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Nuclear Waste Technical Review Board (NWTRB)

Transcript

DOE Research and Development Activities Related to the Geologic Disposal Safety Assessment Framework

Fall 2021 Board Meeting

VIRTUAL PUBLIC MEETING – Day Two

Thursday

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NWTRB BOARD MEMBERS

Jean M. Bahr, Ph.D.

Steven M. Becker, Ph.D.

Allen G. Croff, M.B.A.

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

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

Paul J. Turinsky, Ph.D.

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Sonya Townsend

Casey Waithe

PROCEEDINGS

>> BAHR: Hello, and welcome back to the US Nuclear Waste Technical Review Board's Fall Meeting. I'm Jean Bahr, Chair of the Board. Yesterday I described the board's mission and introduced the other board members. To save time I'll direct you to our website, www.NWTRB.gov where you can find information on our mission and our members, as well as board correspondence, reports, testimony, and meeting materials, including webcasts of its public meetings. If we can go to the next slide.

This slide shows yesterday's agenda. William Boyle and Alisa Trunzo of the DOE Office of Nuclear Energy provided an update on DOE's Spent Fuel and Waste Disposition Program, including interim storage activities. Then we heard from National Laboratory researchers who are conducting the work for DOE about research and development activities related to the GDSA framework, including details of several of its subcomponents, such as PFLOTRAN, dfnWorks, and the fuel matrix degradation model. Today we'll start with a presentation on another subcomponent of the GDSA framework, the biosphere model. Then Tim McCartin and

Dave Esh from the U.S. Regulatory Commission will tell us their perspective on developing and applying performance codes based on their experience in these activities, both at the NRC and in their participation in international programs.

Following that, Sarah Vines from the United Kingdom's Radioactive Waste Management organization will describe the development of environmental safety case models supporting geological disposal of the United Kingdom's radioactive waste. After a 20 minute break starting at 2:15 PM Eastern Time, we'll have three presentations, one on uncertainty and sensitivity analysis tools being applied in the GDSA framework and another one describing implementation of GDSA framework to generic repository reference cases for bedded salt, shale, and crystalline host rocks. The third presentation, which is the last of the meeting, will describe a case study in integrating insight and experience from the international community into geologic disposal safety assessments. We'll 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 this meeting, you'll have seen a link for submitting a comment for the record. Comments we receive during the meeting will be read online in the order received by board staff member Bret Leslie. Time for each comment may be limited, depending on the number of comments we receive, but the entirety of the submitted comments will be included as part of the meeting record. Approximately 5:00 p.m. Eastern Time.

So, without further ado, let's start with today's first presentation, and if we can bring Caitlin onboard and get her slides, we'll get started. I see Caitlin, so that means I can leave.

>> CONDON: Good morning. I was going to share my slides. Do you see my screen?

>> BAHR: I do.

>> CONDON: Great. Hello. My name is Caitlin Condon, I am an environmental health physicist at the Pacific Northwest National Lab and I'm here today to talk about the development of the geologic disposal safety assessment or GDSA framework biosphere model. I am presenting on behalf of myself and the other members of our development team at PNNL, Bruce Napier and Saikat

Gosh.

Today I will be presenting how the biosphere model fits within the geologic disposal safety assessment framework. Some existing biosphere and dosimetry models that were used for guidance during model design. International recommendations for biosphere modeling that were considered during model design. The needs identified for a GDSA framework repository biosphere model. And finally, the design and function of the GDSA biosphere model.

The GDSA biosphere model under development is a new capability for the GDSA framework. Emily Stein spoke about the GDSA framework as a whole yesterday, but today I'm just going to focus on the development of the new biosphere model within this framework. While there is a biosphere model within PFLOTRAN, when includes a drinking water pathway from well water, the new biosphere model will provide a more comprehensive look at potential exposure pathways for receptors in the biosphere. The biosphere model will be able to estimate doses to potential receptors in the biosphere for a geologic repository scenario modeled in PFLOTRAN. As a part of the GDSA framework, the biosphere model will need to be open source and flexible tool. The first step in the development of the new biosphere model was thoughtful design. We began the design phase in 2020 and as part of that process, explored existing biosphere and dosimetry models and looked at international recommendations for guidance.

Some of the biosphere and dosimetry models we examined during the design phase of the GDSA biosphere model development included models developed for the Waste Isolation Pilot Plant or WIPP and Yucca Mountain. The Yucca Mountain biosphere model was called ERMYN, which stands for environmental radiation model for Yucca Mountain Nevada. These two models were site specific and designed for biosphere impacts associated with repositories. The WIPP model used set scenarios to explore dose estimates related to hypothetical human exposure situations and the ERMYN model similarly used exposure scenarios to evaluate the dose to a reasonably maximally exposed individual or REMI in the Amargosa Valley from a hypothetical releases through groundwater or volcanic eruption.

We explored two generic biosphere and dosimetry models, GENII and RESRAD. GENII is an NQA1 code developed at

PNNL for environmental transport of radionuclides in the environment and has been reviewed by the national academies of science.

RESRAD or RESidual RADioactive materials assessment codes is a series of codes developed for assessing human and biota exposure from environmental contamination, including RESRAD onsite, RESRAD biota, and RESRAD offsite and others. RESRAD offsite is used by the NRC for risk assessment for decommissioning and license termination. These models provided useful information about environmental transport and radionuclides and model function and design that was informative during the GDSA model design phase.

Along with exploring existing biosphere and dosimetry models in the U.S., the team looked at international guidance through the design of the biosphere model. Our team looked at the International Atomic Energy Agency or IAEA programs, including BIOMASS and MODARIA for recommendations on development of long term assessments models. The IAEA program BIOMASS began in the nineties and was an exploration of movements of radionuclides within the environment. The BIOMASS program provided a suggested methodology for the development of biosphere assessment models, which included a series of steps beginning at the establishment of the assessment contexts and progressing through the iterations of the model itself. This methodology has been evaluated by subsequent IAEA programs and is still the recommended methodology with some minor updates and revisions for those developing models for an environmental movement of radionuclides. One important take away from the BIOMASS program, was that you shouldn't attempt to perfectly simulate the biosphere. Rather, it would be appropriate to consider the model as an assessment biosphere.

Many of the IAEA programs address long term environmental assessment modeling, both MODARIA I and II programs, which ran from 2012 to 2019. MODARIA, or Modeling and Data for Radiological Impact Assessments had a working group specifically to address questions related to long term environmental assessment modeling, Working Group 6. Working Group 6 also worked closely with BIOPROTA, which is an international collaborative forum to support exploration of key issues related to biosphere aspects of assessment of the long term impact of contaminant releases associated with radioactive waste management. Working Group 6 in collaboration with

BIOPROTA put out a guidance report which was informative for the design of the GDSA model. Some of the guidance we took from the report put out by MODARIA and Group 6 and BIOPROTA was to simplify the biosphere models for longer timeframes, that climate change can be treated as a model input variable and that the biosphere modeling can be captured through a compartment model.

We are also participating in the current IAEA program MEREIA which began this October. MEREIA or Methods for radiological and environmental impact assessment is a continuation of the MODARIA programs and our participation will allow us to keep informed on current international work related to long term radiological and environmental impact assessments.

We also looked at the Organization for Economic Cooperation Development or OECD, Nuclear Energy Agency (NEA), and considered their features events and processes during model design. Emily Stein and Paul Mariner both discussed the GDSA framework FEPs screening yesterday, but today I'll focus on FEPs as they relate to the new biosphere model. The NEA FEPs are all related to long-term safety or performance of a geologic repository. The list was developed as a comprehensive and internationally accepted list of factors that may need to be considered when assessing deep geological repositories. For the biosphere model, we looked at the FEPs which are the biosphere factors. We evaluated this list to determine which FEPs could be incorporated into the model that needs to be both flexible for both location and time period of interest. We created a prioritized list of FEPs to include in the first iteration of the biosphere model. Those FEPs from group five that are not included in the first iteration of the biosphere model may still be incorporated into future iterations of the model as required. Some examples of FEPs that are included in the first iteration of the model are the surface environment, including things such as vegetation, climate, and weather. And also, human characteristics and behavior that define our receptors.

After reviewing the existing models, as well as international guidance from environmental transport and dosimetry modeling, a specific set of requirements for a GDSA biosphere model was established. The first requirement of the GDSA biosphere model is that it's compatible with PFLOTRAN, which includes being compatible in both coding style and language. Following that, it needs to be developed in an open source format. So, this is to allow for transparency and to serve as a tool for both stakeholders and decision makers in the future. Finally, and most complicated, it needs to be flexible. Specifically, it needs to be flexible enough that you can be capable of modeling a variety of sites or locations. Unlike the models developed for WIPP and Yucca Mountain, this model is not tied to a specific geographic location. It needs to be capable of handling a variety of climate states, because this model is neither set to a specific location or period of time, but it also needs to be capable of handling a scenario where a single site might experience multiple climate states during a time period of interest. Depending on the scenario, PFLOTRAN may be running a scenario that spans hundreds of thousands of years and, depending on the scenario location, the climate state may not be static.

And finally, it needs to be capable of growth. We need to have a design that is capable of growth such as including new receptors, like non-human biota, to be more consistent with international communities or accommodate updates to mathematical models governing movements of radionuclides in the environment as we learn more.

The design of the biosphere model starts with its connection to PFLOTRAN. Currently, this expanded biosphere model serves as a post processor to PFLOTRAN with one way coupling. What I mean by this is PFLOTRAN outputs is the biosphere model input. PFLOTRAN is responsible for determining the radionuclide concentration in moles per liter in the groundwater. The biosphere model will determine the potential impacts on the receptors from exposure to radionuclides that reach the biosphere.

This slide shows a high-level schematic of the GDSA biosphere model. That connection to PFLOTRAN is shown here as the groundwater compartment. In this high-level depiction, we see the GDSA biosphere model will track the movement of radionuclides through the biosphere through various pathways that may reach the receptor. The groundwater can be used directly by the receptors or be diluted into a surface water body which is then used as a water source. This water can be used for irrigating crops or flora, as a drinking water source for livestock or fauna, and or as a domestic water source for drinking, showering, or cooking or as a recreational water source for activities such as swimming.

Through either surface water or groundwater irrigation of crops, you can introduce contaminants to the soil and the shorelines which a receptor can then be exposed to. The biosphere model allows the users to define the human receptor characteristics. For example, the rate of consumption for certain crops or whether to include a surface water feature to define the exposure scenario. The biosphere model not only considers the parent radionuclides we get from the PFLOTRAN output, but also all the progeny ingrowth throughout the biosphere. For example, we consider not only the radionuclides defined by the output of PFLOTRAN, but also the progeny ingrowth and decay as it moves from groundwater to the soil through irrigation to a plant during growth and the plant is harvested and stored until it is consumed by the receptor. Also, uncertainty and sensitivity analysis can be applied throughout the model using the Dakota code, which will be introduced and discussed by Laura Swiler in the uncertainty presentation today.

Finally, the biosphere model framework allows us to address climate state and climate change as input variables to the code, meaning for a scenario site, we can use the information about climate states in the biosphere over the course of the time period of interest to define the scenarios for the biosphere model itself.

This image is another conceptual visualization to represent the GDSA biosphere model. The receptors in the biosphere can get doses through the biosphere through 3 general pathways: Ingestion, inhalation, or external dose. An ingestion dose may come from the consumption of crops or animals that were irrigated with contaminated water. The consumption of aquatic plants or animals that lived in a contaminated water body, inadvertent ingestion of contaminated shower or swimming water and/or the inadvertent ingestion of contaminated soil. An inhalation dose may come from breathing in contaminants from volatilized contaminated water such as cooking or showering and breathing in re-suspended contaminated soils. An external dose may come from a receptor working in a field irrigated with contaminated water. A receptor participating in recreational activities in contaminated body of water, and or a receptor exposed to contaminated soils. All of this leads to an estimated dose to the reasonably maximally exposed individual.

The biosphere model was designed to calculate the doses to the reasonably maximally exposed individual, also called the RMEI. An example of a RMEI might be a hypothetical receptor that sources their water from the contaminated water source, hypothetically, grows or raises all of their own food and essentially lives full time at this location. This scenario provides a conservative dose assessment for the RMEI by maximizing the hypothetical receptor exposure to contaminants from a hypothetical contaminated water source.

This model design allows flexibility in how the RMEI is defined. Depending on how you select your modeling scenario, the user will be able to define the exposure pathways based on that scenario's location and time to determine the hypothetical dose to the RMEI.

The impact assessments we are considering in the biosphere is annual dose to the recently maximally exposed individual. For example, a scenario may be to look at the annual doses to a receptor over a 70-year lifetime. For an annual dose calculation, we need to determine the time points of interest over the course of the PFLOTRAN timeline for the biosphere. You see here an example where we're looking at a PFLOTRAN simulation of 500,000 years and we are considering an annual dose to the receptor between the years 100,000 and 100,070 years. Beyond setting the starting point for the annual dose to the receptor, we can also define if there is a contamination introduced to the biosphere through the groundwater prior to the first annual dose calculation. For example, in a biosphere scenario, we can consider if there was previous irrigation at the site with contaminated groundwater introducing contaminants to the soil compartment. An example of this would be if you wanted your model to consider a location that has been farmed with contaminated irrigation water prior to the beginning of your annual dose estimates such as a multigenerational farm site. This prior contamination in the soil compartment would potentially increase the annual dose to the receptor at the beginning of the biosphere simulation, either through increased concentration of contaminants that enter the flora or crops, potentially the fauna, or animals for consumption, or by increasing the dose of the receptor through pathways such as external dose from the soil compartment, inadvertent ingestion of soil, or the inhalation of re-suspended soil.

This framework also allows the user to consider changes in climate state as at a particular site as part of the biosphere scenario. Understanding how a site's climate state may change over the course of the PFLOTRAN timeline will allow the biosphere model user to create scenarios based on the climate state predictions. For example, if you wanted to run a scenario through the biosphere model, you would need to determine how the climate might change over the time period of interest at your site. You would then determine what time points of interest you wanted to model. An example of how varying climate states may affect the scenario of interest could include something as simple as expected precipitation rates. By understanding the potential precipitation rates for your scenario, you would then be able to adjust the expected irrigation rates for your scenario flora or crops accordingly.

Currently, the GDSA biosphere model is in prototype development stage. The framework of the model has been developed and a pathway from groundwater to receptor dose has been created. This pathway goes from contaminated groundwater, used in irrigating crops, both being directly deposited on the flora and being introduced to the soil. From the soil, then there's root uptake to the crops, the crops are then harvested and depending on the crop type, stored for an average holdup time before consumption and finally consumed by the hypothetical receptor based on the receptor characteristics, resulting in an estimated annual dose to the receptor.

Our GDSA biosphere team will continue development of the GDSA biosphere model this year based on the guidance developed in the GDSA biosphere model requirements document, including all the pathways that have been discussed in this presentation. The table on the right side of the slide shows all the pathways that will be included in the first iteration of the GDSA biosphere model. The pathways with the green checkmark indicate a pathway already developed in this prototype stage. And at this point, I would be happy to address any questions.

>> BAHR: Okay. Thank you, Caitlin. Do we have questions from board members? I'll ask one. It would seem to me that the ingestion pathway of drinking contaminated groundwater would be fairly simple to

implement, and that's actually what's already in the prototype before this. I just am wondering why you didn't start with that? Or is it because the others were more interesting to explore because they're more complicated?

>> CONDON: That's a great question. So we wanted to start the prototype by essentially having a way to demonstrate the capability from the beginning to the end. And some of those things include having these more complicated pathways. So while we can introduce the groundwater ingestion pathway more easily, we wanted to show a more complete example of how the framework would function with a more complicated pathway for the prototype.

>> BAHR: Thanks. I see hands up. Paul Turinsky?

>> TURINSKY: I have a question on what finally will be assessed. Are you going to assess things like the economic impact if large acreages have to be taken out of service from farming? Things of that nature?

>> CONDON: I will leave that question to DOE. I think what we want to highlight most with this, we're developing a modeling capability and putting these

capabilities into the GDSA framework, and for that question, I think I would direct that to the DOE.

>> TURINSKY: Okay. I'd be curious to know the answer to that, what their intents is, and I guess a little surprised that the developers don't know how DOE is going to eventually use this.

>> CONDON: Yeah. I think I would let Emily or Dave speak to that question.

>> BAHR: Emily? If we can get her online? Thanks.

>> STEIN: Yeah. Assessing the economics has not been part of our safety assessment in the past, so that developers at this time have no intention to add that capability. Dave, do you want to, or Bill? Everybody has their hand raised.

>> Dave: I'll let DOE comment. That's not part of assessing the dose risk.

