200 -- no. About 80 degrees. In parallel to the heated column, we also have a non-heated column, which has exactly the same setup but there's no heater inside. So, the comparison -- by comparing these two columns, we can understand the behavior of temperature in this coupled THMC processes.

So, both columns was -- was scanned frequently in the CT machine and gave us, you know, the CT density data. In addition to the CT scan, we also have electrical resistivity tomography array installed on -- you know, on -- in -- in the column so that we can learn the spatial distribution -- spatial evolution of some properties of -- of bentonite.

Yeah, here is one example, of the hydration process using the CT density as an indicator what hydration process is. You know, the higher the density means, you know, it becomes, you know, full saturated and the lower density means it's still dry. So for the now heated column, we can see that, you know, it's become, you know -- the hydration for it, you know, about halfway into the bentonite layer, you know, in eight days. And in about three weeks, it becomes fully saturated. So, one takeaway message from this study is -- is initially, the bentonite is not homogeneously packed there, you know? This is -- this is not our -- our intention. It's just like to pack a column homogeneously is very difficult to do. But when the hydration started, actually, we can see the hydration is very homogeneous.

And then comparing the heated and non-heated column, one noticeable different is, you know, for the heated column, we have this dry out zone. And it remains -- there's always a small dry zone until the very end of the experiment. Another thing we noticed is after about 75 days, a thin layer of high density at the interface of the heater. You guys see from this area here appeared and then gradually -- the density go higher under the -- you know, until very end of the experiment which we suspect is some -- you know, the precipitation with some minerals. And exactly what are these? We will find out after we dismantle these -- these two heaters.

You know, as we heard from Dr. Gaus', you know, talk, you know, monitoring is very important, you know, in the very earliest days of repository, you know, even the construction of URL's and also in the latest stage. And the sensors, you know, using this -- in this -- this test, you know, either in the column test or in field test, gave us a temporary evolution at a particular location. But we need the information on -- about the spatial distribution.

Here, we also, you know, studied the deformation of -- of this column and what we use is using the temporary evolution at some point to, you know, to study the, you know, the deformation of this column. The, you know, on the top -- top graph shows the displacement and at a point which is close to the center layers missing the outer rim of this column. We can see initially the move inwards, and then -- then move outwards. So -- and the hydration, the lowest, you know, the largest inward displacements correspond pretty well with the hydration front because in this area, you know, basically, the swelling, the outer rims pushed the, you know, push the bentonite and compressed the inner part which, you know, shows our best, you know, numerous displacement.

The lower graph shows a point which is close to the heater and it also, you know, have the similar behavior initially move inwards then later on it move outwards. But the hydration front is, you know, arrives late, correspond, you know, in, you know, in comparison with the, you know, the inward displacement and because, you know, the outer swelling in the outer rims of bentonite push, you know, bentonite inwards. It happened earlier than the hydration front or before the hydration front arrives.

So, as I mentioned, you know, most time where you can use sensor to study the temperature evolution in a particular location, but we also want to know the spatial distribution. So, ERT, you know, electrical tomography, it was really a good -- it's a good monitoring technology we can use to study the spatial distribution. Here, I'm showing snapshots, like, 11 days for both the heated and non-heated -- non-heated and the heated column. So, this is, you know, time elapse -- time-lapse resistivity results. So, after the, you know, the petrophysical calibration, we can translate the resistivity, which is function of fluid saturation, chemistry and temperature into a water content data here. You know, then we can visualize the spatial distribution or the content at different times. Here I'm showing the, you know, data, you know, the results at day 11. And that as you remember, we also have a safety scan data. So, what we learn from here actually, the ERT data is, you know, is pretty consistent with the CT scan data which will give us confidence to use such technology in the field test.

Now, let's jump into the HotBENT field-scale experiment. The test, you know, is running at the Grimsel Underground Research Laboratory. You know, in the same tunnel that a FEBEX field test was conducted. FEBEX is a Full-Scale Engineered Barrier Experiment, you know. It's studied in 1997 and the final dismantlment was conducted in 2015 after 18 years of heating and hydration. It's probably the long -- the longest heating and hydration experiment on -- on bentonite buffer, but the test that was conducted with the heater at a hundred degree. So, HotBENT will be running at a seventy -- a hundred seventy-five to two hundred degree.

So, the project now is -- is led by NAGRA, also have, you know, participation from -- from us, from Japan, U.K., and the Czech Republic, and Canada, Germany, Spain, and -- and Japan. So, the partners actually share the cost and also, of course, share the -- the outcomes of this research for this research project.

So, this is the design with this field test. It's composed of four modules, you know, heater one, heater two, heater three, and heater four, and it differs in terms of temperature and duration, type of bentonite, and with or without the concrete liner. So, basically, we have two experimental time lengths. The heater three and the heater four will run for approximately three to five years, and heater one and heater two will be running for up to, you know, 20 years. And this is particularly important for geochemical monitoring, you know. This, a lot of sensors but in a hydro--you know, hydrological behavior. But in order to study the geochemical integrations of bentonite, we need to dismantle the test and, you know, take the sample and the matrix, you know, geochemical change in the lab. So, these two, you know, experimental time length will give us two snapshots of, you know, of the geochemical change which, you know, has been particularly important. Look at the other benefit of, you know, running a test at two time lengths.

And the test will be -- we use two type of bentonite, you know, here and the H4 will be used bentonite from Czech Republic and for the rest of heaters, you know, we use in the Wyoming, you know, type of bentonite. So, there are two types of shape of bentonite. One is the bentonite pedestal which is constructed with highly compacted bentonite -- bentonite blocks with dry density around 1.7 grams per, you know, per cubic centimeter. And also, the rest of the area will be filled with granulated bentonite -- bentonite mixture with density a little bit lower about 1.45.

So, this is the timeline of this project. As we mentioned, you know, the project, actually, the conversation started in 2015. Then in 2019, we finalized the design. So, now we are under the construction time period. So, the heating is expected to start in the middle of 2021. So, this graph shows the evolution of this project, you know.

This is -- this one shows, you know, the test on the bentonite pedestals and these two shows, you know, the construction of the niche. A large niche needs to do -- to operate those bigger machines for filling the tunnel with bentonite.

Then this is, you know, the testing of heater, the testing of the -- the machine you will -- that we will use to fill the tunnel with bentonite. And these last two figures show, you know, the emplacement of the bentonite pedestal and also the first heater.

So, this is the installation of the bentonite -- granulated bentonite mixture into the space. So, this is a sequence, you know, first we installed the pedestal and the heater, and eventually will fill the tunnel with bentonite materials. And this is, you know, cross-section view of this auger machine. Just, you know, almost about a month ago, this -- you know, we finished the installation of heater one. What this picture shows what it looks like after we installed the pedestal, the heater, and also filled the space with granulated bentonite.

As I mentioned, you know, this test that will be highly instrumented with all kinds of sensors, you know, we can -- generally, you know, categorize by, you know, the sensors near the tunnel walls, which involves temperature, pore pressure, and relative humidity. I'm just using here one of the sections, you know, here, close to heater one as an example.

We also have sensors in bentonite buffer at different locations with sensor including temperature, pore pressure, relative humidity, and total pressure, water content and displacement.

And as you can see here, you know, the geochemical measurement is -- is missing because it's really hard to have, you know, sensor to monitor -- to monitor any geochemical changes, which we have to rely on the dismantle of the heater of this test to study the geochemical changes.

So, you know, as we expected, this test will give us a lot of, you know, good data on the THMC evolution of bentonite buffer under high temperature. So, it would be a really, really useful data to test our model capability.

So, about a half year ago, we established a modeling platform. In this platform, the -- the goal is to -- that you can experiment on the model, talk to each other and you -- so that we can learn from the test and also we can have the, you know, the field operation.

So, the goal is to have an expedited data analysis and the model updates to understand the system and also to support the decision-making. Also, we will conduct, you know, a blind prediction as part of our model validation process. And like I say, if our model can predict the behavior of this HotBENT field test, our confidence will be, you know, significantly boosted.

Also, we will benefit a lot -- a lot from this multiple modeling teams. For example, you know, each team may have different alternative different conceptual model, which help us analyze conceptual understanding uncertainties. You know, when we talk about uncertainties, we always think about, you know, parameter uncertainties, but actually there's, you know, there's one big uncertainty spotted, the conceptual, you know, uncertainty -- uncertainties. And, also different teams with a focus on different aspects of this, you know, models, hypothesis and data and predictions, you know, by, you know, this, you know, this team effort of hypothesis testing you know, gain insight from this integrated and comparative -- comparative analysis, and, of course, we share information and expertise in this collaborative environment. So, SFWST has been, you know, supporting HotBENT with scoping calculations and also by joining the modeling platform.

And here is one example that LBNL, you know, was conducted in using the 1-D THMC model to predict what we, you know, what will happen if the temperature is 200 degrees instead of 100 degree, so -- especially with geochemical evolutions. So for the modeling platform, we know LBNL, we're showing this, you know, this task with the goal for 3-D THMC model. But the way we do it, you know, step by step, you know, gradually increase level of complexity, you know, starting from TH and then THC/THM eventually.