>> BAHR: William Boyle?

>> BOYLE: Typically economic effects are considered in EISs. None of the people here today are directly working on EISs. Right? We've done EISs in the past. We don't even have a site now. But that's typically

where economic effects are addressed.

>> TURINSKY: Yeah. I raised that, because for nuclear power plants, that's been a criticism that the impact of displacing people or whatever has not been adequately addressed. I don't know if the criticism is well founded or not, but I have heard it numerous times.

>> BOYLE: Yeah. But again, all the talks you're hearing on the DOE side yesterday and today deal with the safety aspect. Right? That's what we've asked them to do and that's what they're doing.

>> TURINSKY: Yeah. But don't provide the raw data to know, basically, do we have to take out this [Indiscernible] from farming and things like that, it would seem?

>> BOYLE: Yes, yes. We know from the history, at least I do from the Yucca Mountain experience, there is a lot of cooperation between what is now called the GDSA staff and the people who put together the EIS. They worked together quite closely.

>> TURINSKY: Thanks, Bill.

>> BAHR: Paul, did you have any other questions?

>> TURINSKY: That's it.

>> BAHR: Okay. How about Steve Becker?

>> BECKER: Hi Caitlin, I am not a modeler. So I found your presentation particularly informative. Thank you. You mentioned in a couple of places you mentioned climate change. I think you said that BIOPROTA is one where climate change could be treated as an input variable. Climate change is clearly a very complex phenomenon and I'm wondering, as you think about climate change with respect to your own models, what kinds of factors would the modelers typically include in considering this phenomenon, what dimensions of it?

>> CONDON: That's an excellent question. For us, we are building this capability. Since we do not have a specific site, that will end up being a more site-specific question. I can tell you the things that we're considering when we think about how to use climate as an input variable are things that will affect our receptor experience in the biosphere. And so one of the examples I mentioned earlier was if we can anticipate a general expected precipitation rate, we will know, based on the growth requirements of our crops that we're including in the model, if you expect much more

precipitation during times that you are growing crops, you would irrigate, you'd expect to irrigate less with groundwater. Things like that. Temperature, other basic variables that might affect how these radionuclides move through the environment or how our receptor interacts with them. For example, if we expect very cold temperatures, we would probably reduce the amount of exposure to the receptor due to swimming. Things like that. Did that answer your question?

>> BECKER: Yes. It sounds like you're considering several different dimensions and perhaps adding others going forward?

>> CONDON: Yeah. So I think the best way we can explain this now is that we are building, essentially, this full pathway of exposure scenario so that when you do know more about whatever you're going to use this for, you can narrow it down based on your understanding of a climate state for a given site to fit these pathways to your needs.

>> BECKER: That was very helpful. Thank you.

>> BAHR: Anything else, Steve? No?

>> BECKER: That's it for now.

>> BAHR: Tissa?

>> ILLANGASEKARE: Thank you. Thank you very much. I think I asked these questions earlier, but let me ask short questions. The first one is so you have vegetation and climate and weather. But do you look at the interaction of climate and vegetation in your scenarios? For example, climate change can have an effect on floras and things like that. So do you look at that?

>> CONDON: You know, in some ways, yes. In other ways, no. I think in the sense that you're describing, like how it would affect forest growth, currently no --

>> ILLANGASEKARE: [Indiscernible]

>> CONDON: Yeah, because that wouldn't affect our receptor. Now, if you wanted to include something in your pathway, we could set it up, but it isn't really designed to consider how it would affect the vegetation. More you would consider that when you're designing your model scenario. If you knew how that site would be affected by climate change, you would set up your exposure pathways to reflect that scenario, and that, in itself, would incorporate that kind of climate change

understanding.

>> ILLANGASEKARE: Yeah. So you're also building human behavior capabilities. The question is, do you have human adaptation in climate change scenarios in the human behavior? Maybe you know. Human behaving in a different context? You may be talking about that.

>> CONDON: Yeah. Essentially what I mean by the human behavior characteristics is we have different variables that we can adjust for how often somebody participates in a recreational activity, how much standard person eats of X, Y, and Z of these crops developed. So they're less about traditional behaviors and more of these behaviors that would affect the reasonably maximally exposed individual. And by going through this RMEI approach, it really helps to -- you can adjust a lot of these behaviors to capture the receptor that you want in the scenario that you want.

>> ILLANGASEKARE: And then you also have inhalation as one of the risk factors. So PFLOTRAN does not have airborne transport? You mentioned in the model, in the biosphere model, you look at the decay processes internally. So do you have some process models running inside the biosphere in I assumes that means you

probably have a process model running, for example, irrigation water in the land, it's possible the wind will carry the particles into airborne inhalation. In the biosphere, you have process models, also. Is that correct?

>> CONDON: I don't know that I would call them process models. I think for the biosphere, we need to be a little simpler for that, because of the unknowns. That would be very site specific. Essentially, what we have is we have an understanding of the typical amounts that you might be exposed to something that was volatilized after showering and cooking activities. We have these standard transfer ratios and we understand what somebody would likely be exposed to if they were working in a field, what they would inhale for a re-suspended soil based on that activity. So it's less actually tracking the movement of these particles given some kind of event like that, because the level of detail required for that is you're unlikely to have it given these modeling scenarios so far in the future.

>> ILLANGASEKARE: In the organic chemicals that I’m familiar with, vapor intrusion into buildings and subsurface structures, so do you look at as another risk

factor in your biosphere model? Humans spend most of their time inside houses.

>> CONDON: We are not considering that currently, though we have developed this to be very generic. In the future if we decide that needs to be considered, we can adapt it. I don't think that that is going to be something we need to consider based on the scenario. We are considering things, depending on your climate state, you could affect the way you're growing crops, whether you’re growing them outside or in a greenhouse and change your receptor exposure that way.

>> ILLANGASEKARE: Last question. A general question on PFLOTRAN because these are open access. Do you have, this is a general question for the whole group, do you have a workshop or trainings for people who can use a user's manual? If someone wants to use an open access code, how do you do it?

>> CONDON: Well, I'll say that for the GDSA, so right now we're developing our first prototype, so we don't have that yet. We're developing our first user's manual. But for the GDSA framework as a whole, I think I'd like Emily answer that question.

>> STEIN: So we do offer PFLOTRAN short courses on a regular basis. Those have happened within the U.S., but also at various international venues. We have recently developed a short course that looks at that next generation workflow, so it's a little more comprehensive of the whole GDSA workflow. That has only been given internally so far, because it's very new, but that's another one that may be offered in the near future. dfnWorks has offered sort courses in the past, and Caitlin, it's certainly something we could also get together for the biosphere.

>> CONDON: Absolutely.

>> ILLANGASEKARE: The reason I ask that question is that I think we should [Indiscernible] people sometimes take the models and run it on their own, and run it the wrong way, and they try to make statements and conclusions. So is there some sort of mechanism to make sure people don't use these models in the wrong way, you know? That's my question mostly. People use the climate model, that’s what sometimes they do. It’s a general question.

>> CONDON: Sorry, Emily. Do you want me to answer it or were you going to answer it?

>> STEIN: I was thinking about that. It's not really something I have thought about in the past and I'm not sure how we would control how somebody else uses the model.

>> CONDON: For the biosphere model, we are developing a detailed user's guide and documentation to explain how we implement. We're trying to be very transparent in how we're building it, how it functions, and how all of these things go together.

>> ILLANGASEKARE: The open access models, it is good thing to have open access code. But at the same time, people can take a course and do their own things and then without any quality control there, I mean, obviously they have -- the people are using the models will have to sort of admit the fact that they are doing it on their own. It's just a comment, an observation.

>> BAHR: Okay. Thanks, Tissa. Just one last clarification. When you are designing your reasonably maximally exposed individual, you're not taking account of how that person's risk may change over their lifetime, for example? Exposures to children may differ from exposures to adults and sensitivity to doses to children may be different from those of adults. Is that

correct?

>> CONDON: Yes.

>> BAHR: Just 70 year adult type --

>> CONDON: That's a little bit of a misnomer. You know, we explain it that way, but the way we design the RMEI is to be conservative, so it looks at a variety of different age ranges to determine our average adult uses the factors that include both consideration of how doses to children versus doses to adults. It's averaged around for a 70-year-old lifetime. Those are considerations we are keeping in mind. We're not ignoring that at all and it is definitely something to keep in mind.

>> BAHR: Okay. Thank you very much. I think we need to move on to our next presentation, so we're going to hear from Tim McCartin and Dave Esh. So if we can bring them onto the screen. And I see some slides about to be shared. Okay. Looks like you're there. And Timothy is going to start. Is that correct?

>> MCCARTIN: Yes.

>> BAHR: Okay.

>> MCCARTIN: Thank you. And Dave Esh and I will provide our perspectives from a regulatory agency on the development and use of performance assessments over the past three or four decades where NRC has been doing performance assessment work. Next slide, please.

We'll touch on four aspects. One is certainly key aspects in the development of a performance assessment model, getting into the decisions about the scope and level of detail. The PA development process, and finally, challenges and lessons learned in the development. And Dave and I will be sharing this. Hopefully it will be seamless, other than there will be a change in voice at certain times. Next slide.

In terms of performance assessment, in the upper right you clearly start with a real site. Sometimes you have a preliminary design, some type of design. You work through your current understanding and you have model support, be it collected data. Sometimes it's data from other sites, because if you're at the very early stages, there's very little data. And you're going to create some mathematical abstraction that will estimate performance ultimately in terms of safety, that generally is in terms of a dose, but what isn't shown here that is just as important, it also gives you a capability of all kinds of intermediate results, be it waste package lifetime, release from waste forms, travel times in the geosphere, et cetera, that help you get an understanding of the performance of the facility.

And one part I really want to stress is that although this is one arrow that goes straight down, and it does, early on when NRC started its performance assessment development, we spoke of an iterative performance assessment program. And it isn't just one flow through the system. You iterate back. You get at the end of a performance assessment calculation and you assess the results, you look at the uncertainties, you look at what you know, what you don't know, and you look at things you could improve. And you go back to the beginning. And that's the iterative nature of performance assessment that is critical. And the performance assessment provides you with a tool for challenging your thinking and your understanding. And I will say in the high-level waste program, we benefited greatly from the critique and review of others.

As you know, DOE had its performance assessment model. NRC had a completely independent performance assessment model. We had technical exchanges where we iterated through and went through our current one. They would go through their current and we would challenge each other, ask questions. Additionally, there were reviews by the Nuclear Waste Technical Waste Review Board, and reviews by NRC's advisory committee on nuclear waste. All of those discussions that were surrounded by the performance assessment were useful in iterating through and improving the models, because reasonable people can look at the same data and draw different conclusions, and that was a very important step, all the discussion and the performance assessment, when you have to put either values on parameters or distributions and you get results, it causes people to think and challenge your thinking, and that really is the essence of performance assessment, to challenge your thinking and to better understand the support you have or don't have or what you have done. Next slide.

Okay. Some key aspects. There's a purpose. Why are you doing the PA? And what questions are you trying to answer? That changes over time as you perform this iterative process. The scope of the assessment. What to include. Disruptive events versus the nominal behavior. What type of modeling approach are you going use? How complex? The system versus process models. Data, models, abstractions. Certainly the uncertainty, the epistemic and aleatory uncertainties we heard about yesterday, propagation of that. There's also risk dilution that NRC was always careful to try to catch, if possible, and that is let's say one case of Kd. I'll be conservative and use a very broad distribution.

Well, in terms of calculating a mean dose, that actually may end up with a lower mean dose if you've got better data. So really it wasn't conservative. As you improved your knowledge of the Kd and if it was to the lower end, it actually would increase the dose. So just taking a broad distribution isn't necessarily a conservative approach. It might cause risk dilution. Of course, at the end of the day there has to be model support for all the assumptions, models, approaches in the performance assessment. And we'll try to touch on those.

Next slide. In terms of purpose, if you look at the high-level waste program, there was approximately 20 years of site characterization. Well, the role of performance assessment in those early days is different than as you go through the process. There was ten years to develop a license application by the DOE where the performance assessment was refined further certainly in the concept of after a construction authorization was granted, there would be a license approval to receive waste. The performance assessment at that time would be update with all of the information you learned during the construction of the repository, and a very important role for the performance assessment was the decision for permanent closure. NRC's regulations require a performance confirmation program where DOE would continue to collect information in that long time period after they first got the license. It would be approximately 95 years of performance confirmation data that would be evaluated, in part, in the context of the performance assessment. We would have expected the performance assessment would change overtime as you got more information.

And so you can see as you're making decisions along the way, the performance assessment is enhanced, is improved, and is answering different questions as you go forward. The next slide.

And Dave will pick up on the scope and level of detail.

>> ESH: This is Dave. Hopefully my audio is sufficient. If not, Tim and I are somewhat interchangeable and he can take over. The scope and level of detail is definitely one of the harder if not hardest steps in the performance assessment process. Typically features, events, and processes are widely used and those are discussed in terms of a bottom up process where you make an enormous list of FEPs, and then you go through a screening process of some sort. You can screen based on likelihood, probability, consequence, or maybe some combination of them, or maybe some aren't relevant. It might be eliminated due to a regulatory requirement, for instance.

Another approach that's used and may be starting to be used more readily is a safety function approach where you come up with what are all the safety functions of your system and then try to build what you need in your model, coming at it from the other direction basically. And then a third is a mix or a hybrid where you combine the two.

But all of this is difficult and can be expensive. But the scope and level of detail that you need in your modeling is typically an iterative process, and it relies heavily on expert judgment and external review, such as provided by the NWTRB, or in the case of NRC, when we look at things that licensees or the Department of Energy has done.

A challenge is that the real world, of course, can be incredibly dynamic and complex. So that creates challenges from getting the scope and the level of detail correct and how you handle it in your modeling process.

Next slide, please. Here is a couple pictures from non-high-level waste examples, which I think are illustrative. First on the right from WIPP, you may or may not be aware that I think it was the early maybe five years ago or so, there was an incident at WIPP where some of the waste generated at Los Alamos National Lab had unexpected exothermic reaction, and they actually resulted in a release of some radioactivity to the surface. So there was a combination of events, unforeseen waste interaction. The drift was open because they were emplacing waste, so there wasn't a backfill to prevent the release. And then there were some challenges or issues associated with the ventilation system, that the point being it was a complex series of events that really were not anticipated in the performance assessment.

So the performance assessment, which I believe was one of the earliest performance assessments in the U.S. done by Sandia and reviewed by the Environmental Protection Agency, did not project any releases from a short amount of time from the facility. That was an interesting example.

The more interesting example is on the left. This is from low level waste disposal facility in Nevada. And the initial report that we received went something like this: There is a large rain event at a closed disposal facility, and it caught fire and exploded. That was the information that we got. So when I heard that, I thought, is this an April Fools joke? It sure sounds like an April Fools joke. Right? Because how do you have rain causing a fire and explosion?

Well, it turned out it was also a case of unanticipated waste interaction, because back in the early days of waste disposal when maybe performance assessment was developing and you didn't get the rigor of the scope and level of detail development process, there was some waste that had metallic sodium that was exposed, and it's a very desert location.

So a combination of complex things had to occur in order for this event to happen. Now, they did, after the fact, assess the situation. They didn't find -- they found very minimal radioactivity had been released, because the sodium waste had very low radioactivity in it. But that was more by luck and not by purpose. If that waste had contained a lot of radioactivity, it could have been a much more significant problem.

It illustrates a lot of things that go into a performance assessment. So number 1, you have to evaluate the system for maybe thousands of years, but the importance of a short, strong rainstorm was very significant in this incident. So a very strong desert rainstorm resulted in high infiltration or percolation into the system. The cover system had aged. The system had been closed for maybe 30 years at the time of this incident. The cover system had aged so that the engineered properties were no longer like the as-built conditions. You developed some fracture in the natural materials that were used for the cover. That allowed a high amount of water to reach the sodium. The sodium was in carbon steel, which experienced some corrosion in the 30 years it was in there, and that's basically the sequence that you could get from a large rainstorm causing a fire and explosion at a disposal facility. A very interesting example, especially when you think about complexity. Next slide, please.

And then the model development process that results from that scope is almost always, as Tim indicated, iterative. And you generally progress from simple to complex. And I would argue there's lots of different types of complexity. So the complexity that many times is tackled is trying to add in dimensionality. Right? Which is very expensive computationally. But when you're dealing with system modeling, complexity happens in the way that the components are integrated and the propagation of the temporal effects through the system. It's a different type of complexity than just making bigger and bigger models, for instance. And initially in the model development process, it's common that your data may be very sparse and the designs may be evolving, but the development process is extremely important that the iterative nature can be used to account for new data coming in and evolution of the designs.