We'll look at the THMC model, then we also started, you know, from 1-D, 2-D, eventually we got it to, you know, 3-D model. Sandia National Lab will also, you know, join the modeling platform and their goal is to study the THMC processes at the interfacial area especially, like, in the model, you know, the metal corrosion and in the metal-buffer material interface.

So, to summarize, you know, this HotBENT project that is composed of lab study and a field test, and numerical models is ongoing. And the heating is expected to-- you know, the heating and the field test is expected to start around June 2021. So, actually, it address several high priority research topics within the campaign, and it will improve particularly the understanding of coupled of THMC process in EBS and interfacial area under high temperature. It also helps us to study the thermal limit repository. It increases the confidence in modeling EPS and the crystalline host rocks.

And here are some, of course, you know, this is a team effort. And I thank you my colleagues from LBNL, also here I would, like, you know, particularly thank Dr. Vomvoris and Dr. Kober from NAGRA, who, you know, provided me with these materials. And that's all I have. And I would like, you know, I will be happy to take any questions.

BAHR: Thank you, LianGe. And also Ed, we could probably get Ed back on the screen to answer questions as well. LianGe, I want to start. I applaud you for employing the multiple modeling teams particularly to explore alternative conceptual models. I'm wondering if you have any more information that you can provide on what are the differences in those conceptual models that are being -- being used, and have the modelers done preliminary runs to identify cases where the models would diverge, and then thinking about where those models diverge, what kind of data do you need to collect in order to discriminate between the models? What -- what sets of data would tell you that this model is conceptually better than the other one?

ZHENG: Yeah, that's a really great question. And I think it is one of the areas of which have higher uncertainty. And in terms of conceptual model, especially, you know, regarding the THMC processes, you know, we can concept-- you know, the THMC processes is very complicated. We conceptualize it in a -- in a various way, you know, it can. For example, for the hydration processes, we can, you know, simulate it is -- as a, you know, multiphase flow, we can simulate and we focus on only, you know, one phase or two phase. And we can, you know, consider, you know, different way to how do we simulate a evaporation within the bentonite buffer. And also, regarding, you know, especially the couple processes, we can, you know, for example, the porosity and the permeability change as a result of swelling, we can deal with the ways with, you know, relatively simplify – simple way or, you know, it's a really compact -- complex model which deals with the very detailed and mechanistic distribution of the bentonite swelling. Also, you know, regarding the conceptual image of the mechanical behavior is also very different. You can, you know, do it if it's a high-level way to, you know, to study the swelling of bentonite and you can do it with various details with simulated tests.

Regarding how do we discriminate of which conceptual model is the better? Actually eventually the data will tell us and think what I learned in the past actually is how to pinpoint one -- one type of data, but the way I learned actually is we need a comprehensive data involves all the THMC data. And also, if -- if one conceptual model can reproduce various kind of data also in the longer timeframe, and I think at that point, we can sort of can, you know, can reach some sort of conclusion that this conceptual model may work better for us.

BAHR: I guess, have you -- have you run the models and found the points at which they diverge? I mean, there are -- there are many cases where, by calibrating different models, you can get several different conceptual models to actually fit the same set of data. A good example is the equivalent porous medium models that can be used sometimes to simulate fracture flow. And so, unless you collect data that -- from the places where those models would actually diverge in their predictions, you don't really have a good way of telling which model is right. So, I guess -- I guess I'm asking, how are you approaching that issue of non-uniqueness of -- of models?

ZHENG: Yeah. Well, this is one of the biggest challenges, you know, in terms of modeling, you know, the non-uniqueness of -- solution of. You know, like you mentioned, often, you know, you have different conceptual model, after calibration with those parameters, you can reach similar level of goodness fit with data, right? So, I think that divergence really show up when you try to model various type of data in a longer timeframe.

For example, what I learned from the FEBEX I situ test, the modeling, you know, a lot of model can model -- can reach similar type of integration of goodness fit for the first of this modeling event, but if it's triple with this model, to second this modeling, which, you know, happened, like, 30 years later, then, you know, why did those model -- still whether or not, you know, can be -- so the -- so the divergence will happen, we predict, a long-term behavior. Or we have multiple time -- time points of data for the spatial distribution.

BAHR: Okay. Thanks. I'll turn it over to some other Board members for questions. Tissa. You're up first.

ILLANGASEKARE: LianGe. And thank you very much. So, I have a general observation and a question that's related to sort of following up on Jean's questions.

So, I think it's really very important that you have recognized the processes at the interfaces. I think people have -- look at the interface problems in traditional geologic settings, but this is one of those complex problem you are looking at interfaces of engineered system and natural systems. And within the engineered system, we have different materials and those interface problems are very challenging as you know because the physics of one system is different from the physics of the other system, and the coupling interface creates a lot of numerical issues, as well as fundamental issues related to how do you -- do you allow two constitutive models at this time. So that is really good.

So, my question has to do with the experiment, and it's a really interesting experiment. And so, you are actually safely use the term validation within quotation marks, so that means that really validation is not a thing, which is -- which is sort of developed for these type of problems. So, my question is that, do we have some sort of metric that we are going to use to say that the model is validated? So the reason I'm asking this question is the -- the traditional validation, the traditional ground model, what we do is we calibrate the model and then use an independent dataset to see if the calibrator model matches with the -- with the independent dataset.

So having thought about some similar ideas, whether you can use this dataset and use part of the data to actually test the model, and then try to see that the model can predict part of the dataset, which you don't use in your sort of model validation, that's my first question, but you can answer both.

Second one is I was looking at your -- the whole -- the clay, and then one of the instruments used, maybe it's there, but I didn't see it. But I think that some of clay materials, one of the issues is the fractures and micro fractures, I think probably thermal. So, I think the fiber optics, because we have a project, we are looking at fiber optics in fracturing -- for fracturing soil, so have you considered fiber optics in this instrument? Or is it too late to look at those?

ZHENG: Okay. Thanks for the question. It's -- yeah, so let me answer that validation question first. So in this modeling platform, we would start some sort like called plan prediction without any calibration. But the, you know, based on the baseline calculation of bentonite, we know the basic properties, you know, put those properties in the model and see how it goes. You know -- you know, in the future compare with -- with the, you know, field, the data collected in the field.

But of course, later on, we will, you know, we will calibrate those models based on the data we know. So -- so -- the -- the model, at the same time, make a long-term predictions, so that's the process. And in terms of metrics, I think, you know, we will use, you know, as much as data as possible from the field to the validation. And then -- but, you know, as some models may have --maybe limited, you know, in terms of their capabilities, they can only be validated by a key type of data, not all the -- all the -- all the data, you know. But I think it's great to have such metrics to consider systematically validate those models. So yeah, actually, I think I forgot to also mention that in this HotBENT field, we use, you know, optic fiber in those --in -- in those instrumentation sensors, so -- but, you know, they already, you know, installed all those instruments and sensors, but I can relay your, you know, your message to NAGRA and see if we can -- we can, you know --

ILLANGASEKARE: You know, we had -- we had an experiment quite recently with Berkeley. We have actually put fiber optics in a -- in a silt layer and then we actually increase the temperature, just surface cracking and we can see very, very micro cracking in the -- in the very small cracks, and even now, it is not in a paper, but we have the data at least, you know, in some the people in your lab that works on this project. Thank you.

BAHR: Okay. Thanks, Tissa. Next up, I see Bret Leslie. All right. Can you stand up?

LESLIE: Yes. Thanks, Jean, and thanks to LianGe and Ed. And I'm not sure who's going to answer this question, but it has to do with the HotBENT experiment and its applicability to kind of the crystalline host rock case. Yifeng yesterday talked about how the rock, the crystalline rock can handle the 200 degrees c in one on the most significant issues for repository in crystalline is sealing of fractures, conductive fractures. So, are there any conductive fractures or open fractures in the HotBENT drift that would give you insights on how well bentonite would work under a real case where the primary safety function is sealing conductive fractures?

ZHENG: In the -- the HotBENT test, the -- the granite tunnel actually does not have significant fractures zone. Although there's one area which, you know, we know that permeability is higher than the other area, but there's no, you know, significant fractures that allows us to tackle this -- this -- this issue. So just answering your question directly, you know -- you know, it's not going to really address the sealing of fractures in -- in granite. The focus is most likely on the, you know, the behavior of -- on bentonite buffer itself.

LESLIE: Okay, thank you.

BAHR: And then Chandrika?

MANEPALLY: Hi, LianGe, it was a very nice presentation, thank you. I just wanted to ask maybe both of you, is there a -- a -- a coordination of your modeling work with your other lab experiment or a field experiment where they inform each other and as you move forward with your experiment, the modeling work is informing you where to focus, where you can -- is there flexibility to change your -- what you're monitoring? Is there some kind of interface or, you know, exchange of information between these teams?

ZHENG: Yeah. Certainly, I think -- certainly we have a lot of, you know, coordination between the lab modeling and field test. Actually, the lab test, actually, initially was designed to support the field test because, you know, we want to find out, you know, -- especially, it support the design of the field test, we want to find out what would happen in the field, you know, when we hit bentonite with 200 degree, you know, what are -- how fast hydration would be, you know, what kind of pressure we need to use in the field to make -- to reach desirable, you know, hydration status. Of course, modeling, you know, is, you know, extensively used in the initial design phase, they'll give us, you know, scoping calculation, what we expect in the field. And also, about, you know, the locations of the sensors, all kinds of stuff.

So -- but eventually later in the field test, (inaudible) refine our model. So, all the things are like, you know, I think it's well-integrated and well-coordinated. I think, eventually, we realized, you know, to -- in order to understand the THMC processing in bentonite, that we need all three components, lab, field, and modeling to function properly and coordinately to give us the best result.

BAHR: Okay. I saw Bobby.

PABALAN: Okay. I have a question for Ed. Ed, on your list of key knowledge gaps, and also on your list of early priorities, are studies related to cementitious materials? Now there have been a number of studies, European studies that have done. For example, there's the 2009 Nuclear Energy Agency report on cementitious materials related to safety cases for repositories. Have you looked into -- looking at the experiments that have been done, for example in URLs, to see what data you can use to at least help you determine, prioritize the experiments that you need to do, maybe design some of those experiments?

MATTEO: Yeah, we -- we have acquired some of the -- some materials, like, from the cement interactions experiment where they've placed, basically, cement plugs into clay formation. We have some of those materials and we've done characterization, others have also done characterization.

One of the -- one of the big things we see in those -- those experiments is actually the -- the clays appeared to be more heavily altered from the alkalinity in the cements than the cements themselves are necessarily altered. But, you know, in the grand scheme of it, that they are shorter-term experiments. And that's one of the reasons we want to develop first, these sort of bench scale capabilities for leaching tests, which we've -- we've done in the -- in the last couple years.

And then develop the computational tools to -- to do better prediction beyond the timeframes of -- you know, one of the big issues with cements is, typically, they're designed for a -- a hundred-year service life. And we're putting them into an environment for a much longer service life than that. And also, an environment where there are things that dry out or going to have pretty -- can have potentially large effects. So -- but, yeah, I think in terms of using those field tests to -- to help us. Certainly, in the BATS test that's going to be very helpful because we -- we will have those and placed in our -- a bunch of tests of the cements and the -- the German URLs from some other seals tests. Those are sort of cements, but salt concrete is really a lot of crushed salt with a bit of OPC added to it. So --

PABALAN: Okay. Thank you.

BAHR: Okay. I see a question from Bret.

LESLIE: Okay. And this question is for LianGe. It has to do with the HotBENT experiment, which is building upon a question that my colleague, Andy Jung, answered earlier which is concerning waste package degradation. Well, this HotBENT is really focused on the bentonite aspects of things. How well-characterized is the heater in terms of its condition when it goes in and any corrosion that might occur during the heating test itself? And how might that information be used to support any sort of conceptual model of the degradation rates at those 175 to 200 degrees C?

ZHENG: Yeah. So, the heater was in place in a -- in a carbon steel canister. So, really it's the canister that is corroded. So, in addition to -- on the -- you know, when we dismantle for example, the heater three and heater four, we will learn a lot what happened to the surface of those canister and the interaction between corrosion products and the bentonite buffer. But in addition to that, we also have a lot of coupons that was buried in bentonite at different locations and it was different materials. And also, you know, we have all kinds of, you know, carbon steel, you know, alloys, and, you know, which could be used as a canister material. And that -- those things -- well, also those coupons will also tell us a lot, the corrosion at different, you know, humid and temperature conditions and that connection between, you know, corrosion products and the bentonite buffer.

LESLIE: Thank you, LianGe.

BAHR: Okay. And I don't, at this point, see any more questions. We're just about at time. So, I'll give one last call for a question. Seeing none. I think that's great. We can move on to our final tag team of presentations. We are going to hear from Jens Birkholzer from Lawrence Berkeley National Lab and David Sassani from Sandia National Lab. And they're going to be discussing the Disposal Research R&D Five-Year-Plan. I see Jens.

BIRKHOLZER: Hey.

BAHR: I will go away.

BIRKHOLZER: Okay. I'm trying to figure out how I can show my mouse here. Where was that again? Oh, there it is. Cool. Great.

BAHR: At the top, you should see there's a little arrow. There's an arrow with a star that will be a pointer. So, if you click on that, there you go. And just (inaudible)

BIRKHOLZER: Yeah. Thank you. Thank you.

BARH: If you just kind of hover at the bottom of the screen, you'll see the slides and you can advance them. Okay?

BIRKHOLZER: Okay. Thanks very much, Jean. My name is Jens Birkholzer. And I'll be giving the first part of our tag team here. And that part is focusing on international activities and how we prioritize those as part of the campaign. I am a senior scientist and also Division Director at Lawrence Berkeley. In the context of today's presentation, I have maybe, two other hats on that are relevant.

I do coordinate the international activities and outreach for the disposal research part of the campaign. And I also -- I'm currently the Chairman of the International DECOVALEX Project which is this sort of model comparison project in the nuclear waste world where we compare various modeling approaches against datasets from -- from experimental activities both in the lab and in the field.

So, I don't really want to talk too much about the international program per se because we did that in the spring of 2019 meeting. But just to recap here, we started to engage and -- and initiate an international research program which has -- over the years, has grown to be really sort of the centerpiece of the campaign. And we largely have started engaging and partnering with multinational initiatives that were already out there and that we, as DOE, started to engage in, particularly where we saw opportunities for active research and engagement with -- with -- with experiments and underground research labs.

So, that includes things like the DECOVALEX Project, the Mont Terri Project, the Swedish SKB Task Forces, FEBEX-DP. We heard a lot about that. And just recently, HotBENT. There are also some other opportunities to engage in information exchange, Nuclear Energy Agency, Clay Club or Crystalline Club or Salt Club. And there's also some European Union Projects.

And in addition, there's bilateral collaboration with different countries out there. We have fairly close collaborations across a wide -- a -- a broad range of individual organizations. And one example for it -- for example is -- is what we do or have done with -- in terms of salt disposal progress with the German organizations.

Now, I don't know if you remember this sort of very high-level overview graphic that kind of shows where we have engaged since 2012. You see, and color-coded here, different research themes. You see one third of this pie, each has sort of a host rock salt, argillite, crystalline. And then in the center we have EBS. And then each of these individual boxes here with the country that it -- it's associated with is its location is a, in some cases, large international experiment that we have participated in. And you see, you know, some of the -- the acronyms you find in the -- in the back of my presentation here, and I don't want to go into detail. I just wanted to show that there's a lot. We have a broad program and it is quite balanced in terms of host rock specificity, in terms of the engineered barrier system, in terms of scale going from inside, outside, and then also in terms of the research theme. I'll leave it at that.

And I just want to talk a little bit about what motivates us and how we prioritize. There is obvious scientific and technical benefits of international collaboration. Some speakers have already alluded to that. We know Lucy in particular. When we started this in the 2010-2012 timeframe, we really wanted to tap into the global knowledge and also gain access to international datasets and experiments. And with those, then of course we could test and validate our development process modeling tools, experimental tools, et cetera. Since we were and we are in a generic space, we also thought that it is critical to understand issues, which is sometimes surprising issues when you deal with real rocks and real sites and, hence, our interest in engaging with countries that have underground research labs that are already in site selection, site characterization stages. And, of course, someone mentioned before, there is something to be said about leveraging resources and sharing cost of science campaigns and particularly large experimental projects.

There is other benefits. Simply building relationships, being seen as a committed international partner can be handy when discussing say, disposal best practices or lessons learned. We heard a lot about risk communication, site selection being important. And then someone mentioned the -- the building a new generation of waste disposal scientists. I think in the U.S. that it is quite or has been quite important because all the Yucca Mountain folks are ranging out. The sheer fact -- and I see it in my organization, the sheer fact that we have really attractive international datasets and partnerships that we can work on attracts our younger early career scientists to be work -- want -- wanting to work in the field of nuclear waste disposal.

In terms of how we prioritize, we laid out some principles in the beginning. Obviously, we want to be working on key technical issues identified by the campaign with relevance to safety. And we're also looking at little bit at cost/benefit, of course. We started from the onset to emphasize active participation, particularly participation that could give us access to URL, experiments. And then I mentioned before, we were interested in balancing a portfolio that would tackle all host rocks that we're interested in, repository designs, and key R&D areas.

Here I wanted to quickly discuss how we integrate planning of the campaign’s priority research topics and international collaboration. Dave was earlier talking about our road mapping exercises. In the 20 -- 2010-2012 timeframe, we had a first roadmap initiative that identified high-priority research needs.

That was done without really thinking too much about international collaboration. But we took that then, we took those research needs and then looked out there, what is currently happening, where could we engage, what are the relevant, experiments that we could participate in, in order to meet these research needs?