So I'm going to hand back to Tim now and he's going to walk-through some examples as this has been applied in the high-level waste project.

>> MCCARTIN: Next slide, please. Okay. For the Yucca Mountain situation, at NRC, we started out with very limited data. There were large uncertainties. We had very simplistic models. It's almost embarrassing today to say that our initial source term code was, I think, four or five lines of Fortran. I think we had an instantaneous release and a fractional release and you just selected one or the other. So it was very, very simplistic. I will say along the iterative lines, as time went on, actually, the source term became a far more complex model than the flow system, as it turned out.

There's a lot of things going on, as Dave indicated, the evolving design, et cetera. And so you're trying to get some initial ideas and trying to assess where the largest safety significance items are, but I would say the biggest thing is you need to keep an open mind in these early stages. You don't know where you need to add more complexity. You have to continue to develop. And every time we did a performance assessment, we identified what the results were, but also the limitations and what we thought we needed to improve for the next iteration. And we continued to do that. And it's always helpful to get the review of others. Next slide.

In terms of, as I said, our initial development was documented in a NUREG in 1992. We actually had an integrated release standard at that time. There wasn't the current Yucca Mountain standard, but we did include all the steps. We looked at scenarios. We considered disruptive events. We did sensitivity uncertainty analysis. Even though it was fairly limited and crude, but at the end of the day, the key is identifying model improvements and data needs. Next slide.

We certainly, as I said, I mean, this is almost redundant. We enhanced the models. We collected new data. We added and removed scenarios. We modified the design. And this is where the performance assessment, you want to challenge yourself. You want to better understand the system. The performance assessment doesn't understand anything. It does what you tell it to do, but at the end of the day, whatever the results are, you want to be able to look at the results and understand, well, why did I end up with that result? Be it a release rate, be it a dose, be it a waste package life time, et cetera, et cetera. Next slide.

The model enhancements cover a broad range of things. I'd like to point out that if my memory serves me right, when I was doing this, I believe it was an NWTRB meeting, at least a couple decades ago, probably three decades ago, that I remember DOE was presenting their design for the waste package, and it had the structural barrier on the outside and the corrosion resistant barrier on the inside and the structural barrier corroded relatively quick and stopped providing that mechanical protection, and then the corrosion barrier failed due to damage, mechanical damage, not corrosion. And I wish I could remember the person, but it was one of the board members who mentioned at that meeting, you've got the package inside out. You need to reverse it. Have the corrosion barrier on the outside and the mechanical barrier on the inside. And that ended up as the DOE design.

And so it just points to the idea of being open to suggestions and the broader range of reviews you can get is very helpful. It certainly, in our developments, it came to adding thermal impact, mechanistic models for the waste package failure. Water contacting the waste. There were a lot of things that are very important to the source term. I can point to the DOE model for Yucca where the corrosion product environment ended up being a fairly significant aspect where certain radionuclides were held up. And so there's a lot of development and enhancements that go on as the performance assessment evolves. It gets more sophisticated. Maybe more complex in some areas. Maybe less complexity, but the key is that you understand why something is occurring and where it ends up, and that is the benefit of the performance assessment, it allows you to challenge yourself.

And now Dave will discuss the ever important uncertainty aspects of performance assessment.

>> ESH: Next slide. Thank you. Thanks, Tim.

So for uncertainty, it's really about including evaluating and understanding the impacts of uncertainty. It's very essential to this process. And I would say for probably the better part of 15 years now, I've worked on non-high-level waste things at NRC. Low level waste disposal, decommissioning, some reactor problems, accident risks, a variety of things like that. And the uncertainty treatment in the high-level waste project, I would argue, I could say is arguably as good as, if not ahead of the uncertainty treatment in most of those other areas. It was early on that uncertainty was recognized and evaluation of uncertainty was recognized as being extremely important. NRC learned many lessons. Some which Tim gave the example of earlier. He mentioned Kd, contribution coefficient, for those who might not be familiar. Partitioning of the radioactivity between the geologic material and the water. Representativeness of information. There's one slide at the end of the backups that I could talk to that's interesting there. I've kind of spent my career and even my life outside of NRC paying attention to uncertainty and how does it impact our decisions and what do we know about it? I think the world is very leptokurtic, I think it is. Fat-tailed. We represent many things as having thin tales in uncertainty space, but based on observational event sequences, I would say many times that things, improbable things are more probable than what way give them credit for.

When we evaluate one of these big models, usually it's a small number of parameters or alternative conceptual models that drive the uncertainty in the overall results, but you don't know that ahead of time, and that's why you build your model, do the uncertainty analysis, learn that, go back and iterate. Whether it's collecting new information, changing your model, whatever the case may be.

When I talk to people that don't work in this field about, you know, sensitivity and uncertainty analysis, sometimes they're kind of puzzled. They're like, wait? So you're telling me you're doing uncertainty analysis to try to figure out what matters in your model, but you built the model. Right? So don't you know what's important in your own model? And so you have to explain, yes, but it's just like the real world. You start putting many things together and it gets complex and beyond our ability to process and to understand. And I would say when you've worked on a performance assessment model long enough and done the uncertainty analysis that you can, as an analyst, anticipate what's going to happen when you change something before you run the computer model. Then you have an adequate level of understanding of the work that you're doing. Next slide, please.

So in terms of the next main component of the PA process, I think it's the most important part of the process. If, after my career is done, I see that people are doing more in this area, I'd be very happy. The bottom line is we're doing computational models because the system may not be observable over the spatial or temporal scales we're dealing with. But that doesn't alleviate your need to come up with why the model is correct. And that usually has two components, components of verification and what's traditionally called validation. We're solving the right equations. For PA you cannot do validation in the traditional sense, because you can't give radiological doses to people and measure them thousands of years in the future. That's not practical to make a decision today. But what you can do is develop a model support program or process that has many -- it's very multi-facetted and it has many components that develop confidence in your decision, and some of those components might be internal review, the quality assurance that we heard about yesterday, NQA1, that's incredibly important. And independent external review, that’s the reason why we're having this meeting, like the NWTRB evaluating things. It's very easy in some of these projects that go on for a long time to have increasingly narrow vision and group think, and I think external review from groups like the NWTRB or people from other countries, like we'll hear from a lady from the U.K. after this, and members of the public that generally can bring perspectives that are very enlightening to the process and it helps us make better decision. Documentation of whatever verification was done is essential. It's not good enough to say we checked it. You need to create a record that shows what you checked. Invariably, some things you'll identify, there might be some mistakes. You want to see why those happened and have a process to manage and correct them. And then the multi-facetted confidence building has all sorts of components to it. We could spend a whole day talking about that. And one of the things I liked when I worked on the high-level waste project was the natural analogues report they had developed, which I thought was a very good piece of information to support the PA and evaluation. Next slide, please.

So in terms of lessons learned here, we have about five minutes, and I have three slides to go through. So we're in good shape. Lots of lessons have been learned in this PA development process at the NRC. And with the

DOE and other groups. PA is very useful, even when the data and design are in the initial stages. You can get insights into how the system might work. What are the key components or likely to be the key components? What are the areas where you're really lacking in information that you need to collect something? So that iterative nature assists, integration of data collection and model parameters enhancements that are inevitably going to occur. And then in addition to that, detailed analysis outside the performance assessment can be useful to inform and assist the model development process.

So even though our computational power is much better today than when I started or even when Tim started 90 years ago, okay, we'll make it 60 years ago, Tim, even now the computational power is extremely stronger today than it was then. You still can quickly run into limitations. And so you have to use abstractions and simplifications in a system model especially. So we strongly support that. You have to show that your simplification captures all of the essential behavior, but when you're doing system modeling, it's a very common occurrence that you need to use simplification or abstractions. Next slide, please.

Sensitivity uncertainty analysis were conducted for every version of our PA model and developed all sorts of insights that we used to enhance and refine our models. So NRC started TPA code development through many iterations. I was involved in some of them and it progressed from Fortran to what I believe now is GoldSim. We still have Fortran code, of course, too. So the technology evolves over time. Your modeling has to evolve with it, make use of the better tools that might become available.

A platform like GoldSim is so much more transparent than code written in Fortran. If you have to give it to the regulator to review, you can see what's going on inside a GoldSim calculation, where it’s much more difficult inside blocks and blocks of Fortran code.

And we found that there's a big benefit to having flexibility to incorporate alternative approaches and scenarios. I think that's a comment or at least something I'd like to hear about from the DOE is how their generic approach that they're developing now could incorporate alternative scenarios, because sometimes these codes are kind of like battleships or aircraft carriers. They're hard to change direction on once you have made something. And in a system model, many times it's the alternative conceptual models or combinations of them that are the drivers of your uncertainty. So your system that you developed to evaluate the system has to be able to accommodate those alternatives that may inevitably arise.

Next slide, please. And then independent modeling. This is very essential. And I think it leads to continued evaluation and improvements. It definitely promotes technical discussion with experts. I think the question came up yesterday, like how do we or other groups maybe learn about what DOE is doing right now with the work that they're doing since the Yucca Mountain project was stopped? I believe I spoke with Emily at a conference and heard some of her talks before. They were very good. So we have interactions that way, learning what people are doing. We definitely have interactions with people throughout the international community, whether it's with the IAEA or individual member states will contact us on questions or things they want to coordinate with, like we had a detailed interaction with Japan, one recently with China, previously we had one with Belgium on their low level waste, or I guess more than low level waste, but low and intermediate level waste disposal in Belgium.

All of those interactions with experts lead to continuing development and capabilities. And this independent modeling that we do, it's informed by data, but sometimes you have holes in data. Your approach is to leave those holes in place and see how important they are. And if it's very important, fill it in. Like as Tim talked about with the risk dilution example.

Ultimately, staff capabilities are enhanced by doing this independent modeling, and that really helps us to review the licensee models. You know what to look for. You've worked through it yourself, so you can identify the problems and then you know what questions to ask a licensee if they didn't talk about those same challenges you may have experienced.

And I think that's it. I think we're right on time. Next slide I think is questions. So thank you.

>> BAHR: Thank you both, Tim and Dave. Those were very informative presentations. I'd like to go back. You both talked about using PA models through a range of activities. Tim's listing actually started with the

site proposal after site characterization when it's first site selection. Can you comment on how you might actually use these kinds of models even before that to inform the process of site selection and also inform the process of designing conceptual repositories? At the moment, DOE is using three sort of generic repository designs as part of their test cases, but couldn't you try a variety of designs using those models early on to think about what should you be looking for in a site and what should you be looking for in a design? Either of you want to tackle that?

>> ESH: Tim, do you want to give it have a first stab and then I'll talk?

>> MCCARTIN: Sure. There's absolutely no reason you can't use performance assessment to try some hypotheses and some design alternatives prior to going further in a site. In terms of site selection, that's always, for NRC, we don't participate in site selection. That's a DOE function. But there's no reason you could -- you can't use it. We would be more interested in looking at the kinds of data that would need to be collected at a particular site, not whether a site would meet the requirements. But NRC has a slightly different focus

there, but I think performance assessment is a very useful tool at the earliest stages.

>> ESH: What I would add to what Tim says, so I work outside of high-level waste now, and I work on complex decommissioning sites and low level waste disposal and a lot of international activities, and what we experience is that the analysis can be used early on in many of those decision-making processes to answer questions like, well, what geometry should I put the waste in? Or what sort of barrier performance am I going to need to meet the regulatory criteria? Or for instance is there any benefit to this particular type of barrier? Most of the problems I work on in the U.S., it's already at a particular site, so you're not selecting a site. But outside of the U.S., for instance, I work a lot on borehole disposal of disused sealed sources. And for that, the member states are trying to pick a site where to implement that technology. And the analysis greatly benefits that process of trying to identify, what are the criteria or characteristics of a site that you might need to make that decision?

>> BAHR: Thanks. PEDDICORD's hand is up. We'll go to him.

>> PEDDICORD: Thank you. This was really a suburb presentation. I want to express my appreciation to you all for a great talk and really your excellent work.

A couple things come to mind on this. First of all, you ought to copyright and make a million dollars off your, quote, improbable things are more probable than what we give them credit for. I think it ought to go on all our business cards as well, too. Before you get to copyright, I want you to know I'm going to use that in my class this afternoon, that this is something our students need to hear. So I want to commend you on that. I think that carries tons of insight and history with it as well.

I really appreciated your comments on critiques and what you have found to be benefits of critiques from others. I think that's another key point. You mentioned the board, and we certainly appreciate that and the Advisory Committee on Nuclear Waste. What I was wondering about is you utilize kind of deep dive, one time critique or pulling together of groups for one time critiques. I'm familiar with what you all do with PIRT teams. Maybe that's more over the reactor side. But I wondered if you do things like that now on the waste side as well?

>> ESH: Thank you for your comments. These performance assessment calculations can many times be quite large. Right? So with not just complexity of the computational model, but the documentation might be enormous. So for instance, I do a lot of work at the Hanford site in the U.S. And they have something like 4 million documents or something like that. I don't know. It's an incredible number of documents. But there is very valuable information in there, especially with historical operations that may have been done under conditions or regulations that were a little different than today, to put it politically correct. So when you review that sort of system, we've found there's benefit that you need to have probably both the breadth and the depth, but the depth has to be selective and risk-informed. The information is just too much. You cannot review everything. I mean, in a licensing review, you'll review everything to the depth that it needs to be, but in terms of implementing an external review team, the structure is benefited by having a breath component to it. We have all the people with the right disciplines to look at it. Then in the key areas, they can really drill down and look at some of those in detail. If they find problems, then expand out from

there.

>> PEDDICORD: Yeah, thank you.

>> MCCARTIN: And just to follow on in the high-level waste area, I know a couple key points in time we had an external peer review of our performance assessment code, and also at times on very specific topics brought in outside experts to look at what we were doing. One of those was in the area of igneous activity. And so you want to be flexible and you agreed with us an outside external review there is no substitute because at the end of the day, being a [Indiscernible] we all bring a bias to our analysis, and we know point of view, but you certainly have to remain open-minded to whatever, you know, and there's a lot of good reviews out there that we benefited greatly.

>> PEDDICORD: Thank you very much. Excellent. Appreciate it.

>> BAHR: Did I see Tissa's hand up?

>> ILLANGASEKARE: Yes. Thank you very much for your presentation. I’m sort of familiar with some of the work [Indiscernible] uncertainty. My question is that in the [Indiscernible] approach, so in the

[Indiscernible] approach you sort of mention this briefly. Is the conceptual model [Indiscernible] situation? Like when you go back, it will take you loop. Let's say that more data becomes available and then you develop your scenario, uncertainty, for example, based on a certain conceptualization. But when you collect data, as the data comes, then your conceptual model can change. Is that correct?

>> ESH: Yes. Your conceptual model can change. You might not get it right the first time or even when you collect information, there may be viable alternatives that all comport with the data. Right? So you might have alternative A, B, and C, and you think that C is the most probable, but A and B, you can't eliminate. Show those are sources of uncertainty that in the non-high-level waste field, we have trouble people incorporating. And I think in the high-level waste field, if I remember back in the day, they had some alternatives for various things in their evaluation that they had different alternative conceptual models that were at least formally assessed. The conceptual model uncertainty, unless you have an infinite budget and infinite time to collect all of the money and then

characterization techniques that can resolve all that, you're always going to be left with some residual model uncertainty is what we term it. And so, yeah, it's important to have a system that can account for that and adjust. You can't just develop a model that has one type of hydrogeology and then you learn through characterization, we've had these fast pathways that our tool can't accommodate. I think that's what you're getting to.

>> ILLANGASEKARE: So basically, you have the sort of structural uncertainty and the measurement uncertainty. So the structural uncertainties come from the scenarios. So my question is if you are looking at a very long time simulation, if the scenario – once you learn about the uncertainty, can you improve the scenario uncertainty based on your simulation itself in an iterative loop. For example, my question is when you do a very long simulation, do you assume the same scenario? The scenario can change as you go in a million-year simulation, for example.

>> ESH: If you're properly doing dynamic system modeling, obviously your scenario can change. So, like, I'll give you -- we did, in the fields I deal with,

there's a lot of surficial processes. Those are very complicated and things can go on. Like for instance, if you use an evapotranspiration cover at a disposal waste site or a complex decommissioning site, and it relies on the vegetation that's present to reduce the amount of moisture that goes into the system and eventually reaches your waste. Well, that plant community can evolve overtime due to invasive species, for instance. You can have wildfires that affect that vegetation overtime and those are all components of the dynamic system model. You can evaluate those as scenarios. What if I have a fire scenario? Do like what if calculations? Or you can incorporate those processes into your system model itself and let it propagate through all the scenarios and their occurrences and the probabilities, et cetera. But yeah, absolutely, I think the scenarios can change in overtime, especially, I mean, the benefit of going to geologic disposal is that you're trying to mitigate a lot of that complexity with the scenarios. Right? So you try to control your site and eliminate those uncertainties or at least mitigate them. In the field that I deal with and that's really not practical, because many times the contamination is already in the environments. So you have to assess the environment it's in rather than control the scenarios.