And then later in 2019 when we came back to update the roadmap, we did it in a different way, we fully integrated international activities and potential for new experiments into the discussion about updates on the research needs. And, of course, we do things in between. We don't really wait for these workshops.

We have essentially a process of continuous re-evaluation that is typically done in the annual campaign working group meetings we have once a year. So, we look at emerging or changing research needs. A few years ago, gas pressure buildup, became a hot topic, seal performance, and recently, interfacial processes or campaign changes priorities, higher thermal limits related to DPC's. And at the same time, there may be new international opportunities that have been developed, say, DECOVALEX-23 which just started. In some cases, we are creating those opportunities and then we're putting all that together and re-revising our portfolio.

Just going back to the campaign structure, you may remember, I think Tim showed it, we have host rock specific accounts or -- or themes. We have crosscutting themes. And international is one of them. But I can tell you that this is a very lean and very small theme here because it only includes me and my planning and coordination activities. There is no actual research in there.

The reason for that is that we wanted the actual international activities to be sitting in the same work package where also the generic activities are conducted. So, these are fully integrated. So, I am essentially the enabler or connector or coordinator that will work with, say, Yifeng or Carlos or Ed or Emily and others in order to do an integrated planning opportunities.

Also just sort of an observation that we really have been changing our mode of operation from initially just participating in ongoing efforts into actively planning and creating opportunities as time went along.

And there are a few examples where we really have recently taken research leadership and active engagement in this international context. HotBENT is one example where we have from the beginning on worked with NAGRA and others. We have now a task in the SKB EBS Task Force, which is -- which was -- was presented by LianGe, the HotBENT lab experiment and he's leading that task. We're chairing the DECOVALEX Project and we, in that project, have now two tasks that are led by scientists from Sandia and include work that is close to our hearts, the BATS salt heater test, which Kris is leading and the -- the performance assessment task, which -- which Emily is leading.

With that, I just wanted to give you a few sort of examples that -- that bring out some topics that I wanted to mention. The first is that we really, when we are engaging in new research -- research themes that we value an integrated planning of multi-scale and sort of individual viewpoints that work together and international is part of that. When we started with high temperature effects, we wanted to understand the fundamental alterations that could occur and that's done with sort of small-scale lab imaging of heated set of bentonite samples for example.

But then we also need to understand really how the entire system behaves, a system where all the coupled processes occur together and that could be done, let's say HotBENT, with a lab experiment or with an international field experiment. And, of course, modeling placed into the pair and then optimization studies.

And all those lessons learned then feed into performance assessment. And into Emily's group, taking some of these, you know, high fidelity models and translated back into models that can understand the impact on performance. So, we laid these out, and in this context, we then were -- it became clearly -- pretty clear that we needed a field -- in-situ experiment at scale.

And that brings me to another topic that if you do engage internationally and if you do want to build large, long-term experiments, you really have to engage in long-term planning and you have to be willing to go the full Monty in terms of sometimes five, ten, or twenty years of -- of building a program and executing that program.

Here is an example of HotBENT. We really started discussing the need for high-temperature research in 2013. Initially with NAGRA in 2015, there was a joint paper, which LianGe mentioned earlier -- Irina, in fact, is on that paper Stratis Vomvoris of course. It made the case that an in-situ heater test will be needed. And that paper then was used to build a coalition with other partners that were all interested in engaging together and then sharing cost and then building a partnership that could -- would eventually lead to -- to this heater test that is starting next year. And it will run for 10 to 20 years, so we really have to make sure that there is a consistency throughout the time period which also includes a consistency of course in funding.

We can also smartly combine and sequence our international activities. This is an example from DECOVALEX. And whoops. And an example where we were interested in better understanding gas migration in clay-based materials.

We started with a very fundamental sort of modeling of lab experiments in DECOVALEX-2019 which went from 2015 through 2019, with lots of individual different modeling approaches being tested.

And now we're moving this into a new type of phase in DECOVALEX-2023 which is about understanding on a full-scale behavior in comparison to a field experiment called LASGIT at Aspö Hard Rock Lab. And we're doing a blank prediction -- there was a question early about gravitation, we're doing the blank prediction from the approaches here to those at larger scale. And depending on where things go, we may actually think about engaging in another field experiment that is heading to testing gas permeable seals, which would allow gas pressure release as while hopefully still being a seal for -- for water migration or fuel migration. That's the gas experiment at the Grimsel Test Site.

Finally, we are also forward-looking a little bit. Here we started activities that have to do with us being interested in moving from the current stage of, say, generic concept evaluations in which the campaign is heading towards the next stage that will be site selection characterization.

I think we are well set up in terms of best practices and lessons learned because we have very close collaboration with countries that are at different stages in this sort of site selection, site comparison stage. Germany very early on I think similarly with the U.K. Switzerland already now down to three regions and detailed characterization. Canada, same thing with two sites. And then, Sweden already, you know, almost at the end of their detailed site characterization process. So, lessons learned in terms of how to conduct siting, how to work with the public, how to do communication, we can learn a lot there.

At the same time, we have been developing site characterization methods where we felt we --we could advance the science and we could feed some of the scientific needs. I don't want to go into detail. There is a project that has been and is being conducted about characterizing flowing fractures in relation to the hydromechanical behavior in the deep borehole in Sweden and also a fault characterization study at Mont Terri in Switzerland. Both of these are by the way, co-funded by non-nuclear waste related parts of the DOE. So, there is some -- some crosscutting value in that.

With that, I am summarizing my part of the presentation. Just really briefly, active collaboration is a central and fully grated element -- fully integrated element of our research program. These activities have been extremely beneficial I believe. And here you can read yourself for those benefits. We are prioritizing those activities in an open and in an integrated and a frequent planning effort across the campaign. And I would say that there is always opportunity to expand if we have the desire to do so, and the needs to do so, and the means to do so.

There is a report that is written every year, I just want to point you to it if you have more interest. There are the acronyms and abbreviations that I used, have been used here if you want to take a look later. And with that, I will hand it over to Dave. Thank you.

BAHR: Thanks, Jens. It looks like Dave's coming up, so we're --

SASSANI: Thank you, Jean. Thank you, Jens. Very nice coverage there. Good day to everybody, probably afternoon for most of us, if not all of us at this point. I'm David Sassani. I am at Sandia National Laboratories. I'm the National Technical Director for the Spent Fuel and Waste Science and Technology Campaign for the Department of Energy. And I spoke yesterday to some extent about what we've done within the campaign and -- and its previous namesake, the Used Fuel Disposition Campaign for doing planning and prioritization of our R&D activities and disposal research.

And as Jens just summarized very nicely for our -- the international part of our work, the evolution that's gone on through time has taken us from harvesting the information, to collaborating directly, to now planning and running some international activities, and where we're going with that. And I'm going to continue talking about moving forward. And today I'll cover Disposal Research Five-Year Plan that we put together this past fiscal year and in 2020. And I'll give you some details on that and how we're utilizing it and what it does for us.

So just a little outline of the talk today, program planning introduction, a little bit of overview and background regarding challenges for planning within the generic program, and just a recap of the completed prioritization efforts and the disposal research campaign current coverage.

And then I'll go into the five-year plan, a little bit about its purpose and structure. And then walk through the R&D priorities for each of the technical areas within our campaign, within the disposal research program. Jens showed some of those listings of those and I will as well. And then I'm going to give you a current integration example from our just completed fiscal year 21 planning that occurred between the end of September and into October. And I'll finish up with some summary and conclusions today.

So, this is a figure that if you were in the meeting yesterday you saw a number of times. Tim presented this and it got presented also to some extent in my -- my talk. There is the generic disposal concepts that we started out with salt, argillite, and crystalline examples from international experience. And our -- our basic goals for the program over here that Tim has covered looking to develop the sound technical basis for these multiple viable disposal options in the U.S. with increased confidence in the robustness of those concepts and developing science and engineering tools to support the disposal concept implementation at some point in the future.

The challenges that we have for planning relate to the wide range of geologic disposal concepts, so this is generic stage. Irina covered this very nicely in her presentation. So you do things slightly differently. And we're attempting to constrain the generic R&D most important for each of these concepts and then to define how -- how much is complete enough for the generic R&D. And we also want to take advantage and utilize the vast international experience and integrate that with our other crosscutting activity aspects in a clear fashion within the program. So those challenges are -- are not things that are bad. They're just what we need to deal with when we're doing our planning and prioritization.

So, the drivers on planning and prioritization, Tim in his presentation to kickoff this meeting yesterday, he covered these in a lot of detail. Program direction, which when I put this in here, it refers both to directional in scope, as well as budget direction that comes from the congressional appropriations, the generic nature of the R&D studies, and focusing on the safety assessment capabilities that Emily covered and spoke to in one of our more recent activities in the -- unsaturated zone systems that we're doing. And the international investigations which include very site-specific work, as Jens put it, on actual rocks, actual sites, with actual URLS. And those give you a vast insight as to what aspects need to be considered and covered in a program.