>> ILLANGASEKARE: Thank you very much.

>> BAHR: I see Paul's hand up.

>> TURINSKY: Yeah. I had a question. When you were developing your performance assessment model for let's say Yucca Mountain, did you have public engagement during the development process? And I'll talk about the non-subject matter expert, just so they get a gist of what their concerns were? Maybe some of the attributes of performance that you were using, they had a different [Indiscernible] what they were concerned with. They might have some idea of a scenario, like heavy rain in the desert that you hadn't thought of?

>> MCCARTIN: Right. And throughout the development, when we did our first performance assessment, which was a demonstration that we could do a performance assessment and not so much on the actual behavior of Yucca, it was a public meeting that we had public comment periods, and then ever since then, DOE and NRC, we would go back and forth, and approximately we would do a new iteration, each agency, about every three years and about every year and a half we would have a public

technical exchange where either DOE would be presenting their latest version or NRC. So we would be presenting their latest. So it would be always that public meetings and then, of course, there were many technical exchanges on very particular aspects, and all of our participants were allowed to provide comment. And so we did hear from them.

>> TURINSKY: Okay. Once you get to the licensing stage it almost becomes an adversarial sort of environment.

>> MCCARTIN: This was before we received the application, yes. Once we get an application, it is a much more formal process. And as people know, there were approximately 300 contentions. Many of them with respect to the performance assessment and/or assumptions and parameters used in the assessment.

>> TURINSKY: Okay. Thank you.

>> BAHR: Okay. Well, thanks again to Dave and Tim. Very informative presentation and spurred lots of questions.

And now I'm delighted that Sarah Vines from the U.K. has been able to join us at a time that's probably not as convenient for her as it is for us, but we appreciate your participation. I see Sarah there. Are you going to be working your slides, Sarah, or is someone going to --

>> VINES: Let me give that a go and see if I can do that. How is that?

>> BAHR: Yes. That's great. Thank you.

>> VINES: Excellent. Okay. So thank you very much for inviting me. It's very good to be here, and I say it's evening here, so I'm at home. If it you do hear some domestic noise, I apologize for that. But intention is to present to you this afternoon this presentation on environmental safety case modeling in support of geologic disposal of the U.K.'s radioactive waste.

So my name is Sarah Vines and I'm the post closure and environmental safety manager at Radioactive Waste Management, which is the U.K. company that has the remit to act as the implementer of government policy of geological policy of the U.K.'s radioactive waste. I've got 20 years experience working on the scientific underpinning of geological disposal. I'm a chartered engineer. I'm a fellow of the Institute of Materials, Mining, and Mineral. And my PhD was on pitting corrosion of stainless steel. And my early career roles were in the printing industry and the research councils in the U.K.

So to give you an overview of what I'm planning to speak about today, I'm planning to give you a brief update on siting in the U.K., because people are always interested in that. Talk a little bit about what the focus is about environmental safety case work, the aims and objectives of it. The scope of that environmental safety case work, and particularly highlighting our 2016 generic Disposal System Safety Case. And then I'm going to talk about what we're doing in current work.

So talk first a little bit about siting process in the U.K. This diagram is from our policy document about how we will evaluate sites in England and Wales and forms a number of stages.

So the first stage of this policy is that pretty much anyone can come and talk to us and express some interest in talking about the prospects of siting a geological disposal facility in an area of land. And if those talks are successful and both parties want to continue, then we set up a working group. And that working group involves both the interested party and RWM. And that working group has the job really to identify a search area that we're going to attempt to search for a suitable location for a geological disposal facility. And also, to set up a community partnership, which is where we invite all the relevant people that we need to be on that group. And at that point, when we set up community partnership, that's when some investment funding and engagement funding starts kicking in. And it's at that point when we start doing the local studies of the investigations, which are there is an image of an airplane doing some seismic studies. Of course, if it was in an inshore area there could be a boat, and then working up, then, to a process where we might start to drill some investigation boreholes.

So we're currently at the point where we've engaged with quite a lot of people, interested parties, and we're very fortunate that we've now established three working groups. So we just are working with those and hoping that we will be able to set up some community partnerships very soon.

So that's where our siting process is. And then just a reminder about geological disposal in the U.K. So similar to geological disposal projects internationally is all about isolating radioactivity from the surface environment. Containing the hazard until it's decayed. And it's about passive safety, which is not relying on human action. And also, I think, really relevant in the U.K., we've been working on nuclear technology since the Fifties, and so we've got a lot of different types of waste streams, and we divide them broadly into what we call our low heat generating waste, which we would dispose in disposal vaults, where we might be stacking packages up seven high. And then what we call our high heat generating waste, which is more likely to be the vitrified waste we've got from reprocessing. Also some materials that have not yet been declared as waste, like our spent nuclear fuel, and potentially also separated stocks of plutonium. We call these the high heat generating waste and we'll be more likely disposing of those in disposal tunnels. And while the volume of this waste is smaller than the volume we have of the low heat generating waste, because it needs to be managed, the heat needs to be managed, it's spread out more. So the volume of that is bigger.

So the focus of our work and the environmental safety case is really about demonstrating that it is feasible to make an environmental safety case for the U.K.'s higher activity waste because we haven't yet chosen the site that it is gonna be at. So we can't do a site specific evaluation. That also means the environmental safety case is there to support site evaluation, to ensure that relative safety requirements will be met by the site and that we have, in our site evaluation policy, we have six factors that we're doing the evaluation on, which safety and security is one of them and very much in the heart of what we're doing there.

Also, we use our safety case to support packaging of waste so that we ensure that any waste that is packaged now is suitable for its eventual disposal, and we're also very much about capability development.

One of the reasons, I think, that we need to do capability development is because of the very much staged approach we've got to producing the safety case. This diagram comes from our regulations from our environment agency. And so it's a different submission they're expecting at different stages. So at the point where we're starting to define which sites you might want to take forward for deep borehole studies to do the investigation on, we have to submit what we call an initial site evaluation. And the expectation is that that may not need to include any quantitative assessments, whereas on the other hand, by the time we get further on in the point where we are presenting our initial environmental safety case for operations and so on, we will be needing to develop qualitative, develop calculations that really reflect the site. So we need to build up that capability of how we're going to do that now.

So to say a little bit about the scope of our environmental safety case. The environmental safety case is quite a broad document and includes perhaps a structured approach to safety claims, arguments, and evidence. And then it also includes numerical assessments, which would be our post closure safety assessment. And also, we need to do an operational environmental safety assessment. That includes what the environmental impact of any discharges that might occur during operations.

And as was mentioned earlier, we also have alternative lines of arguments and very much drawing on things like natural analogues and also drawing on our underpinning knowledge base, where we have a series of status reports about underpinning knowledge on waste packages and how they might evolve, our engineered barrier systems and how they evolve, geosphere, understanding of groundwater and understanding of gas generation. Criticality safety. Lots of details about radionuclide behavior. Analysis of the biosphere. And those kind of things. So very much the scope of the environmental safety case is really broad. We need experts on this really wide range of science, which makes our job more interesting.

So I’m going to say a little bit more about the three items on the left in terms of what it is that we're doing in the safety case. So first of all, on claims, arguments, and evidence, we have two regulators in it the U.K. that we work with. One is our environment agency and the other is the Office of Nuclear Regulation. Both of these organizations include in their guidance and principles that safety case should include a set of claims, which is supported by structured arguments and underpinning evidence. So we're looking to emphasize this logical structure in our safety case at the moment more than we have done in the past. And so we're developing a system to do that.

So we've got an am safety case management system that we've been doing which we call ViSI. So in this, we would explicitly perhaps display our safety claims in the underpinning arguments. This is something we're trying to populate at the moment. All our claims would perhaps trace back to our kind of fundamental protection objective that we would provide safe, secure, and implemental or geological disposal solution.

And then we also, then, have underpinning that a whole structure of different safety claims. And then for each safety claim, we would then have some detailed information where we might explain the basis for that claim in law, regulations, and also explaining arguments and where our evidence is coming from, and we're trying to do that in a way that you can click through it and highlight the references and that kind of thing, which is proving very useful to us.

So that will be our claims arguments and evidence part of the safety case. Once we move on, then, to the post closure safety assessment, where we've got methodologies and models for assessing various different aspects in the numerical assessments in order to demonstrate that we might be meeting the guidance levels or the dose criteria, whatever we've got for that different bit. So we would include in that groundwater pathway. Looking at gas generation and migration. We would need to consider not only radiological dose effects, but also the impact that non-radiological contaminants could have. We need to consider inadvertent human intrusion. We need to consider the impact not just to people, but also the environment, both non-human biota, but also groundwater protection. And we need to consider the post closure consequences of criticality. And as we were just hearing, the treatment of uncertainty is really, really important within these assessments.

And I'm going on to speak a bit more about that later. We also do this operational environmental safety assessment, which covers what we call our period of authorization, when we've still got kind of institutional control of the site.

So our 2016 assessment on this very much focused on the gas pathway and only qualitatively discussed any solid or liquid discharges during this period. And it was developing our approaches to this work, looking at considering more about the non-radiological contaminants, developing how we do our dispersion model in the biosphere, and doing more work on gas generation.

And I think for this bit, we would really expect that we wouldn't need to do any detailed assessment as part of an initial site evaluations, but we're developing our competencies and our approaches for future stages of the process.

So I'm going on now to talk a little bit more about what we call our generic Disposal System Safety Case that we produced in 2016. So you know, some people go as far as saying calling this is a safety case is a bit of a stretch. It's maybe more of a feasibility study. And it's very much generic, because we don't, at this point, have a site. So it's based on our inventory of geological disposal in the U.K. and what we think we would need to dispose of, but it draws on illustrative disposal concepts that have been studied internationally and it makes use of illustrative geological and hydrogeological environments, which we've pretty much made up, and then also draws on our wide knowledge base, both the U.K. knowledge base and the international knowledge base. So I've got some little cartoons of the geological environments. I've got some bigger versions of those coming up, too. If you can't see those, don’t worry.

So this is what we decided to do in terms of choosing illustrative disposal concepts. And we tried to draw on concepts that existed internationally that I got a lot of history and precedents and illustrated different things that would be useful to have a go at modeling. So we kind of divided our approach into higher strength rock where we've used for the low heat generating waste, we've used our U.K. concept, which is stainless steel containers with a cement back fill. And for the high heat generating waste in the highest strength rock, we've used the Swedish concept, KBS-3. Very durable container with a bentonite backfill.

For lowest strength sedimentary rock, we've used Swiss concepts. We've used the Opalinus clay concept for those models. And then in our evaporite rock example, we've discussed the U.S. WIPP concept, embedded salts for the low heat generating waste and a German concept for the high heat generating waste. So that's how we've really drawn on all the understanding that's developed in these different concepts. We've put those into our research status reports. We've borrowed data and modeling approaches related to those concepts to really support the modeling. We've very much drawn on a lot of different knowledge there. And that's gone down very well. I think whenever we get any kind of, like, big review about when we had a big review looking at whether we were ready to launch the siting process, what do other countries do is definitely a question that gets asked a lot. We have to draw on all of that. It's very, very beneficial for us.

So this is our illustrative high strength rock example. So it’s a metamudstone overlain with a sandstone. So while this is a high strength rock example it’s perhaps a slightly better high strength rock example than [Indiscernible], but it's got GDF there is sort of a red. It's discharges through -- we've got two discharge pathways, one of which goes to a well. The other one goes to the sea. We have some dilution in the overlying sandstone, and so that shows the kind of conceptual environment that we've been modeling.

And then our lowest strength environment is a mudstone overlain with a chalk. There you can see the GDF there. It's got the mudstone layer. And then you have two layers of chalk above that and then in this case it discharges both to a well and then to a river.

And then I haven't actually got a drawing of the evaporate environment. I think we decided for that we weren't really ready to be carrying out any numerical calculations in that environment.

So to talk a little bit more about uncertainty, the U.K. regulatory guidance is fairly specific on our need to quantify some uncertainty and implies we would do probabilistic calculations of risk and they would form at least part of our post closure performance assessments. They illustrate examples of uncertainties that they think can be reliably be quantified and they also give examples of things that they think can't reliably be quantified and perhaps different ways of doing it. They put things about future human actions and so on in there. And they suggest that we perhaps also use scenarios which is another approach that we've got to presenting uncertainty. So that's one aspect that's of interest. Also, I think the other aspect of interest is the time scales. So I think in some countries, the regulations are quite specific about the time period over which you have to do the numerical assessments. In the U.K. they've said it's up to the implementer to define the period that we do numerical calculations and to justify that. So we kind of use this diagram to say that in the initial transient period, you've got quite a lot of uncertainty as GDF would perhaps re-saturate, and as you kind of use up the oxygen and it becomes anaerobic, so that's perhaps quite difficult to do probabilistic calculations at that time. And also, in the really long-term, once you get beyond perhaps 200,000 years, you get increasing uncertainty about what the biosphere and geosphere evolution might be and it becomes difficult to quantify the uncertainty at that stage. So probabilistic safety calculations, we perhaps see as important in that kind of like 1000 to 100,000 years timeframe. But then we also have the other aspects, like the narrative of how the system might evolve. Complementary safety arguments. Use of analogues. Recent arguments and perhaps deterministic calculations as well.

And then I think we were discussing this kind of thing in the previous presentation, but we very much look at wanting to use a hierarchy of models in the work that we present. So our Total System Model, we'd see as being relatively coarse and abstracted than supported perhaps by a series of other models. So we would have our component level models, which would include our source term, our hydrological regional ground flow model, biosphere models and then even under those we'd have our process models which would be where we would get perhaps a bit more detailed. We might have cement leaching model that might be quite detailed, but then we just -- that would give us the understanding that they would then use to inform our higher level models, or in some cases we perhaps might use process models to explain why we're ignoring something in the Total System Model. So we spent quite a lot of time looking at if we had nonaqueous phase liquids in a container, could we enough they didn't get out of the container and therefore we did not need to use a nonaqueous phase pathway in our system model.

But we do need to consider how we treat uncertainties in that post closure safety case. So it's a complex system. It's got a range of processes. Quite a lot of these have got high uncertainty. And we need to include the uncertainty in the model and that helps to provide our understanding and we can establish this iterative loop of gathering more data, doing performance assessment, and really focus our site characterization program and our research program so that they're needs driven and really focused on getting the data that we really need. So that's why we want to start doing some really, really high-level scoping calculations early on so we can really understand, you know, what matters and what information about the site we really need to get.

We have a number of different strategies for dealing with uncertainty in any given scenario in the performance assessments. Sometimes we might be able to demonstrate that that uncertainty is completely irrelevant and doesn't matter. And sometimes if you've got, for instance, a really low quantity of a radionuclide, you may not need to know what its solubility is, because you may assume it all dissolves and still doesn't cause you a problem.

We've been talking about the second technique, which is addressing the uncertainty, explicitly using the probabilistic techniques. Also we could have bound the uncertainty and shown that that's acceptable. We can maybe rule out some uncertain processes or events. So the example we tend to quote here, and I'm not sure if it's a fair one, we don't assess meteorite strike. If we had a meteorite strike, worrying about the GDF may not be the biggest problem we have. And following on from that, we've also got either explicitly ignoring uncertainty or agreeing a stylized approach for handling uncertainties. And that's one of the things we do with the biosphere where we internationally agree reference biosphere models so that we don't have to perhaps worry about how much offal people might eat in 50,000 years time. We might agree to use present day behavior for that.

And recognizing that and modeling often shows that the outputs are sensitive to a small number of parameters, and those are the ones that you really need to work on.

And I think like you guys, we have an approach to defining scenarios to model performance assessments and one of the challenges is to decide what you're going to include in the base scenario and what is going to be a variant scenario. So base scenario is the way that we expect the system to evolve. It's likely to include the way that we expect climate to change and also to include, you know, studies of how radionuclides might migrate by gas and groundwater pathways.

And then we also need to include variant scenarios where we've got deviations from that base scenario. Perhaps some things that may or may not occur.

Often the sorts of scenarios that we particularly think about there, we consider human intrusion into the facility to be a variant scenario, and we also look at a potential criticality as a variant scenario, look at what the consequences of that might be and demonstrate that although that is an unlikely event, if it were to occur, we could still tolerate the consequences.

And then this part is about how we actually define our uncertainty and how we develop our distributions for different parameters. We feel that that needs quite a structured approach and that it's got real need for subject matter experts to be involved, but also somebody who's got the skills of the analytical part to do the facilitation of that, because it's really quite tricky. We've sort of found that we need better trainings, practice, and feedback to help the experts overcome their bias and become a bit more calibrated, and that we've developed methodology and tools to do that. We've been trying to have a proportionate approach to say that we can develop an approach, perhaps that can be done quite quickly, because in the past when we've done some structured solicitations they've been very resource intensive.

So to summarize our 2016 assessment calculations, the calculations that we presented in that safety case have got migration of radionuclides in groundwater where we've used a conceptual model based on the illustrative environment. We've used our source term from the U.K. inventory. We've done probabilistic models, which we've done in GoldSim using distributions for the key parameters, and we've used biosphere factors to convert flux to dose for, for example, the well or the marine discharge.

And I sort of put in the green box on the right that these calculations are illustrative. They really just demonstrate the feasibility that we could make a safety case in the U.K. for these wastes.

We've also done some assessments of migration of radionuclides in gas. We have a more deterministic model of gas generation. And because gas migration is so site-specific, we've just really referred to gas migration studies from elsewhere to kind of indicate how we could do that in the future.

We've talked a bit about human intrusion, which we consider as a variant scenario. We've really just referenced an international IA project for that. And then for criticality safety, we have done a consequence assessment based on our previous 2010 safety case to demonstrate that, even if there were criticality at this, that it has, when you consider the changes in the inventory that that gives you, and perhaps any fracturing that might change the pathways, it still leads to an acceptable consequence.

Finally, going on to talk a little bit about our current work. Some of the things that we're doing now is where we're developing really more integrated design and safety case strategy using a kind of systems engineering approach. We're talking a lot more about how we're going to develop requirements on the integrated design, we’re busy populating our claims, arguments and evidence, because we think that presenting that in a structured way to be a useful way of communicating with our regulators and other stakeholders. We're developing our model strategy, that hierarchy of models to try and say what's needed when, how are we going to procure it, what is our IT approach going to be? And we're doing all of that to kind of try and identify what is our information and research needs that we're going to have to underpin our models?

We’re perhaps having an increased focus on both the low strength sedimentary rock, clay type environments, and halite environments. We need to do work on variant scenarios to get a better feel for how we'll do assessments if we have a halite host rock. And we're also doing lots of underpinning research, which we've got a quite thick Science and Technology plan which the link is there on the right. But some of the particular highlights is underpinning research. We've got a big project on gas migration and pressurization. We've got quite a bit of work going on in non-radiological contaminants, groundwater protection. I'll say a bit about that next. And also looking at more work on marine biospheres. Because what we're finding in our siting process is that we're getting a lot more communities that are interested in exploring whether we could perhaps have a GDF where we have our surface facilities on land, but our underground facilities in what we call the inshore area, so within sort of underneath the sea bed, but within 20 kilometers of the coast.

So I've had a lot more focus recently on the non-radiological contaminants of our work. I think those are from interest, both in terms of the impacts of humans at the surface, but also in terms protecting groundwater and the groundwater protection framework regulations. We used our Total System Model approach based on those illustrative environments to have a bit of a go at seeing what would happen if we put some example contaminants into those environments to see how far they migrate. So we considered those two different environments, and we explicitly calculated what the concentrations of those contaminants might be along the groundwater pathway for a small number of what we might call example hazardous and non-hazardous pollutants. And the results of that, we showed that the model outputs for the low strength sedimentary rock demonstrate that the geosphere does play an important role in reducing the concentration of those pollutants. The model concentration of some pollutants was below, I think, comparison values we're using within a few meters of the facility, so that was very good. And of the pollutants that we modeled, only beryllium migrated a distance. It was still above the comparison value as it started to get into the overlying layer. And then in the high strength rock environment, we found actually that all our inorganic pollutants that we modeled discharged from the host rock at concentrations above the comparison value, but then they were quickly diluted and became below the comparison value output points in the overlying sandstone, but those results are very sensitive to how you represent the groundwater flow and the contaminant transport. Actually one of the things I think is good is we learned a lot about our model by using it for the slightly different purpose, and I think that's something that we found, you know, the more we used the models, the more we get a good understanding of the modeling choices we've made and what they mean.

And then briefly, we've got our integrated design and safety case approach that we're trying to use now so that we want to include optimization processes that consider both operation and post-closure time scales and to demonstrate that risks are as low as reasonably practicable or achievable. We're thinking about the management arrangements that the work needs to be carried out under, and we're looking at trying to identify what the requirements on the design might be and how we justify those.

And so starting to use the systems engineering approach so that perhaps the systems slightly more holistically.

We're really looking at what our high-level sponsor requirements are from our parent organization and from legislation, and trying to develop what the key requirements are, what the GDF actually needs to do so that we can, rather than saying we've used this illustrative design because it's been used by other countries, saying what actually do we need our concept to do for us.

So then in summary, to say that, yep, we've done our 2016 generic Disposal System Safety Case. It really is a feasibility study. It supports waste packaging advice. It supports our capability development and underpinned by an extensive knowledge base. However, moving forward, we're going to be site-specific work, and that will involve much more integrative design and integrated design safety case approach, and that will progress in a staged and iterative way. Thank you.

>> BAHR: Thank you very much, Sarah. I was wondering, have you or do you expect to use these generic safety cases in your engagement with communities that you're hoping to enlist in the siting process? And if you have already, could you tell us a little bit about your experience with that?

>> VINES: Oh, okay. So I think so far, our engagement with communities has been quite high-level in terms of safety messages. So we haven't really got into the details of the 2016 safety case with the community. I think we could do and I think it could be useful at some future stage. Also, you know, we definitely have used it to talk to different stakeholder use and I think communities value the fact that the regulators have looked at it and they value that that's there. But yes, so far I think we find communities have wanted more high-level discussion.

>> BAHR: Okay. Thank you.

>> VINES: We're quite often asked about earthquakes and volcanos.

>> BAHR: Very common in occurrences in the U.K., I'm sure.

Lee Peddicord?

>> PEDDICORD: Yeah. Thank you. Very interesting. Thank you for the great presentation. I'd like to back up a little bit and understand the context for the radiological waste management organization. I did a little googling and so I see that you're part of gov.uk.

So you are a government agency? Do I understand that correctly?

>> VINES: Yes, so we are. So we're a subsidiary of the Nuclear Decommissioning Authority.

>> PEDDICORD: Oh, okay.

>> VINES: And that is a government organization which was set up to deal with the legacy of U.K. wastes and to, you know, decommission them and find long-term management solution for those wastes.

>> PEDDICORD: The famous John Mathieson?

>> VINES: Oh, yes.

>> PEDDICORD: So then you interact with the other government organizations, environmental agency and the Office of Nuclear Regulation. So I guess that is a fairly common occurrence in the U.K. where you'll have these intergovernmental agencies in both cases? You're subject to their review and regulations, I assume?

>> VINES: Yes. So we're subject to regulation. Well, shall we say at the moment, the environmental agency, we have a kind of agreement with them that they have a pre-authorization regulation, because they don't have --

because we're not yet a licensed organization. We don't hold a license yet, so we have a kind of voluntary agreement with them where they talk to us and sort of regulate us in that kind of, you know, almost practiced way.

>> PEDDICORD: Yeah, okay. I guess the message is to check the space from time to time and see how things allow. But then my last question, so yours is a different construct than, say, SKB in Sweden or NAGRA in Switzerland where they're really organizations of the industry. But with that in mind and similar to here in the U.S. on things like spent fuel, and you have kind of these varieties of spent fuel, Magnox, AGRs and your lone PWR and who knows what else is going to come, so will the radiological waste management organization or NDA, do you, in fact, then take title to that fuel since they're coming out of private utilities as we're going to be doing in the U.S.?

>> VINES: It's quite complicated. So the spent fuel hasn't been declared waste yet.

>> PEDDICORD: Well, that's right. Excuse me. Go on.

>> VINES: It might be. So I guess part of the reason

for establishing the Nuclear Decommissioning Authority was perhaps to recognize that there are wastes in the UK that are a liability that we need to deal with. But certainly in terms of, say, nuclear new builds, then it would be a requirement that the operators would need to pay for the disposal of those wastes.

>> PEDDICORD: And then do you also handle waste from AWE?

>> VINES: So we do work with AWE and they do have some wastes that need to be disposed of in a GDF. But we wouldn't be disposing of any weapons.

>> PEDDICORD: Well, no. I need to do more reading, don't I? But thank you very much.

Thank you, Jean.

>> BAHR: I see Tissa's hands up? We can bring him on screen. There we go.

>> ILLANGASEKARE: Thank you very much. So in your slide 19, you had a sort of model hierarchy of conceptual models. I have a very specific question about your process models. So here the process models have been developed a number of labs working on these and

universities. So who developed the process models, and do you develop your own models or you collaborate with universities and other organization to make sure the process models are validated adequately before you put this in your system?

>> VINES: The process models would be mainly developed by contractors or universities, yeah. So similar thing that we would -- so all our contracting has a quite stringent process for selecting contractors to do work. They have to compete for the work. As part of that, they would be expected to have various quality processes and so on.

I guess what we're not doing is putting the results straight in. We're taking the understanding and that kind of aspect, but we also have in place kind of what we call a model register and a system of model owners. Each model as a risk assessment associated with it where we say what is it being used for? And what processes, what quality is needed and had that kind of thing? So we've got quite a process there where we kind of try and check that we're getting the right kind of outputs from process models that we can feed it to broader understanding. Or also, if we need to make decisions of them. So for instance, you know, we did run into some issues at one point where a model that was designed to kind of do thermal calculations was used, then, to look at how fuel might need to cool before it could be disposed of. And it was certainly from being kind of low level process model. It was used to inform quite big decisions, and it was a mistake in the model. So that did lead us to really look at some of these aspects about having a quality plan that considers not only what the model is, but what decisions and things it's being used for.

>> ILLANGASEKARE: So in your design and safety integration slide, you mentioned you're a systems engineer. So my question is in your diagram there, it maybe a different type of diagram, in your systems approach as you integrate your numerical models into a systems analysis. Is that correct? Some may use systems analysis, your numerical model is looking at different connections between the different components of the system? Is that part of your systems analysis?

>> VINES: We're very much in the early days of our systems integration type thinking. And so yeah, I think at the moment we're kind of imagining that. It will be

more a case of looking at different requirements and then perhaps doing some requirements trading. So I think we wouldn't -- I can imagine, for instance, that you might be looking at translation systems and saying, here is my gas generation model. It tells me how much hydrogen I might be generating, so perhaps that gives me maybe one requirement on the ventilation and maybe the breathing rates for the workers perhaps gives me another requirement. I need to maybe compare them and see which one is the bounding one rather than the whole thing would be a massive numerical automated analysis.

>> ILLANGASEKARE: Thank you very much.

>> BAHR: I see Bret Leslie's hand up? Bret?

>> LESLIE: Sarah, thank you for the presentation. It was very helpful. My question is a little bit of a philosophical one. You really are focused now on generating understanding, but that's really driven by the regulation, which is claims, basis, evidence, that kind of qualitative approach, and I think the question I have is are you doing anything different to address your development of your program to generate information that the citizens can use as you develop your working groups? Or is it just a lucky happenstance that the claims,

evidence, and arguments lends itself to that higher level discussion that the citizens are seeking?

>> VINES: Yes, that's interesting. I think -- I guess we're always thinking, you know, that the clearer and -- all of us appreciate a simple presentation of what matters for safety. And you know, in some ways, our prime audience for our safety case is almost ourselves, to kind of convince ourselves that we're doing the right thing and that it's going to be safe. So I think some of those messages are the same as we would also want to present to communities. I think it will be interesting to see. As we get into those community partnerships, I think there's various processes for engagement funding and having those discussions, and you know, we might even be thinking about having citizen science projects in terms of perhaps particularly as we start characterizing, you know, the environmental assessment to make the baseline for the thing. I could envisage that it would be nice if we could really get the citizens involved in that. So I think it will be interesting to see what topics they're interested in and to what extent that does drive where we put focus. I think we also might see that driven by particular

academics or people who really want to question us about particular topics. We've just recently set up this research support office and it often -- often, you find that people always want to see their thing represented well. I think perhaps if you take glass dissolution where you've got the people who have spent 40 years developing a very detailed process model of glass dissolution. And I've just got this very simple rate and communication is what people want to see and what you think you need is perhaps a disconnect between the people who want to see their topic and the performance assessment model that is perhaps quite keen to make it simple.

>> LESLIE: Thank you, Sarah.

>> BAHR: I see a hand up from Bobby Pabalan.

>> PABALAN: I have a question about the status of the siting process in the U.K. You indicated there are three working groups that have been established. I guess depending on the progress of these discussions in working groups, the next step would be focused studies on specific sites. Is there a particular timeline when you can expect decisions to be made with respect to when focused studies can be started?

>> VINES: Sure. So I guess we very much have to work at the pace of the community. So on the one hand, we mustn't ever take that for granted. On the other hand, we also have to develop some plans that we can sort of say, well, if things go well, what might we expect? So the next thing that we might do for focused studies on the communities where we have working groups is that we'd ideally like to do some seismic studies so that we can understand the geology better and we are making plans that we might be able to do that next year if things go well with the communities.

>> PABALAN: And so for the different sites, they will include both low heat generating waste and high heat generating waste?

>> VINES: Yeah. That's definitely the aspiration that we've got in our white paper that designs the policy. The hope is we build just the one GDF for all the waste that we need to dispose of, but there is also the possibility, I suppose, that if we have a site where it's just not feasible to dispose of all of it, then, you know, we haven't ruled that out, having more than one GDF if that turns out to be the better way to progress.

>> PABALAN: Okay. Thank you.

>> BAHR: Chandrika is here.

>> MANEPALLY: In an earlier slide, you refer to having simple models in the earlier stages and then making it more complex. My question was at this generic stage, were there specific metrics that helped you decide the level of detail that needs to be incorporated at this stage versus planning to incorporate in the future. You referred to the gas generation saying that it's very site-specific so you're not going to include it. I was just wondering if you had any more metrics.

>> VINES: Yeah. I think probably we didn't have a very structured process for deciding what we were going to include and what we weren't going to include. Some of it is probably slightly being an adaptation from previous models and pragmatic. I think we tended to use what we call our near field soup model where we look at, you know, how much this radioactivity do we think could get into groundwater if you assume things are, you know, kind of a well-mixed thing and you look at what the solubilities are? Our near field model is very much based on solubility and sorption modeling, and then we've kind of used these representatives of geosphere to

kind of say, well, how could we work out some sort of travel time from the near field to the biosphere and very much used things like the permeability and model diffusion processes to do that. I don't think we have metrics to decide whether we need more detail, but I think it’s perhaps maybe a bit more of an iterative process to say, okay, what makes sense to represent?

>> BAHR: I see Dan Ogg’s hand up. This will be the last question, because we are scheduled for a break.

>> OGG: Hi. Thank you, Sarah. I’m Dan Ogg with the board staff. I wanted to follow up on Bobby Pabalan's question and that is referring back to the time line of activities. Are you currently authorized and funded to continue your work to the whole five, ten, 15 year program or are you just authorized for a certain part of that where you to stop and rethink the process and be approved for the activity?

>> VINES: Yes. There is a kind of business case approval process that we have to go through and so I would say that it's a sort of progressive thing. I've forgotten the exact phrases that we used, but we have an outline business case approved and a more detailed business case approved, so it's very much an ongoing

process to keep refreshing that. Spending reviews that happen every three years. It's a case of working with government on that.

>> MANELLY: But right now, your free working includes, including outreach from stakeholders and communities, you're pursuing that now?

>> VINES: Yeah.

>> BAHR: Thanks again, Sarah, for spending a part of your evening with us. And we're scheduled now for a break that will go until 2:15 Eastern Time. One 11:45 Pacific time. See you all back in about 20 minutes.

[BREAK]

>> BAHR: Okay. Well, welcome back to our meeting. I hope everyone had a great break. Now we're going to hear about uncertainty and sensitivity analysis from Laura Swiler at Sandia National Laboratories. If we can bring up Laura. Looks like her slides are starting. We'll wait for you to get into presentation mode. Perfect. Thank you.

>> SWILER: Good afternoon. My name is Laura Swiler, I'm at Sandia National Labs, and this afternoon I'll be

talking about uncertainty, quantification, and sensitive analysis in GDSA.

An outline of my talk. First I'll discuss the objectives and strategy that we took in developing the tools for the GDSA framework. I'm talk some about an international collaboration we have on sensitivity analysis. I'll talk more specifically about some UQ uncertainty quantification and SA sensitivity analysis tools we've incorporated into the framework and I'll describe a particular example of how we've used these tools to apply them in the crystalline reference case.