I covered in detail in my presentation yesterday our completed prioritization efforts on the campaign, the 2012 roadmap and then the 2019 roadmap update. And those take about two years to complete, so they are large-scale planning prioritizations. And, you know, something that you might do on a five-year basis, plus or minus depending on what's going on. But as Jens indicated, there's also a continuous reassessment that we do, at least on an annual basis, with our annual meeting, annual assessment of priorities, annual budgeting that comes from the congressional appropriations, all of that. And all of this leads to the entire package of disposal research coverage.

And I'm showing here again a flow diagram for the SFWST campaign for FY20, because that is the fiscal year in which we wrote the plan, so it is based on this and just the disposal research side of things. And you've seen this many times. We have host rock focused technical areas. We also have crosscutting technical areas as well shown here. And the geologic disposal safety assessment is sort of a unifying, integrating force across all of these activities to give direction, as I think the question was asked, how do you know what to incorporate, you know, and show whether it's important to safety or not, that's an iterative process that starts with the evaluation of features, events, and processes and then goes to building things into the safety assessment and then doing sensitivity analyses and uncertain quantifications that give you the insight to make those decisions.

So here is the Disposal Research Five-year Plan. At least there is the cover sheet of it. This was authored by myself and the technical managers for the technical areas in disposal research. Jens Birkholzer is one of those, Emily Stein is, as well, and then Geoff Freeze and Chris Camphouse are the other two. And the purpose and the utility of this five-year plan is that the strategic guide to work within the disposal research R&D technical areas and those are control accounts, in the PICS-NE system, the DOE -- the details of management and planning are in for the Department of Energy. And it's a concise consolidated plan report for the disposal research program.

Well, what does concise and consolidated mean? Well, it's the entire report is 40 pages, I think it's 41 pages long, and it's about 30 pages of actual text and content and information, 10 pages of front matter. So, it's fairly directly readable. It provides the thrust topics in each of the disposal research technical areas. It's a living document that we plan to update annually.

This is the shorter term, re-planning, reprioritization aspect and that will be based again on the program direction, the technical progress that has occurred within that year, and our enhanced knowledge and understanding of each technical R&D topics those -- that we've laid out and prioritized.

The structure of the plan is a relatively simple one. We look at thrust topics in each of the disposal research technical areas for both of the near-term, which is about a one to two-year timeframe. That is basically the present disposal research R&D portfolio with some hoped-for modifications modestly in the next one to two-year timeframe. That's a fairly certain period of time on these programs that are annually funded by congressional appropriations.

And then there is a longer-term look on a three-to-five-year time frame, again, where the thrust topics are laid out which provide a vision of where the disposal research R&D is heading, and that's considering no major program changes occur in that timeframe.

We may be fortunate, or stuff may happen and we'll have to re-plan and reprioritize. It's implemented by executing the work and revising the plan each year. And the real details of implementation is the annual planning that gets loaded into the PICS-NE system which has all the work packages in each of the technical areas and I'll speak to one of those towards the end in an example where we did some integration re-planning in fiscal year '21 planning.

The first revision of this report will add reports on the progress for the short-term thrusts and the bases for any revised prioritization to the thrust topics therein. So I'm going to go now through these thrust topics for each of the technical areas and highlight some of those in short-term and long-term aspects.

So here are a couple, first starting with the argillite disposal R&D. You've just heard a lot of work that we're doing in these, in this meeting, so I'm not going to spend too much time on this. And in the near-term, which again is the one to two-year period. It's one of the -- one of the highlights is the coupled thermal, hydrologic, mechanical, and chemical processes. That's one of the thrust areas for the argillite.

And out in the longer term, in the three-to-five-year period, there's a couple of thrust areas, thrust topics. And one of those is to focus on the field testing and process understanding from our international collaborations and get that incorporated into our models and move forward with models for safety assessments.

In the crystalline disposal R&D technical area, the near-term thrust topic highlighted here is the flow and transport in fractures, including matrix diffusion interactions, which may be quite important for aspects of the transport timeframe. Longer-term thrust topics is looking at candidate buffer materials under a range of disposal conditions. The HotBENT test is a test regarding the evolution of the bentonite backfill, and so we would look at candidate buffer materials from tests such as that, but also look at potential additives that can go into buffer materials over this longer time period.

Moving on to the salt disposal R&D area, I think you saw this very well in Kris Kuhlman's presentation.

Near-term we're really looking at the effects of heat-generating waste on the evolution to salt, and particularly brine availability and movement within the salt itself. In longer-term thrust topics integration of the models that we developed based on these tests and process understanding into the safety assessment framework will be a focus.

In terms of the Geologic Disposal Safety Assessment that Emily covered very nicely today, near-term thrust topics to emphasize, and the questions regarded this, is development of uncertainty quantification and analyses and sensitivity analyses and capabilities to extend those and to answer some of those questions about what really matters in terms of the safety coming out of the safety assessment. And also looking at repository systems analysis, this will be a shorter-term thrust, doing the things we do on each of these potential concepts, demonstrating capabilities to do the safety assessments for those.

Longer-term is going to be incorporating models from host rock investigations. That is taking the process level, develop models, and incorporating them into the systems scale to assess how those change or affect the safety assessments themselves.

Now, the direct disposal of dual-purpose canisters, there was a full Board meeting held this past July in 2020.. I think it was the first virtual meeting of its kind I attended, I was not a part -- a participant, although I think maybe I answered a question or two, but I'm not going to go into a lot of detail here since we just did a whole meeting on it. But this is the diagram that synthesizes the activities that are going on in this technical area. And for those of you who were not at the meeting, if you look -- go from the center of this diagram out on any spoke, basically you're moving from before any dual-purpose canisters were loaded, to the point we are currently in 2020 where about 3,000 are loaded, and then moving in a future timeframe to 2030 where more will be loaded, and then out even beyond that to where the rest of them, rest of our spent fuel would be loaded in dry -- these dual-purpose canisters in dry storage.

So it's before any are loaded, to where they are all completely loaded, temporal evolution from the center to the edge, shown by these concentric circles. And activities that we're working on to assess the feasibility of doing this are then shown by the pie wedges and covering whether they cover simply later to be loaded packages where you have to re-arrange -- redesign baskets or do fuel modifications, or if they cover both the current suite that are loaded and the future ones. And some of those were focused on short-term of the criticality consequence analysis and the injectable filler testing and analysis studies. And in the longer-term, we want to do a demonstration of injectable filling testing of dual-purpose canisters. So that's the focus there.

This next slide covers the international collaboration that Jens just spoke to in detail. There is a little inset of his diagram that he showed. And in the short-term continuing to look for new international opportunities is a focus and being more active in terms of conducting and planning the experimental work, also shorter-term thrust. And in the very long-term, and Jens stated this also, developing the best practice technologies for site selection as we go further into this generic system, that's a focus here as well.

The engineered barrier system, you heard Ed Matteo and LianGe Zheng from Berkley talked to this to a certain extent and then in the short-term the bentonite buffer drying and re-saturation processes is our focus.

And longer-term particular things like HotBENT, those underground research laboratory studies for the performance of the engineered barriers and the design materials used in the system, even including cement and concrete, things like that. That's -- that's a bit longer-term focus.

The Online Waste Library, which is an inventory and waste characterization activity, near-term thrust, or as the change control process and a release control processes for the Online Waste Library, which were just put in place this past fiscal year and implemented for releasing version two of that. That's a short-term thrust.

And then in longer-term, considering interface capabilities for developing inventories for the safety assessment framework is a thrust.

I think this is the last set. Here's technical support for underground research laboratory activities. You heard no presentation on this, but there is an activity set where we're looking at utilizing an existing tunnel underground, the ESF at Yucca Mountain, not for characterization of that site but for doing passive monitoring for generic, unsaturated systems things like temperature, relative humidity, airflow, compositions, to characterize the breathing under ambient conditions of such a site. And then, if ventilation is run, how does that affect it.

There's -- also in longer-term, it's actually is collecting the data over a long timeframe for use in a generic, unsaturated system. And that passive monitoring case, and also looking at cosmic radiation detection activities, and making those measurements.

This last topic area you have not seen yet because it is not a disposal research activity, it is a campaign management control account, the knowledge management area. We've been very actively working on this. And in the near-term, the basic thrust is to expand the topical coverage beyond the disposal research program that has been the focus to this point and expand it into the storage and transportation R&D area as well.

And then for longer-term thrust, it's to greatly expand the efficacy of this knowledge management repository to larger portions of the nuclear energy fuel cycle community beyond just SFWST.

So now, I'm going to move to an example where we actively were using our planning of the five-year plan and our annual planning activity to do some integration and reassessment. And this has to do with what I just showed you in terms of the OWL, the Inventory and Waste Characterization control account which we changed dramatically in the FY 21 planning.

It is a good example because it focuses on our waste form characteristics and development and particularly a lot of spent nuclear fuel characteristics for post closure. And this was an aspect that was actively being worked from a modeling and a testing standpoint in the 2010 to 2013, '14 timeframe which is when the mixed potential model and the radiolysis model were developed and integrated to be the fuel matrix degradation model that's been coupled to the safety assessment case.