So first our objectives. Our really one main objective was to build on the well-established methods that are out there and that we've already developed as part of the WIPP and Yucca Mountain and other large system assessments. We really want to build on these conceptual and computational frameworks, and as has been mentioned previously, part of this is including allowing for the treatment of epistemic and aleatory uncertainty. We want to use approaches that help address regulatory requirements, and use some of the well developed methods over the years, including Latin hypercube sampling, correlation coefficients, scatter plots, and regression analysis. And really leverage many of these existing algorithms. I will talk a bit about our Dakota toolkit and other codes.

So the main objective, as I said, is build on this great legacy with well-established methods. Another is to keep abreast of new methods. In the last 20 years, there's been a huge interest in the computational science community to develop more advanced sensitivity analysis methods, including variants-based methods, and these methods partition the variants in an output to the relative contributions from the variances of different inputs. So you might want to say, oh, in this particular response, 30% of the variants we see in the response is from input number 5. And 50% is from input number 2, et cetera. And so these kind of methods have become extremely popular and there are a number of ways of calculating them I'll talk about.

We are using surrogate models to explore the large, sometimes large input parameter space of very expensive simulations. So surrogate models. You can think of these as metamodels or emulators, statistical models, things like machine learning models that are cheaper and faster, and we build these from the runs of our very high fidelity computational codes.

And then finally, looking at methods that allow efficiency gains, allow us to extract as much information as possible from our high fidelity runs. And these include multi fidelity models.

And then finally, we want to maintain leadership in uncertainty and sensitivity analysis for geologic repository performance assessment. And as part of this, we are participating in an international working group.

So I'll talk a little bit now about that international collaboration. It's called JOSA, Joint Sensitivity Analysis Group. It's an informal group, and really, our primary goal is just to exchange ideas, information, how some of these newer methods work, and it emerged from earlier activities that we had with Germany and the U.K. It's informally supported by OECD’s and NEA's Integration Group for the Safety Case, and you see the list of participants here. We have a really nice group. It's very collegial. We meet about once a month by video, and there are about ten folks from across these organizations who participate.

And one of the products of this group, is a report, we call it report Volume I. We recently issued this. It’s shown on the right here and I'm happy to send it to anyone who is interested. In this report, we carried out some comparative sensitivity analyses. We had four different cases studies we called them where various organizations or countries provided a set of runs, realistic runs, you know, on a repository of interest to them or a generic repository, and then these case studies were analyzed by the various participants.

And so you see an outline of this report, and in just a couple of things I wanted to highlight, the report contains quite a nice exposition on sensitivity analysis method. This chapter 2 is about 40 pages. And then we talk about how we chose some of the cases, and then there is a chapter on each of the cases, a clay, a shale case, the Dessel case in Belgium, and a case from IBRAE.

And so what were some of the approaches that we investigated? I've categorized them and sort of in four bins. Graphical methods, correlation and regression analysis, variance-based methods, and moment-independent methods. I won't, you know, read this whole list. I think many of you are familiar with some of these methods. The correlation and regression analysis were used extensively in WIPP and Yucca Mountain. The variance-based methods are these newer class of methods I mentioned, and there's just a whole bunch of approaches for calculating them. And so these can just be considered sort of different flavors of them.

And a few highlights from this report, things that we've learned, correlation and linear regression approaches really continue to be used widely. They're informative. These variants-based methods, especially what we call the first order or main effects methods, are now easily generated in many tools and using many algorithms. They're becoming a main sensitivity analysis approach, and when we compared across organizations and across algorithms, the results would always identify the same most important parameter, but sometimes the lower ranked parameters flipped rankings a bit, and we feel that that's probably due to the surrogate models that were employed in calculating these indices. Certainly some accuracy issues can arise.

Data transformations are very important in repository work. Often you have quantities which vary by over orders of magnitude. There are graphical methods, scatter plots and graphical methods are always very helpful and we will always use those. So really, in the bottom line I wanted to leave you with on the international participation, excuse me, our participation in this international group is that we really benefited from it. It's a great way to learn and we plan to continue this effort with an additional set of case studies in 2022.

So now I'll talk about particular uncertainty and sensitivity analysis capabilities that we have and are using in GDSA. So you've seen this picture before. It's a picture of the computational workflow for GDSA. And I will highlight this box in the top center, this Dakota box. This is a toolkit that has many uncertainty and sampling methods, sensitivity analysis methods. Dakota has two roles, as Paul Mariner mentioned. One is to generate samples and perform some of these studies, perform surrogate construction and the variant space methods. Another is to actually launch the PFLOTRAN simulations and help manage the parallelism within the larger workflow.

So what is Dakota? It is a suite of algorithms, some optimization algorithms, some uncertainty and parameter calibration algorithms, sensitivity analysis methods.

Dakota is a tool developed at Sandia. It is really a longstanding framework. It's been under development for 27 years. It's what we would call a legacy tool, although we are constantly adding new methods to it. It's been developed specifically with a focus on performing assessment and uncertainty quantification for computationally expensive simulation models. So we put in methods in Dakota where, you know, we're trying to really -- we assume we can't do millions of runs of our expensive model, and so we have, as I mentioned, surrogates and other methods. And so Dakota is a separate executable, depending on which method you choose, will generate sets of input parameters at which it wants the model such as PFLOTRAN evaluated, and then the responses are returned to Dakota and accumulate the information this way. It's a publicly available code. You see the website down here. And just a quick overview of some of the methods in Dakota. This is a large menu. I don't have time to go into all of our methods, but I wanted to leave you with the sense that we have many methods available. The ones that are mainly used in GDSA are the ones highlighted in red. Certainly we have a variety of sampling methods. Latin hypercube sampling, which is a stratified sampling method that generates sample points that are well distributed over an input space is, you know, commonly used method. One thing I will highlight, also, under the UQ section, I'll talk about this on the next slide or two, is a new method called the polynomial chaos expansion. You can think of it as a specialized surrogate that is really tailored for uncertainty analysis. We have a number of epistemic methods, and I'll talk some about nested sampling. We also have bounds analysis, Dempster-Shaffer evidence theory methods, and I'll talk a little bit about this new effort in multi-fidelity UQ.

And then on the right you see a variety of sensitivity methods. I won't, again, go into great detail, but we certainly have all the flavors of correlation on the raw data, on rank data, partial correlations, graphical methods, variant space methods based on samples and/or on surrogates, and then we have many surrogate methods in Dakota.

So you've heard the phrases epistemic and aleatory uncertainty. A little bit more detail about these. Epistemic uncertainty is lack of knowledge uncertainty. Lack of knowledge about the appropriate value to use or the appropriate model. It's sometimes what we call reducible uncertainty: Aleatory is inherent variability or randomness. It's really irreducible. If we were all able to be in the same room today, the height of individuals in the room is aleatory uncertainty. It's not reducible. In terms of performance assessment, we treat these, we like to separate the effects of epistemic and aleatory uncertainty, so we'll sample them in a nested loop. So we may sample in this figure on the upper right, sample a set one realization or instance of epistemic parameters, send that into an inner loop. The inner loop will sample our aleatory parameters conditional on those epistemic samples. And then will repeat the process. And what this results in are the two figures in the lower part of this slide. So in the lower right, each set of aleatory samples, maybe you have 100 aleatory samples, will result in one of these colored lines, one cumulative distribution function. And then this whole ensemble or set of colored lines represents each line is based or conditional upon an epistemic sample realization. So you see the whole bounding effect. We want to understand the range in this ensemble result, front based on the epistemic uncertainty as, you know, you see the range in the median by this dark, dark arrow here.

But we also want to understand the slope of these CDFs, which would represent the aleatory uncertainty. And on the lower left you see an example of how these nested sampling and ensemble results were used in WIPP. This is a flip of the cumulative distribution, called a complementary cumulative distribution. What's the probability that a response is greater than a particular value given on the X axis? But you see you have what we call horsetail curves sometimes, and the exercise is to ensure that the entire ensemble of results would be less than a regulatory requirement given in the dotted line.

Three research areas, areas of our research I want to highlight. One is these variance-based decomposition methods. As I mentioned, these have really become a very common sensitivity analysis method. Sometimes they're called Sobol indices. They're sensitivity indices which summarize how the response variability can be apportioned to individual input factors. So we have two primary sets of indices. One is called a main effect index, which measures the effect of varying parameters, say X sub i alone, averaging over the other factors. And then there's a total effect, when measures the effect of varying a particular parameter, but also including its interaction with other variables.

The calculations for these, the formulas are fairly simple, but the calculations require lots and lots of samples. They're all conditional expectations of variances, and it's an expensive process, so I just want to highlight that typically, we do use surrogates to calculate these indices.

Polynomial chaos expansion I mentioned earlier. These methods are a class of methods that's also become extremely well used and popular in the past 20 years. And the idea is that you can think of it almost as a regression model, but the basis functions for the regression are carefully chosen orthogonal polynomials, and they're chosen to represent certain distributions. So we use [Indiscernible] polynomials for normal distributions and Legendres for uniform and, you know, at the end of the day, you generate samples, you construct your expansion, and then you can get analytic expressions for the moments and for these indices. And so one big advantage of polynomial chaos is that you get analytic expressions for the variance indices, and that's really nice. You almost get them for free once you've constructed the expansion.

And then finally, multi-fidelity methods. These methods are really just coming into their own in terms of the computational science community, the last five years has really seen an explosion of research, and the idea is that you want to exploit the hierarchy or ensemble of models with varying fidelities, and you want to run your cheap models lots and lots of times and do relatively few runs of your expensive models, but then combine those in a principled way to get the same kinds of statistics you would as if you were running lots of your high fidelity simulation. It's really a variance reduction kind of approach.

And just to give you an example of how multi-fidelity might be used in performance assessment, I'll show a quick example and this is a very simplified crystalline example. On the upper left here, you see a vertical slice of what we're modeling here. So again, it's really fairly simplified, but in the lower left you see three pictures which are the three fidelities of the model. So we start with our high fidelity model, which has a cell size of 10 meters and then a medium fidelity, with cell size of 20 meters, and then our coarsest, which has a 40-meter. You can see as you go from left to right that you're increasing the coarseness of the model. On the right we see an example of how we can use these multi-fidelity methods in the sensitivity analysis. I'm showing main and total effects for two quantities of interest in this study that we ran. The peak of the maximum iodine 129 concentration and a median residence time of a tracer that had an initial spike in the repository. And so in both pictures, if you look at the orange and the blue lines, the blue sensitivity indices were calculated using 828 evaluations of our high fidelity model and the orange indices were calculated using what we call an equivalent number of samples, which was about 21 of the high fidelity models, really under the hood what was that? That was 18 of the high fidelity runs and 108 of the two low fidelity runs respectively. And so, you know, the good news is that this process is identifying the same parameters. It's quite consistent, and this was really just an early study to understand if these methods would be viable for some of our performance assessment computations, so we're continuing to investigate multi-fidelity methods.

So the final section I will present is the application of some of these tools to our crystalline reference case. Tara Laforce will talk more about the reference cases in the next talk. But I'll talk some about the crystalline reference case right now with respect to the uncertainty analysis. On the right you see this diagram. The model domain here is given, it's approximately 3,000 meters by 2,000 by about 1,260 in height. The repository is given, shown in this slab here. It's located at a depth of 585 meters. We have 42 disposal drifts. Each contain 4012 PWR waste packages. There is about 1700 total waste packages. The drifts are backfilled with bentonite buffer in this generic case, and you see the dimensions of the DRZ. It's a big model. It's almost 5 million cells. And the gridding is anisotropic. There is a question of Jeffrey yesterday about that. We do have higher fidelity grid cells around the repository region where elsewhere the grid cells are bigger.

We have used the dfnWorks software that Jeffrey described to generate discrete fracture networks of the crystalline case and the repository. These are meshed in Cubit and the simulation was run in PFLOTRAN. I'll highlight a few things. When we run these, we calculate many responses. We look at these four observation points. We look at our quantities of interest at these four observation points in the aquifer. The aquifer is the top 15 meters of this, but we also look at various fluxes. We look at the flux going from the rock to the aquifer. We look at the fluxes going from, say, the aquifer to the east boundary and the rock to the east boundary. We have lots of quantities, just to give you a sense of that.

A little bit more detail, and again, this is a busy picture, but I just want to give you a sense of the structure and how we set up these large uncertainty analyses. Again, we're employing nested sampling here. It's a little bit different than what I presented in the earlier slide. Our outer loop sampling is shown in this picture on the upper right. Our outer loop sampling is over dfn, so we have 25 different discreet fracture networks. For each one, for example dfn one, dfn two, et cetera. Let’s say for dfn one, then we go to this inner sampling loop and we generate 40 samples of our epistemic parameters, and then we continue. And so in this way, the total number of samples is a thousand

PFLOTRAN runs. This took us about two weeks to generate on our HPCs. We look at the three sets of parameters. The dfns in blue here, how do we measure the different dfns? Yesterday Jeffrey talked about these graph metrics, and they've proven really useful to us. In particular, we have identified three. The relative shortest travel time between the repository and aquifer. The average degree, which we sort of use as the measure of connectedness and the number of fractures intersecting the repository. In terms of the epistemic parameters given in orange, they are listed here. I'll talk a little bit more about them in the next slide. And then we have about 30 or 40 quantities of interest. I couldn't fit them all on the slide again. I'm happy that they're in our summary report for this year and I'm happy to discuss them, but the one I wanted to focus on is this maximum iodine concentration in the aquifer. We calculate that at each time point and then we take the peak over all time. And so when we say peak total, it's the peak over all the time points.

And then also, again, we calculate a lot of these fluxes and fractions of a tracer remaining in the repository and things like that.

So on to results. The right part of this slide shows some scatter plots where you see on the Y-axis, the peak iodine concentration in the aquifer, and then our different parameters on the X axis of these scatter plots. A few things I want to highlight, then. One is this fractional dissolution rate of the spent fuel. You see a strong trend there. You also see a trend with respect to the number of intersections and the average degree. On the left, if we look at the upper left plot first, this shows the total sensitivity indices calculated two different ways. One is with this polynomial chaos expansion, second order expansion, and the others with a simple polynomial regression model, of order to quadratic regression. The good news is these surrogates both performed almost the same in assessing the sensitivities and if we only perform the variance-based analysis over the epistemic parameters, we see that that in this fractional dissolution rate of the spent fuel, that is the most important by far, the most dominant parameter. But the lower figure shows a different picture when we add the graph-based metrics in. Then you see that the number of intersecting fractures with the repository and the average degree become the most dominant parameters affecting that peak iodine concentration. So the dissolution rate of the fuel is still important, but not as important as these dfn related parameters. So I really wanted to highlight that having this capability with the graph metrics from the dfn allowed us to understand the effect of the spatial heterogeneity in these results, and really the fracture network and where the fractures land has quite a big effect, even larger possibly than the source term engineered barrier uncertainties.

Another capability I wanted to highlight is that we can plot these sensitivity indices over time. And so the picture on the right shows all the thousand traces of the max iodine for each run, a thousand runs. We show the trace of the max iodine concentration over time. So again, you get this sort of ensemble result. And then on the left, the upper left, if we only, again, include only the epistemic parameters is when the waste packages start to breach, say somewhere around 10,000 years, you start to see that these two parameters relating to the waste package degradation rate, the mean and the standard deviation of that in these purple and magenta colors, are the most important parameters and the mean of that waste package degradation rate stays important through most of the simulation until right near the end when that rate, the dissolution rate kicks in. And so the previous picture, this top figure, is really analogous to the final time point here. But this is nice, because it shows us the entire evolution of the sensitivities over the entire simulation. Similarly, when we add on the bottom figure, when we add those graph metrics in. Wow, does the picture change. The average degree becomes important. And again in later times, the number of intersections in this light blue with a repository really becomes important. And so the capability to plot these sensitivity analysis can give us additional insight and physical interpretation.

So to summarize, our next steps, we're going to continue our investigation into these methods and we want to, you know, continue development. We want to look at more of the multi-fidelity methods. We think they have great potential. We want to incorporate different spatial representations into the multi-fidelity approaches and look at more efficient methods for estimating tail probabilities. And also for assessing surrogate accuracy.

In summary, I hope I presented in this talk today really the capability development. We focused on capability development. We have a rich set of capabilities that we can bring to bear, including established methods and variance based methods and surrogate methods. We've applied these capabilities to a variety of reference cases, and the reference cases have been extremely useful for demonstrating things we need to address such as the spatial heterogeneity from the discreet fracture networks. Finally, sensitivity analysis is very useful for helping us understand the behavior and importance of processes evolving within these models.