But as program direction changed, primarily funding decreased, the testing that was laid out to do validation of that modeling, it kind of went off the board, even though we kept the models percolating along. And then some of these activities moved off into the argillite and crystalline areas. And in the last couple of years we've developed a few more activities and funding levels have gone up and those testing activities and modeling activities were scattered across six of these areas.

And so what we did for integration within the disposal research campaign for waste forms, in particular spent nuclear fuel, was take the control account in FY '21 and bring together under one umbrella all these various -- and these are work packages at different national laboratories, all relating to spent nuclear fuel behavior in post-closure, including cladding, degradation, model development, and some planning to do SNF degradation testing possibly this year and into the next.

So, this work package which had -- this control account which had one work package, and now integrates all of these. I think there's nine work packages in it currently. And with that, we're also integrating with the storage and transportation R&D efforts where they've been doing excellent work on characterization of cladding, doing post-irradiation examination of the cladding and characterization of it and evaluation of its degradation behaviors in -- in storage conditions over long timeframes. And we're also integrating with the integrated waste management campaign in terms of the interfaces for the inventory information.

So now, this is, again, the pie diagram with the three host rock areas and cross-cutting activity shown by the concentric colored circles. And what I've added over here is no longer grey because we've talked a bit about it. It's the inventory and waste form activities which our current focus is on spent nuclear fuel testing. Where we're planning this currently hoping to finalize that plan in this fiscal year and potentially initiate the testing later in this fiscal year. The plan will cover testing that will be highest priority for validation of the fuel matrix degradation model itself. But also, lower prioritized testing looking at specific more -- the other mechanistic aspects of the spent fuel and its behavior and I've shown that in here. It's in between the DPC and EBS crosscutting activity as a purple band, corresponding to this purple color, to include it as part of the crosscutting activities and because the model itself focuses in these conditions for both crystalline and argillite, that's where our initial focus will be for that.

So just summarizing multiple drivers on the planning and prioritization, we've been over that a lot in this meeting and I think some of these were also hit on very nice in Lucy’s and Irina's presentations as well. And then within the campaign, the detailed planning activities have occurred, and they've given us large scale prioritization of our R&D activities throughout time and helped focus our planned activities into this five-year plan for the R&D priorities in the near term and the long term. And we're integrating those technical thrusts within the disposal research R&D campaign and then also across the storage and transportation R&D into the integrated waste management campaign, which is DOE NE-82, and beyond. And, you know, because there's interfaces between that campaign as well as -- there's interfaces with that campaign as well as the other branches of the Department of Energy.

So that -- that is my last slide, even though it's jumping around, there is the disclaimer that's here which relates to the standard contract in reference to the discussion of direct disposal of dual-purpose canisters. And I thank you and I'll take questions at this point and -- and possibly Jens will as well.

BAHR: Thanks, David. Yeah, so let's bring Jens back on. And I have one question for each of you. For Jens, you mentioned a variety of international and -- and binational collaboration efforts. And I was just wondering specifically about the IGD-TP program, which we heard about from Irina this morning, which is admittedly focused on

European countries, but have there been occasions where DOE has -- has partnered with some of those efforts?

BIRKHOLZER: The -- the answer is no. And, frankly, I'm not quite sure why not. I think we've been focused a bit more on such collaborations where we could directly engage and do research and the IGD-TP, I think is more about planning and interactions but I think it could be, now having learned a lot more about it from Irina, I think it could be valuable to perhaps join in, if were allowed to, and listen and to see if there is anything we could get -- contribute to or could get out of that type of engagement. So I'm -- I'm --

BAHR: It -- it sounded like a lot of the lessons learned from other countries' experiences would be valuable things for DOE to be aware of.

BIRKHOLZER: Definitely. It's not that we weren't aware. I mean we have been engaging with individual members of this symposium.

BAHR: That's -- group -- group discussions can be valuable.

BIRKHOLZER: Absolutely. Absolutely. Particularly if we would at some point have a chance to move forward in our stage in the campaign and go into site selection and comparison and things like that. Thank you.

BAHR: And then for David, you provided an example of taking research programs related to waste characterization and waste inventory that were, sort of, scattered among different programs and -- and integrating them in this new model. What does that mean beyond putting them into a list under a heading in a -- in a flowchart? Are there increased opportunities for the people leading those efforts to interact and combine resources? I mean, just from a -- on the ground standpoint, what does that reorganization --

SASSANI: Yes. So, yes, it isn't just moving it around on a PowerPoint slide. That -- in fact, a number of those work packages at different laboratories, some of them existed last year and the year before, and -- but were funded at fairly low level start -- until starting about a couple years ago when program funding went up and so we started refunding those to look at some of the experimental activity and get that growing again. Then we added a number last year.

For example, the two cladding modeling activities, one at Sandia and one at PNNL, those work packages were initiated last year and they were driven in fact by considerations for direct disposal of dual-purpose canisters which from their standpoint, they really would like to know what does the fuel bundle look like through time, not just let's assess the safety of already failed fuel which, from a safety standpoint, you know, it -- if you assume the cladding is not there and you start allowing the fuel to degrade, you can very easily make the case that that's the appropriate way to handle it from a safe standpoint. But with the -- the criticality aspects, they -- they have a little different bent on them and they want to know, well, how long is the configuration going to be maintained, when might it go away, and you don't have the same drivers on it. So, we really needed to go back and start looking. And of course, we in fact, started with the cladding models that were evaluated on the Yucca Mountain Project.

So, we are putting those conceptual models together. So those modelers, and one of them at PNNL that's led by Brady Hanson who was very active in the storage and transportation R&D area, and Brady is part of the planning consortium that we have across these laboratories we're putting the experimental plan in place. So, it really was to focus these.

We had one planning activity in the safety assessment area that was headed by Oak Ridge last year to start development of this testing plan, a draft of it at the end of the last fiscal year. They are still the lead on it going forward but there's also planning -- there's work packages at PNNL and Argonne and other laboratories, I think Los Alamos as well, to help with that planning aspect and build that plan together. Not simply for the validation tests but to lay out similar to the S&T, R&D gap analysis. What is it that we need to know about spent fuel in the post closure timeframe going forward? And where are all the places we could do tests to learn things and answer particular questions? And then that will get prioritized in that list as an appendix to the plan for starting the validation testing. So, it does -- it does bring people together in a coherent group a little bit more. And it is then all integrated under one of the -- Sandia's work packages for waste form modeling and testing.

BAHR: Okay. thanks. Bill Boyle offered to answer my question about EU participation in your program, so I'm bringing Bill on.

BOYLE: Okay. Can -- can you hear me?

BAHR: Yes.

SASSANI: Yes.

BOYLE: Okay. So, my answer goes back approximately 20 years or so. So maybe things have changed since then. This isn't the first time the topic of DOE -- the waste disposal people and DOE participating with the European Union on EU activities. And checked into it more than once approximately 20 years ago. And the impediment every time was, when it came time to sign the paperwork to be involved, even though we were paying totally for our own participation, there was a clause put in by the EU that the US government and DOE would hold them harmless no matter what. And good luck getting that by a government attorney. We gave up.

And so maybe things have changed. Maybe they no longer require that clause in their paperwork. But that was it. It was -- there -- there was no way that attorneys and DOE were going to sign off holding somebody completely harmless and we would have to indemnify them no matter what, you know, it -- we gave up. But maybe it has changed. Jens, you're welcome to check into it. But I'm doing this from memory. Irina's slides from this morning listing all the participants, I bet they're all European. You know, are -- are the Japanese involved, are the Canadians? You know, it's easy for them because they're part of the same group to hold each other harmless. Outsiders, not so friendly.

BIRKHOLZER: Okay. Thank you, Bill.

BAHR: Okay. Thank you -- verification, Bill. So, we have some questions from Board members. Tissa had his hand up first, I believe.

ILLANGASEKARE: Yes, I want just to compliment the last presentation as really good that it shows how things come together. There are some interesting, good things about -- and I liked the idea of the experiment and modeling going together. I think they are agreeing that emphasizing the experimental part, and how they are learning from each other.

And also, -- I also like the slide seven, Jen's slide number seven. I think -- I think your -- your international thing was the middle slice there, now I think you are making a larger circle and from all the presentations quite clear that the scope of the internataional program is -- should cut across all these other things. I think I like that.

And I also like the idea of the 2015 paper to start this experiment. Like these are really good idea to get these papers out early and innovate peer review so that they sort of -- sort of build a science based on some other people participating in this -- the process.

And then I also like the idea of multiscale testing and because I think the process models are mostly tested at a smaller scale unless on a larger scale need more and more integration it becomes then you need multiscale testing. I think this is any great -- good way of doing it. Because later as we go to these larger systems, the interactions become more complicated. Those are the things we can be tested. But we can get a really, really good process model based on a simple column experiment, but when you go to the interaction, we need to go to a larger scale. So, I think I -- I like that -- the idea.

Also I really like the last slide I -- that someone came in David’s presentation that's this idea of -- of crosscutting with other nonnuclear DOE programs. The reason for that is that actually -- like for example, good example, in fracture monitoring, you know, Jens mentioned the characterization. There are a lot going and I think it's -- and then your problem is the nuclear problem is, like, more complex but there are lot to be learned from the last time going in other -- other areas. So, this also maybe -- maybe good thing.

Those aren't question, mostly comments to say that things are coming together well.

SASSANI: Uh-hmm. Thank you.

BIRKHOLZER: Yeah. I'm not sure what to say but thank you.

BAHR: Thanks, Tissa. Yeah, if you would like to respond, that's fine or if not, we have a question from Mary Lou that we could go to.

BIRKHOLZER: Well, maybe just one sentence about the crosscutting and the synthesis going beyond nuclear waste. I think -- and -- and -- and I think it -- it -- there is a value in the way we are organizing our science in the US in terms of having national lab scientists doing some work at least and that we often are not just working in one field. As my folks doing nuclear waste disposal research also work on geothermal or in others. So, we're kind of -- we're naturally integrated so for say, right? The high temperature chemistry and mechanics that -- that you need in geothermal reservoirs is quite often very useful in nuclear waste disposal. So, I just wanted to point out all of that. We -- we -- we -- we are, kind of, working across borders often and that -- that is quite -- quite helpful, I think.

BAHR: Okay. I see a chat message from Mary Lou. She says, "I do now have a question." But maybe she means I do not have a question. Let's just bring her live and if she doesn't have a question --

ZOBACK: I do have a question. And thank you.

BAHR: Okay. Yeah.

ZOBACK: I -- I forget about turning that thing on and off. Great talks and Jens and -- both of you. It's wonderful to hear that the international work or the collaborations and the opportunities are feeding directly into the research planning, the long-term plans. So that's -- that's great.

One thing that struck me -- and this -- there's nothing loaded about this question. I often get reminded at our meetings that the national labs are not the Department of Energy, so I think that's a fair statement. But Lucy brought in, I thought, a really important point. I think the international collaboration's fantastic. But what about domestic collaboration and bringing in the US academic community? I know there is some acronym, external research program, and occasionally we've heard from someone who's funded by DOE that is an academic person, and -- and I -- and I ask this -- you know, I understand the program's small now. You're trying to do whatever you can do, given all the constraints you're working in, but if something were to change in a big way, has there -- any thought been given to broadening the program? Broadening the voices and the perspectives and not just be a national lab program, but rather engage the entire academic community, those interested. And yes, a lot of times, academic research is a little unfocused, but we found at the USGS in our external program, when you ask focused questions, people were interested in applying their research to it. So -- and there's also a self-serving component to this. The reality as a siting program moves forward, the most likely informed critics are going to come from the academic community. So, if you have them on board from the beginning and are taking their input and they're providing input on the research plan, it's a good way to engage a broader community to solve this vexing problem.

SASSANI: Jens, do you want to start? Or do you want me to go? Because I'll -- I can cover the nuclear energy university program aspects as well as some other parts.

BIRKHOLZER: Well, I mean, I could certainly, as a researcher, answer that. We obviously value collaboration with university groups, and as you know, Mary Lou at Berkley we're very close to UC campus.

And in fact, as part of our work we do for the campaign, we have relatively close interactions with the nuclear engineering department down there and we have a few grad students and a postdoc here and there, but it's not at scale, really. It could be at a bigger scale, and I think that we're definitely valuing that. I don't think it's my place to comment on where the DOE puts its budget. There isn't any key program without the nuclear energy university program. It's across the entire Office of Nuclear Energy, so the disposal part is probably relatively small, but, Dave, maybe you can add a little bit to that.

SASSANI: Yeah, I -- I'm -- I'm happy to add to it. It -- it currently -- and I -- I've been more involved with it over about the last three to four years. But nuclear energy university program puts out a call every year for proposals and they do pre-application proposals, well, which just occurred in September. Those get reviewed and assessed, and rated, and then full proposals get submitted, I believe. Submittal is February 11th, coming up, with a full proposal?

ZOBACK: Yeah, I -- I don't need a full detail of how to submit a proposal.

SASSANI: Yeah, I'm sorry about that. But I -- but just to give you a scale, in disposal research over the last couple of years, there's probably been five or six fully-funded proposals, which are three-year grants on the order of $800,000 a -- for the full three years. For university researchers doing R&D related to the program, relevant to the program, but a little more cutting edge than maybe what would be done within the campaign. The same is true on the storage and transportation R&D side as well. And so, there's -- I would guess there's roughly 25 active university program activities going on in this area. And generally we'll bring them on our annual program meeting every year to give presentations and talk, but yeah -- you know, you're -- it -- it's -- it's a very good area for that collaboration, for reaching out, and helping build the next generation of scientists in these areas. It's fully supported by the Department of Energy and either Bill or Tim could add to that if they want to add any specifics.

ZOBACK: Okay, thank you.

BAHR: Okay. And now I see Bret Leslie. I'm not sure if this is a question or if this for the public comment period. But let's bring Bret on.

LESLIE: I'm going to ask a question before we get to the public comment period. Dave, you had a slide and it came away that talks about defining and what is complete enough. And I came away from the series of talks not really understanding what are the viable disposal options that DOE is considering. And -- and -- and I'll give you some background. All we heard about was commercial spent fuel and high-level waste. We didn't hear anything about DOE standard -- DOE fuel, which is uranium metal, which is highly reactive in reduced conditions. So, I don't know in defining your things whether you defined it well enough to know whether you have the adequate technical bases that these are viable.

SASSANI: Well, good question, Bret. No, you -- you didn't hear anything about that. And primarily, the reason for that, the way I believe it, it's not that we haven't done anything with it. The Online Waste Library has the DOE high-level wastes in it, and it also has some connection to the DOE SNF database in terms of the major material that's out there, which really is the N-Reactor fuel, which is about 85% by mass, and it is metallic fuel. Because the DOE SNF database exists in vast detail at Idaho, we don't -- we're not reproducing that database within what we're doing, but we have analyzed in -- in a few of the reference cases, we've included the DOE-managed SNF as instantaneously degrading spent fuel, which is how it was incorporated into the Yucca Mountain SAR. And because of its small -- relatively small volume in mass compared to the other fuels, it doesn't have a large safety impact. So it's -- from that standpoint prioritized, now that doesn't that there might not be other pieces to look at for specific some specific investigations on it, but it's been a lower priority than what drives the system, which is the commercial spent fuel and the high-level waste class.

LESLIE: But I -- but I guess you cannot really -- really assess your FEPs unless you include all your waste that could be there. For instance, the hydrogen generation is a big deal for the uranium metal. That's how we get -- how we get hydrogen isotopic information. We interact water with heated uranium metal.

SASSANI: And --and offgas the hydrogen, right.

LESLIE: Correct.

SASSANI: Almost quantitatively. Yes.

LESLIE: So -- anyway, thank you, David.

SASSANI: Yup.

BAHR: Okay, thanks, Bret. I see Bobby with his hand up.

PABALAN: Hey, Dave.

SASSANI: Hey, Bobby.

PABALAN: I've got a question -- got a question for you. Yesterday in your presentation, you mentioned one of the key objectives emphasizing the safety of a geologic repository system is to provide a vehicle to communicate the understanding of safety to a broad audience of stakeholders. And in the first two presentations today, Lucy and Irina both emphasized the importance of effective communication for a successful geologic disposal program.

While I know that the DOE programs that are not site-specific or a generic stage, but are there any activities you are conducting with respect to communication? And this could help in laying the groundwork, so to speak, so that when you get closer to the site selection stage, if that is the case, or also to address Mary Lou's comment about broadening the community of people interested in nuclear waste disposal, are there any activities related to communication?

SASSANI: So, in term -- in terms of that, Bobby, I would say we have one activity that sort of relates to that, which is the knowledge management activity although it's being developed and it's all still in-house. Because this program is an R&D program, it's not necessarily an actual siting or site selection program. That, as I tried to indicate with some of those program diagrams that -- that's probably a little off in the future, when there would be some waste management aspects that would drive us to start considering site selection again, or site -- siting activities.

DOE may want to comment more specifically about siting aspects. They -- in the U.S., we all know and understand that there's been some issues in -- in those regards, and it's -- I don't see a real clear path forward at this point. I think we have -- we do a lot of technical communication, but the R&D program is really not here to do the public interaction, although we have had small pieces where we've engaged with University of Oklahoma, particularly Hank Jenkins-Smith in terms of looking what's out there and what might -- might be doable. That, I think with the knowledge management aspects that we're putting together, we may grow something out of that. Although that is -- the knowledge management really is for the backend of the nuclear fuel cycle and the future generations that are going to do this work, when that type of a program starts up again.

Now, that said on the disposal research side, the storage and transportation side -- R&D side of the SFWST program interacts directly with industry and the NRC, and there are a lot more public communications aspects that go on there, because it is an active, actual program doing those things.

PABALAN: Okay. Thank you.

BAHR: I see Bobby -- we got Bobby, we see Chandrika, and then Bill Boyle may have wanted to clarify something. And then we probably, at that point, need to go to the -- to the public comments.