I have a list of references and I'm happy to provide extensive documentation on any of the methods I've talked about today. Thank you.

>> BAHR: Thank you very much, Laura.

I see Paul's hand is up. I’ll turn to him for the first question.

>> TURINSKY: Hi, Laura. I have a question about something you didn't talk about and it's more the input to the code and it gets into model calibration. How are they using Dakota or whatever tools Bayesian MCMC capabilities to basically get the initial uncertainties

on the parameters?

>> SWILER: We certainly have a variety of Bayesian calibration methods in Dakota. And for everybody's benefit, deterministic calibration you can think of as parameter tuning, finding parameters of a model which will best fit some observational data in a least squares sense. Bayesian calibration is a bit more advanced and gives you a full, say, distribution of parameters when propagated through the model will have a distribution of results consistent with observational data.

>> TURINSKY: And correlation between parameters.

>> SWILER: And correlation in those parameters.

We have that Bayesian capability. Remember, we’ve only done these generic sites for which we do not have a tremendous amount of data. We have taken some existing historical data to populate these but I want to emphasize we have done a lot of capability development. We’re not at a particular site where we have well data or other data at that site that we can calibrate the model so when we get to that stage, we certainly have the Bayesian capabilities to do that.

>> TURNINSKY: I'm thinking more of the individual

models, single physics or few physics models. That's what you're sampling. Permeability, things like that. They do have data for that. I'm wondering how they're coming up with the uncertainty treatment to come up with the uncertainties?

>> SWILER: Yes. We haven't spent a huge amount of time on uncertainty characterization. Again, we've taken, for the crystalline case, we've taken some, you know, data from international studies and things done on this, but there are several others, the NRC folks and Sarah also talked about there's several frameworks to do, you know, expert elicitation and initial characterization. So again, we'll use those when we get to a particular site.

>> TURINSKY: Okay. And what about model uncertainty itself? Not the parameters? How is that being addressed?

>> SWILER: So in a couple of ways, we can sample over different sub-models. I think David and Timothy spoke about the need to be able to assess just different model forms, and so if you have, you know, A, B, and C for a constitutive model, we can incorporate that within the Dakota framework very easily and generate samples from

different subsystem models. We also, again, to assess model form error in the truest sense, you need data. Right?

>> TURINSKY: Right, yeah.

>> SWILER: So we do have some Bayesian framework, sort of in the spirit of Kennedy and O'Hagan, where if you have data, you have the model, you can construct a representation of that difference and actually generate samples from that difference, if you will.

>> TURINSKY: Okay. Thank you.

>> BAHR: All right. I see Emily's camera on. I wasn't sure if she had something she wanted to add? She's shaking her head no. Tissa then?

>> ILLANGASEKARE: Thank you. So you used the word surrogate in two contexts. You have a surrogate model and you have surrogates in your uncertainty analysis? Is that correct? You use surrogate and maybe I need to get close. You used surrogate in a tool context, if I understand, surrogate models, and then you used the word surrogate in the uncertainty analysis, also. It is the same thing?

>> SWILER: It is the same thing, yes. I'm sorry if --

>> ILLANGASEKARE: So my question is maybe it's a basic question. You are using surrogate models because of the efficiency. Because you need a lot of simulations. But not the full model, so when you prioritize your ranking of parameters, how do you know the parameters in the surrogate model and the parameters in the full model match up in their priorities?

>> SWILER: So we have a number of -- that's a great question. We have a number of accuracy metrics, things like root mean-squared error, cross validation, holdouts, mean absolute error. There's many ways that we can assess the error. We try to examine that the error in the surrogate is much less than the error of the uncertainty in the model. Especially for these variance-based metrics. The surrogate accuracy -- like you saw in the international work, where we had some of the lower parameters that would flip order in the rankings, that may be from surrogate accuracy. I think this is still an open question that needs more examination, but there are well-established surrogate accuracy metrics that we do use, and we want to -- yes. We want to continue that exploration.

>> ILLANGASEKARE: So as more data becomes available or you know more about uncertainty, can the surrogate model get closer to the real model?

>> SWILER: Certainly that's the hope, yes. The more data you have, the more accurate they will get.

>> ILLANGASEKARE: Okay. Thank you very much.

>> BAHR: I see Bret Leslie's hand up.

>> LESLIE: Laura, thank you for a very nice presentation that explained how you are adding the capability to GDSA for doing uncertainty and sensitivity analysis. A question may need to be answered by Emily or Dave Sassani. Many other countries have done similar uncertainty analysis on disposal concepts that are mimicked in GDSA. So for instance, the Finns and Swedes have done crystalline rock, bentonite, and copper. And they know what the important parameters are. When you come to GDSA and DOE and the national labs how have they used that information to influence what is brought into GDSA? In other words, using the results of other countries from those sensitivity analysis, this is what other people find is important, does the GDSA address those important features now?

>> SWILER: I'll let Dave and Emily answer, but I will say for the references cases that we've examined, we have seen the same kinds of parameters bubble up. Things like the glacial till permeability, Kd parameters, buffer porosity and permeability tend to be these common parameters. But with any sensitivity analysis, it's very dependent on the range of your uncertain inputs and the whole setup. So I don't want to over-generalize, but at least our initial forays into the reference cases have been consistent with what others are seeing, but now we'll let Emily or Dave speak.

>> BAHR: Emily is on screen. Dave is on screen now, too.

>> SASANI: You want me to go?

>> STEIN: You go and then I'll add anything else.

>> SASANI: That's a good question, Bret. And it's certainly all of the GDSA reference cases are informed by those site-specific studies that have been done out there. And we're working along with those countries in a number of ways. The generic aspects that you would expect would show up, things like for a crystalline

fractured system, the number of fractures intersecting the repository, that's a pretty big parameter. It's dealt with in the engineering aspects of, for instance, the Swedish evaluations by trying to avoid fractures and not place waste packages near them, and they do some forward looks at, okay, so if you do have a fracture intersecting and it fails the buffer and it fails the canister, then yes, you have a very fast pathway. And then things like the fuel degradation rate is a direct linear behavior in terms of the response at long time frames for the peak dose. So we see those major aspects, and particularly in the example that Laura put forth, but also we see that interesting interplay of looking at developing this capability for doing the sensitivity and uncertainty assessments in the stochastic fashion and seeing the interplay between those parameters for the fracture system versus for the engineered barriers works, but it's all at a pretty high-level generic place at this point.

>> LESLIE: I should have noted that I'm a member of the board staff when I introduced myself. Thanks.

>> BAHR: Emily, did you want to add to that?

>> STEIN: I could add to that and I would say that I

don't think it's true that very many other countries have done this uncertainty and sensitivity analysis in the same way that we are doing it. So for instance, in in the SKB safety assessment, they do sample on uncertain parameters when they've gotten to one dimensional flow paths. So they sample on things like radionuclide Kd. But their sampling is not on the whole system model that would include bentonite characteristics or waste package degradation. In the French safety assessment, they don't use uncertainty sampling at all. So I'm not sure that there is a one-to-one comparison available for us to make.

>> LESLIE: Okay. Thanks. Appreciate that.

>> BAHR: Do we have any other questions for Laura? Okay. Thank you for an enlightening presentation and also for the list of references, which I'm sure the board will be happy to review. And we'll move on now to Tara Laforce, who's going to tell us more about the reference case simulations.

>> LAFORCE: Can you see my slides? I'm Tara Laforce and I'm presenting on the reference case simulations on behalf of myself and Emily Stein. A little background about me. I have been working at Sandia in the geologic

disposal safety assessment for about three years. I also work on the Waste Isolation Pilot Project. And I'm the work package manager for repository systems analysis package, where most of this reference case work is done.

So you've seen this slide before. We talked about or Emily talked about yesterday that what we cover in GDSA is what is in these three highlighted boxes: Assessment strategy, post-closure basis and FEPs, and post-closure safety assessment. What we cover in reference case studies is just in the green box on post-closure safety assessment, and that is FEPs analysis and screening, scenario construction and screening, PA model and software validation, barrier and safety function analysis and subsystem analysis. PA and process model analysis and results. Uncertainty characterization and analysis, and sensitivity analysis. And what I'm going to talk about today is mostly E, F, and G at the bottom of Section 4.2. So it’s PA and process model results, including uncertainty and sensitivity analysis.

This is another slide you guys have seen before. Emily gave this in her introductory talk. And this is a listing of things that we work on which were highlighted as being of high importance in the 2019 roadmap update.

And the things that we have been making progress on in GDSA are the bold terms, which are high temperature impacts, criticality, waste package degradation, generic performance assessment models and radionuclide transport. In the full scale performance assessment or PA cases, we have been working on the ones that are highlighted in yellow, so that's high temperature, waste package degradation, generic performance assessment models, and radionuclide transport. There is work going on criticality, but it is not in the full scale simulation with uncertainty analysis for performance assessments.

There's another slide you guys have seen before on the framework. In fact, you guys have seen this slide several times. So what is in the green boxes on this slide is in the performance assessments models. So for each of our three performance assessment models, we do uncertainty sampling and sensitivity in Dakota. For the crystalline model, we use dfnWorks to create fracture networks. Moving down to PFLOTRAN in the source term and EBS evolution model, we have inventory. We have decay and ingrowth, waste form degradation, waste package degradation, radionuclide release, and thermal effects. In terms of flow and transport, we have advection, diffusion, and dispersion. We have discreet fracture networks for the crystalline model. All simulations are multiphase flow. This is a question that I know came up yesterday. All of our simulation in performance assessments are full two phase compositional flow. They do include heat effects on flow and fluid properties. We have sorption and solubility, we do not yet include colloids. We have isotope partitioning, decay and ingrowth, thermal effects and chemical reactions. And finally for the biosphere model, our biosphere component in the performance assessment right now is very simple, it is a simple dose calculation for all of our cases. What I'm going to talk about today is the maximum iodine 129 concentration in a potential drinking water aquifer, and the reason for that is that as Paul said in his presentation yesterday, that tends to be a leading factor in terms of exposure pathways for a more complete biosphere model is that iodine 129 in a potential drinking water aquifer.

So next slide. Reference case simulation overview. Our overarching goal in this project is to develop and demonstrate numerical modeling and analysis capability to provide a sound technical basis for multiple viable disposal options. To that end, what we're doing is we conduct studies on potential host rocks. We find gaps and enhance capability in process models and the workflow as necessary. Our driving development of process models. In recent years, we've been focusing on high temperature waste package disposal.

And in all of our cases at this time, we're only considering undisturbed scenarios. And the reason for that is as has been discussed before, the disturbance in scenarios tends to be site-specific. Since we don't have a site doing a disturbed scenario is quite challenging. So at the moment, we're only looking at undisturbed scenarios. We're using the generic FEPs screening done by Vaughn in 2012. Our uncertainty and sensitivity analysis is done in Dakota. As I said before, our main performance metric is peak iodine 129 in an aquifer.

One thing I want to emphasize here, is we do not draw conclusions about what rock is suitable. Our studies are about preparedness for wide range of possible repository sites. And we don’t draw conclusions about what might be better or worse. We just look at what potential rocks are there? Are we prepared to model that, what might the key uncertainties be in these different rock types?

These are the processes common to all three of our performance assessments models. One is coupled heat and fluid flow, these are fully transient simulations. All of them have some kind of cross model flow in them as a background flow field so that we are looking at these peak iodine concentrations, we have an upstream and we have a downstream of the repository because there is cross model flow. We also have flow which is generated by the heat because if the waste package gets very hot, that could hypothetically evolve the gas phase and that would drive liquid away from the waste package and then at a later time as it cools, the liquid, the water would then come back towards the waste packages. So our model includes fully coupled heat and fluid flow.

It includes radionuclide transport in advection and diffusion. It has radionuclide sorption, using linear distribution coefficients or Kds. We have radionuclide precipitation and dissolution. Radioactive decay and ingrowth in all phases. And one thing I want to emphasize is that all of the radionuclide transport is solved within PFLOTRAN at the same time as the fluid flow, as Michael talked about yesterday. So this is a coupled process.

Finally, all of our PA simulations have waste package degradation, and they have waste form dissolution in them.

Okay. So this is quite a complicated slide. I'm going to spend quite a bit of time here, I think. So this is our reference case simulation overview. Our generic concepts. Across the top we have the different types of waste. And down the left we have our three main potential host rocks. We have shale, crystalline, and salt. So at the beginning they're mostly looking at defense spent nuclear fuel, which is SNF, and high-level waste, which is HLW. There is a study on each of the rock types on those. And then they started moving on to commercial spent nuclear fuel, or CSNF, and they were looking at four pressurized water reactors, so 4-PWR waste packages. And they did shale and crystalline in that. And then more recently they moved on to doing 12 pressurized water reactor assemblies for commercial spent nuclear fuel, and I'm going to talk about two of those 12-PWR simulations today. The first one is from

Mariner et al. and Swiler 2019, and is on the shale case. And the reason I'm talking about that one is that the later shale cases we have are not full performance assessment analysis with uncertainty analysis involved in them.

So in keeping with the shale case, in 2020, they developed a concept for a 21-PWR commercial spent nuclear fuel shale repository but a concept is just, they came up with a conceptual model. They did not build a simulation model. And then in 2019, there was a few simulations done by Sevougian et al. on 24 and 37-PWRs. But that was just a few deterministic cases, not a full uncertainty analysis. For shale I'm going to talk about the 12-PWR cases. For crystalline, I'm going to talk very briefly about the 12-PWR cases that Laura Swiler talked about in the last presentation. I'm including it in my talk for consistency with the other two cases and to tell you a little bit more about the geology of our models and such.

For the salt case, they did simulation on 12-PWRs Mariner et al. in 2015. They did a concept on 21-PWRs in 2019. And we did a full uncertainty analysis in 2020 on a mixture of 24 and 37-PWRs and that's the other case

I'm going to talk about today. So the cases I'm going to talk about today are shale, 12PWRs, crystalline, 12-PWRs, and salts, a mixture of 24 and 37-PWRs.

Okay. So this is a salt reference case. I'm talking about it first, because it's the most recent. So in the salt reference case, we modeled 3100, 24 pressurized water reactor assemblies or PWRs and 2000 --

>> PreCon Host: The speaker is frozen.

>> LAFORCE: Am I back? Jean am I back?

>> BAHR: You're back. I thought it was me.

>> LAFORCE: No, no. I just got kicked off the network for a second.

>> BAHR: You are back.

>> LAFORCE: Okay. Good. All righty. Get the slides back. Are my slides back?

>> BAHR: Yes.

>> LAFORCE: Okay.

>> BAHR: This is the slide on which we lost you.

>> LAFORCE: These are quite long slides, these ones.

>> BAHR: Start this one over again.

>> LAFORCE: Start from the beginning?

>> BAHR: Yeah. Pretty much.

>> LAFORCE: Okay. So in the salt reference case, we have 3100 24-PWR and 2000 37-PWR waste packages in 102 drifts. In this schematic, the repository is right down there. Our numerical model is not quite this big. We use a half symmetry domain. We assume this south boundary of the model is closed and acts as a reflective boundary. We explicitly simulate 51 drifts and then there are 51 reflected drifts across this closed boundary. Even so, our numerical model as 9.2 million grid cells so that we can capture quite a lot of the geology -- not geology. The flow downstream of the repository.

One of the geological features of all of our models is that we have flow from west to east. This is west on the schematic. And here's east. And in order to enable monitoring a significant distance downstream from the repository, this model is about 7 kilometers east/west, 2.2 kilometers north/south, and 1.2 kilometers thick. So this is quite a large model. Our monitoring point where we monitor for maximum iodine concentration is 5 kilometers downstream of the repository.

Looking on the right at the geological features of our basin, this repository is in a large massive halite, which is relatively homogeneous. There's a dolomite aquifer on top of the salt block and that is where our potential drinking water aquifer is, that is where our exposure point is in the dolomite aquifer above the halite. Above that we have sediments. Right in the immediate vicinity of the repository on the far right we have the rough damage zone, which extends to an upper anhydrite and lower anhydrite barrier not barrier, feature. Each of these anhydrites is potentially more permeable than the halite rock and the disturbed rock zone does go all the way through the anhydrites. So the anhydrites are only 1 meter thick each, but they do represent a potential flow path away from the repository, because they are in contact with the disturbed rock zone.

So that's our geology of this model. Looking at the repository, and the uncertainty side of this model. So our repository features, first of all of our backfill is just run of mine salt. So are our shafts. Our shafts are just run-of-mine salt. We assume instant release fraction of iodine 129 of .1, and then subsequently have fractional dissolution of the spent nuclear fuel. On the left we have the schematic of the repository. It's a little hard to see. The 24 PWRs are all on the left, 37 PWR’s are on the right. They are separated into their own drifts, and in this case, the 37-PWRs are all downstream of the 24-PWRs, because our flow is from left to right.