SASSANI: Is Bill going to clarify first?

BAHR: Yes. Bill -- maybe we should bring Bill on. He says -- there was a question about site-specific studies.

SASSANI: Uh-hmm.

BOYLE: Yesterday as one of the public questions as well. Absent direct permission from the United States Congress, we are forbidden from doing site-specific studies anywhere other than Yucca Mountain. It's in the new-- in the '87 Act, with the amendments. It prohibited all other work, site-specific. So, there you go. Now Congress can fix that. They can put -- even in an appropriation bill they could, on a one-year basis, override that, they -- they have never done so.

BAHR: Okay. Thanks for that clarification. Okay, so let's go to the question from Chandrika. Sorry to take her off and on.

MANEPALLY: Thank you, David, for the end -- and Jens for the presentation. My question was what about your research prioritization. When you are deciding what is important, what is, you know, the high, medium, low level, do you ever think about maybe having design specification or tech specification in the future, which could probably make a research topic not necessary? For example, you could say you are having a sacrificial -- you know, bentonite buffer zone or you're having thicker, you know, layer of upper or stainless steel and then to take care of the corrosion, so we really don't have to go into that detail level of understanding right now that you guys in this stage.

SASSANI: Yes, that's -- it's a great question and it -- it -- it relates very closely to kind of the screening arguments that are put together in the features, events, and processes as part of the performance assessment system, where you would walk through and your justification for not including the detailed evolution of the bentonite buffer around the canister could be, well, we did analyses in detail and we did experimental work and we showed this only affects 15% of the buffer material, there's still 85% there that doesn't seem affected, and therefore we're not going to include that explicit representation into the safety assessment. You know, we're -- we -- we don't -- we don't have to build that model to that level of detail into the system.

So that -- that is -- that is something that we would consider going forward. It likely wouldn't happen until we get a little bit more design and site-specific information to really make those -- those arguments, to screen them out. So in the generic sense right now, we focus more on the capability development to be able to do the assessments if we need to, and we try to focus on the highest priority aspects that affect safety, but some of those in a future sense could get screened out when I talk about those -- those different decision points in a program's progress, you know, when you get to down-selecting sites and doing more design specific work, you may drop a lot of those off out of the direct incorporation into the safety assessment.

MANEPALLY: Thank you.

SASSANI: Uh-hmm.

BAHR: Okay. Well thanks to all the speakers. And I understand from Bret Leslie that we have about 12 comments, so I'm going to say goodbye to David and Jens, thank you again.

SASSANI: Thank you.

BAHR: We will bring up Bret for the public comments.

PUBLIC COMMENTS

LESLIE: Okay. So, Jean, remind me at the end to re-look at the -- the inbox, because we had one come in last, yesterday when we were wrapping up a meeting.

So let me start with yesterday's meeting and as I will remind the audience, I will be giving these comments in the order that they were, well, were received.

So yesterday, Kayleen Walker had the following message. “DOE Sandia Lab Technical Gap Report (December 2019) updated their prioritization of unsolved problems - technology gaps - with thin-wall, welded-shut canisters currently used to store spent fuel waste. The report makes priority number one the problem of through-wall crack risk and thin-wall canisters. It acknowledges there is no inspection or repair technology, and no plan in place to repackaging fuel assemblies into new containers. And it states there is not sufficient information regarding consequences of through wall cracks. The report indicates an urgent problem of over 3,000 loaded canisters in the US. *Gap Analysis to Guide DOE, R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment* SAND2019-15479 R, December 23rd 2019. https://www.osti.gov/servlets/purl/1592862/. While the DOE has spent decades and billions of dollars on R&D of permanent repositories, the NRC continues to allow the use of canisters that do not meet the Standard Contract or basic safety requirements. Canisters cannot meet qualifications for ASME N3 nuclear pressure vessels. Only thick-wall, bolted lid cask designs can meet ASME N3 requirements and basic safety requirements. Only installation of hot cells will allow for repackaging of fuel and inspection of container contents. Please look into this seriously radiological hazard with current dry storage SanOnofreSafety.org. Thank you.”

Today, we had a number of comments, and I will, again, give the context in terms of when they came in.

During Irina's talk, the first comment, Sven Bader, Orano Federal Services, "Do all countries in Europe with radioactive waste have geology suitable for disposal and the financial resources to build disposal sites?"

In Lucy's talk, the next comment, Tom Peake, US EPA, member of the Nuclear Energy Agency Integration Group -- Integration Group for the Safety Case. His comment, "NWTRB members and DOE staff are encouraged to attend the NEA IGSC meetings."

And there were a number of series of comments that came in around Emily's talk. A first comment, Donna Gilmore, SanOnofreSafety.org, "What overpacked materials and thicknesses are being considered for the DPC? Are there any technical documents about this available?"

The next comment, by Shannon Chu from EPRI. "Did the criticality analysis consider radiolysis of the water and any potential for hydrogen deflagration?"

Another comment by Donna Gilmore, SanOnofreSafety.org. "What assumptions are you making about the initial condition of the canisters, such as cracking? Are you aware there is no current technology to inspect or repair cracked in the canisters? Are you assuming inspection and repair technology will be available?" Gap Analysis to Guide DOE R&D in Supporting Extended Storage and

Transportation of Spent Nuclear Fuel: An FY2019 Assessment SAND2019-1547” --

BAHR: I am back, but we lost Bret. Are you there, Bret?

LESLIE: I'm here.

BAHR: Okay. I think if you said anything after drinking your water, could you repeat it?

LESLIE: Okay. All right. So, I had finished saying “Are you assuming inspection and repair technology will be available? The next thing I said was *Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment* SAND2019-15479R, December 23, 2019. Again, the -- email -- I mean the web address https://www.osti.gov/servlets/purle/1592862/.

Another comment by Donna Gilmore, SanOnofreSafety.org, “Are you aware there is an unknown amount of water in the DPCs?”

One final comment also during Emily's talk was made by Sven Bader, Orano Federal Services. “By using representative waste package loadings from UNF ST&NDARDS, what improvements are expected and how do these improvements compare to the previous representative loadings used? Could the previous representative loadings potentially have provided non-conservative activities?”

Next we had a comment that came in around LianGe's talk. Again, Donna Gilmore, SanOnofreSafety.org. "The coupons won't tell you about stress corrosion cracking of stainless steel."

And then after the presentations over -- were over, Kayleen Walker repeated most of her message from yesterday, but I will read it into the record. "While DOE spends many decades and billions of dollars researching in permanent repositories, the NRC continues to license DPCs used for dry storage that do not meet the Standard Contract of the NWPA, or critical safety requirements. The December 2019 DOE Sandia Lab Technical Gap Report updated the prioritization of technology gaps regarding unsolved problems with the thin-wall, welded-shut canisters currently used to store spent fuel waste. The report makes priority number one the problem of through-wall cracks in thin-wall canisters. It acknowledges there's no inspection or repair technology, and no plan in place for repacking fuel assemblies into new containers. And it states there is not sufficient information regarding consequences of through wall cracks. The report indicates urgent problems with over

3,000 loaded canisters in the US. The NRC is approving canisters that cannot meet qualification for ASME N3 nuclear pressure vessels. Only thick-wall bolted lid casks designs can meet ASME N3 requirements and basic critical safety requirements. Hot cells will be necessary for repackaging of fuel, inspection of container contents, or dealing with canister failure yet not one hot cell exists in the US capable of handling canister fuel. Please look into the serious radiological hazard with current dry storage. Congress needs to know, thank you. *Gap Analysis to Guide DOE R&D in Supporting Extended Storage and Transportation of Spent Nuclear Fuel: An FY2019 Assessment*. SAND2009 -- 2019-15479R, December 23rd, 2019. Again, the web address https://www.osti.gov/servlets/purl/15892862/. More info, San -- SanOnofreSafety.org."

Coming down to the last two that I have in the inbox so far, Donna Gilmore, SanOnofreSafety.org. "Are you aware of Holtec thin-wall canisters (DPCs), are gouged, scraped, or scratched as each is loaded into Holtec concrete carbon-lined overpacks, both aboveground and subterranean systems? Are you aware this embeds carbon particles in the walls of the canisters? These are corrosion cracking issues that should be evaluated in any planning for storage, transport, and disposal -- and disposable for both short and long-term timelines."

Final comments that I have so far was Steve Frishman, Nevada. Question, "What generic R&D value is there in the five-year plan element for passive data collection in the Yucca Mountain Exploratory Studies Facility, the ESF?"

And Jean, And Jean, there are no other comments that have come in while I've been speaking.

BAHR: Okay. Just as a reminder, all the public comments will be posted as part of the transcript and the record for this meeting, and that includes comments that come in, written comments afterwards. Correct, Bret?

LESLIE: Yes. The -- the written comments will be posted on our website. Correct.

BAHR: Okay. Well, thanks to everyone for your attention over the last two days, to all the presenters in different time zones and particularly our international presenters who may no longer be with us, but I think we really benefited from their -- their external perspective. And thank you very much and I am going to close the meeting now.

(Whereupon, the meeting concluded.)