We also have -- you can't really see it on the diagram, but we also have in-drift placement of all of our waste packages. That's actually the case in all of our simulations. So we have 200 simulations with uncertain parameters that are sampled using Dakota's Latin hypercube sampling algorithm. The seven sampled properties divided into natural barrier properties and engineered barrier properties. The first natural barrier property is the porosity of the dolomite aquifer, which is our potential exposure pathway. In this model, the porosity of the dolomite, the permeability of the dolomite is a function of the porosity. When you change porosity, you also change the permeability of the overlying aquifer. So you change one parameter, but in effect, two of your inputs in your PFLOTRAN input deck are changed. Another natural barrier property is the permeability of anhydrite beds that sandwich the disturbed rock zone, and the third is the permeability of the disturbed rock zone itself. Our engineered barrier properties, which we sample on are the backfill permeability, that’s the crushed salt backfill. Our shaft permeability and the mean and standard deviation of the waste package degradation rate coefficients, so that’s actually two uncertainties, one sampling on the mean and one sampling on the standard deviation of the waste degradation coefficient. And then our performance metric, as I said before, is maximum iodine 129 in the dolomite aquifer 5 kilometers downstream of the repository. In the full analysis, they looked at a lot of other performance metrics, but this is the one that's consistent across many of these simulations and the one I'm going to talk about today, because it's also one of the most useful.

If you look at the results, these are just the results from peak iodine 129 at the 5 kilometers downstream of the repository. We conducted a variance-based decomposition global sensitivity analysis. What is shown here are the partial correlation coefficients, they are a measure of linear correlation between parameters and the quantity of interest although there's only a linear relationship, it's handy, because it gives the direction of the relationship. So that's what's shown in the picture on the right. The picture on the left is just the iodine concentration after a million years between ten to the minus six and ten to the minus 11 molar concentration. And that is from our base case model. So if you look at the uncertainties on the right, you can see that peak iodine 129 in the aquifer is most sensitive to the disturbed rock zone permeability, and that makes a lot of sense because the disturbed rock zone is what gives it a pathway to the shafts and then the flow goes up the shafts and into the dolomite aquifer. And the dolomite aquifer porosity permeability itself, and remember, we sampled on porosity, but when we changed porosity and permeability is a function of that. So high porosity leads to high permeability.

So as you would expect, the correlation with the disturbed rock zone permeability is positive. I have high permeability in my disturbed rock zone I see more iodine in my aquifer. Dolomite porosity permeability is a negative correlation which means when I have a high dolomite porosity, I have a lower concentration downstream and the reason for that, we think, is that you get this very wide dispersed plume in that case as opposed to some kind of channelization of the flow.

Okay. Yeah. Okay. So very briefly, the crystalline reference case, Laura actually talked about a lot of this, we have 1680 12-PWR waste packages in 42 disposal drifts. This simulation does not have the reflective boundary because with the fractures, you don't have the symmetry anymore. In this example, we have a lower temperature, because we have a greater waste package spacing. Laura designed it that way intentionally so we would not see high temperatures in her simulation, and our peak temperature is lower, around 120, 130 degrees Celsius. In terms of our geological features, this model is about 2 kilometers by 3 kilometers and then 1.2 kilometers deep. Once again, we have an east/west hydraulic gradient. So we have an upstream of the repository and a downstream side. We can talk about downstream concentrations. It has two fracture networks. We have deterministic fracture network, which are the big fractures that are the same in every realization, and then we have the 25 stochastic pressure networks Laura just talked about and then there is a sedimentary aquifer overlies the repository, it's just 15 meters thick and is assumed to be some kind of glacial deposits so it is given glacial deposit properties.

And in terms of the numerical model features, it has 4.8 million grid cells. Iodine 129 is one again the radionuclide of interest, and in this one, we use discreet fracture networks, which were then upscaled into a equivalent continuous porous medium or ECPM model.

Okay. So moving on to the repository features. In this case, we have bentonite backfill. As you've probably heard a couple times, backfill is potentially very important in the crystalline case because of all those fractures. In this case, we have instant release fraction for I-29 and subsequently fractional dissolution of spent nuclear fuel. Once again, we have in-drift placements of 12-PWR waste packages. Laura ran a thousand simulations with uncertain parameters, once again using Latin hypercube sampling. There's 25 realization of the discreet fracture network. The eight sample properties are divided into natural barrier properties and engineered barrier properties. The natural barrier properties are permeability of the disturbed rock zone and permeability of the overlying aquifer. The engineered barrier properties are porosity and permeability of the bentonite buffer. In this case, they are sampled separately. The mean and standard deviation of the waste package degradation rate coefficient, the fuel dissolution rate and the instant release fraction upon waste package breach is a sampled parameter in this case, but in the other case it was a assumed to be a constant. And in this case, the performance metric is element wise maximum I-129 in the aquifer, whereas in the other cases, the performance metric elements was maximum I-29 at some specific point in the aquifer. So this performance metric is also a little different.

So moving on, be I'm showing the total sensitivity indices. The top and you did see this picture an hour ago. The top picture shows the sensitivity indices if you do not include the importance of the fracture realization and the bottom one shows the relative indices if you do include the importance of the fracture realization. So as Laura said, the fractional dissolution rate of the spent fuel, the rate UNF, is the most important parameter by a large margin if you don't include the fracture network sensitivities, followed by K glacial, which is the permeability of the overlying glacial sediment, which is our aquifer and exposure pathway. When you start including the stochastic variation in the fracture network you see there's a very strong dependence on these fracture network characteristics, but the rate UNF, the fractional dissolution rate of the spent fuel is also still important and the glacial permeability is maybe not quite so important once you start looking at the characteristics of the fracture network.

So the final case is the shale or argillite reference case, which was studied in 2017 and again in 2019. In this case, we have 4200 12-PWR waste packages in 84 drifts. Once again, because our shale is not a fractured model, we get away with modeling a half symmetry domain. We have 42 drifts and asymmetry boundary right here along the South axis of our model. We close this boundary and our whole repository is reflected, and so we have 42 real drifts and 42 reflected drifts, basically. Even so, this model is quite big, 6.9 million grid cells. Geological features, once again, we have this small head gradient from west to east. West is on the left, east is on the right. Our model is about 7 kilometers long, about 2 kilometers deep, 2 kilometers in the north/south direction and about 1.2 kilometers deep. And we assume in this shale model that this is a soft shale. It's not a brittle shale. So we don't have fractures and we don't have to worry about creating fractures outside of the disturbed rock zone, because this is quite a nice soft shale. Not a brittle shale sort of case.

In this case, we actually have two potential drinking aquifers. We have a sandstone aquifer above the repository and a limestone below the repository. So if you look at the schematic on the right, you can see this is a more complex geological strata. We have overburden at the very top and then bright yellow, we have a sandstone aquifer. We have a few shale silty layers and the repository is in the bottom shale. Below that, we have a limestone, which is also a potential drinking aquifer, followed by a shale underneath, and that shale underneath also has another aquifer in it, although that doesn't turn out to be terribly important to the model. It is a feature in the model, which you'll see in a second is actually sampled on, and once again, with this very long model, we're looking at the maximum iodine 129 in both aquifers, 5 kilometers downstream as our main performance metric.

Okay. So looking at our repository features now, you see our repository, our drift is all in rows. Once again, we have in-drift waste package placement for our 12-PWRs. We have bentonite backfill in this case and we have instant release fraction of iodine 129 of .1 and subsequently fractional dissolution of the spent nuclear fuel. In terms of the sampling, once they did, in this example, they did incremental Latin hypercube sampling of uncertain parameters. What they do then, they have an initial sample size of 50 and then they go to 100 and they go to 200. Because it's incremental, the first 50 samples are the first 50 samples in the set of 100 simulations. The first 100 simulations are in the set of 200 simulations, so you're running 200 total simulations. In this example, they sampled ten parameters, including some are natural barriers. Some are engineered barriers. The natural barrier properties were the permeability of the underlying limestone aquifer, the overlying sandstone aquifer, the lower sandstone at the bottom of the model and the disturbed rock zone. Another natural barrier property they sampled was the porosity of the host shale, and then another thing they sampled on although they did not end up using is there was there is neptunium 237 in this model, and they sampled on the Kd in the buffer and in the shale, but that is actually not used in the analysis that I'm presenting.

For engineered barrier properties, they looked at the permeabilities of bentonite buffer, the mean waste package degradation rate, and the fuel dissolution rate. And once again, our performance network, performance metric is maximum iodine 129 in aquifer downstream.

So if you look at the picture below, you can see I actually present four potential observation points. We have two in the sandstone, one is the sandstone immediately above the repository. One is the sandstone 5 kilometers downstream. So that's Observation one and Observation three in the sandstone. And we have observation one, the limestone, which is directly below the repository and concentration of iodine in the limestone 5 kilometers downstream from the repository. These are in categories in the pictures in the plots on the right. These are the lower aquifer. We have limestone above the repository, limestone downstream, the upper aquifer which is the sandstone aquifer above the repository and sandstone downstream.

So these sensitivity indices are calculated with both calcium processes and polynomial chaos expansions on the long transfer results, because that gave planer results, and they are both shown on the graphs. The incremental sampling sizes are also shown on these graphs. So we have GP is gaussian process 50, gaussian process 100, gaussian process 200, and then we also have polynomial chaos expansion, 50, 100, and 200. For all of these uncertain parameters in all of the plots. You can see in three of the four points, the permeability of the resident shale is a very important parameter. For the downstream observation points, that's these bottom two, the permeability of the aquifer is the most important, is also a very important parameter. So here we have K limestone is very important for the limestone aquifer. K sandstone, which is permeability of the sandstone, is very important for the sandstone aquifer.

And in all of these cases, we have very small sensitivity for the permeability of the disturbed rock zone and permeability of the buffer, which indicates maybe in this example, these variables could be fixed without change in the variance of the input very much.

And finally, so our overview of our results to date. We've run statistical analysis over hundreds of simulations using Dakota and PFLOTRAN for our 3 generic host rock types. Our model behavior appears realistic and our methods are robust. What I mean by robust is you look at a different sampling method -- not different sampling methods. You look at different ways of calculating the indices or different sample sizes, particularly in the last example with the shale, and you get the same things of importance. That indicates our method is probably quite robust. Across all three reference cases, aquifer properties have an impact on the iodine 129 results. It was the least important to the crystalline, but was very important to the other two. Other quantities of interest for at least one of the cases was the disturbed rock zone permeability in salt. The fuel dissolution rate in crystalline, and porosity of host formation in shale. This is very consistent with what Paul was talking about yesterday, that the salt is primarily dependent on the rock to keep the radionuclides in, crystalline is very dependent on the engineered barrier system, and shale is actually kind of dependent on everything a little bit. In this example, it was most sensitive to porosity of the host formation.

So our next steps, the next couple of years we're going to make a big push on the DECOVALEX task F projects, and that's numerical modeling and analysis of crystalline reference cases, which were developed in conjunction with a group of partners from around the world. That is the next presentation, so I'm not going to talk about that here. We're also going to drive development of process models in particular for bentonite evolution, waste package degradation, and also salt consolidation in creep. Because salt consolidation in creep was not in the salt model yet, we used semi-consolidated parameters for the whole simulation. In the longer term, we would like to look at gas generation and disruptive events, although as I said before, disruptive events can be challenging to do in the generic context. But we're going to look at if there's possible to generalize disruptive events as much as we can and study that as well.

And finally, we have my references. And thank you.

>> BAHR: Okay. Thank you, Tara. I have a question to lead off in the case of the salt reference case. You found that the permeability of the aquifer was negatively correlated with the peak concentrations, and you attributed that to dispersion in the aquifer. Dispersion and dilution in the aquifer. In the case for the shale repository you found that both of the downstream aquifer permeabilities were important. Were those negatively correlated or positively correlated with the high concentrations?

>> LAFORCE: I believe they were positively correlated, because they didn't have the link between porosity and permeability. In the salt case -- is that correct, Emily?

>> STEIN: So the shale case is actually kind of interesting, because the correlation of the concentration with the aquifer permeability is different close to the aquifer -- sorry, close to the repository

than it is further away from the repository. Close to the repository, the correlation is negative. Higher aquifer permeability carries things away faster, keeping the concentration low. And at the far end of the model domain, the correlation is positive, because the higher aquifer permeability brings the radionuclide there more quickly.

>> BAHR: Thank you for that clarification. I think Tissa's hand is up.

>> ILLANGASEKARE: Yeah. Thank you. A lot of [Indiscernible] in the computers. So I have two questions. Do I assume the Kd to be linear, is it for numerical convenience or do you have some evidence that Kd is linear?

>> LAFORCE: I actually think this is a question for Emily as well.

>> STEIN: So that assumption of linear Kd is valid when you're talking about trace concentrations of solute.

>> ILLANGASEKARE: So close to the source still the concentrations are assumed to be tracer?

>> STEIN: Yeah. You know, it's something that we

haven't looked into thoroughly, and I think you're bringing up a point that would be worth considering more. Generally speaking, the assumption of linear Kd is one that many, many performance assessment models, not just in the U.S.

>> ILLANGASEKARE: Yeah. I sort of knew the answer. So the second question is that you assume porosity and hydraulic permeability are correlated, which is reasonable. When it comes to transport, the effective porosity is different from the total porosity. So that effective porosity may not be correlated to the permeability. So my question is that I don't know the answer to that. I'm just speculating. So that means that in the case of looking at sensitivity analysis, it's probably not a bad idea to have that correlation, but when you come to the transport sensitivity, that assumption may not be that good. Is that correct? Because the advection dispersion process is going to be controlled by the effective porosity, not the total porosity. The total porosity is related to hydraulic conductivity and, I mean, there is physics to support that. But the question is that the effective porosity, which comes in the advection computation in your model,

that may become an issue, isn't it? I don't know the answer. I'm asking you.

>> LAFORCE: Yeah. We assumed that they were the same in the simulation.

>> ILLANGASEKARE: Yeah. The effective porosity can be different. It's my experience calibrating effective porosity, I find that effective porosity can be quite low in some of the sets, in the calibrations, it's much lower than the total porosity that you mentioned.

>> STEIN: And that's certainly true for diffusion dominated system. There also, we haven't gone to the step of specifying effective versus total porosity.

>> ILLANGASEKARE: You might want to think about it. Because advection dispersion equation is one that basically moves the material and the velocity is controlled by the total porosity, to some extent effective porosity also. It's a generally good assumption for [Indiscernible] media.

>> LAFORCE: Remember, this is the dolomite aquifer, which has relatively high permeability. It is a flowing system more than a diffusive system.

>> ILLANGASEKARE: Yeah, yeah, that may be the case. Jean, you can comment on that.

>> BAHR: That was why I was asking about those correlations. If you have a low effective porosity, then you're going to have a high advective velocity for the gradient.

>> ILLANGASEKARE: Yeah.

>> BAHR: For the gradient through the system. [Indiscernible] permeability. You mentioned that in I think it was in the shale case or maybe it was in the salt case that you were using elemental iodine concentrations? I wasn't sure what you meant by that? Can you just explain what's the difference between a peak iodine 129 and the elemental iodine 129 as metrics?

>> LAFORCE: I think our simulation only contains -- well, as iodine isotopes, I think it only contains iodine 129, because it does have such a long half-life, and also because it is a relatively, almost completely nonabsorbent radionuclide. So it tends to be the one that goes the furthest.

>> BAHR: But you mentioned that you were using a different iodine metric in one of the cases.

>> LAFORCE: Oh.

>> BAHR: One of the cases, and I wasn't sure what you meant by that.

>> LAFORCE: Oh, sorry, no.

>> BAHR: Did you mean iodine as an element or talking about an element or a grid cell in the model?

>> LAFORCE: Sorry. Yes. Element in the model. So in the shale and salt case, which were done previously, we have maximum iodine concentration at discreet points in the domain. The domain, the points I mostly talked about was this 1 point in the aquifer 5 kilometers downstream. So it’s the maximum at that point. In the crystalline case, Laura did something much more sophisticated and she looked at the maximum anywhere in the aquifer as a function of time, and that was the maximum iodine 129 that was used in those. Sorry, yes. So the difference is -- one is the entire volume of the aquifer maximum and the other is the maximum iodine at a single pointed in the model or a discreet set of points in the model.

>> BAHR: It looked like in the crystalline case, the envelopes of peak concentration seemed to be converging

towards the end of time to a maximum concentration, but that wasn't an outlet point, that was anywhere in the model.

>> LAFORCE: Yeah. But the maximum does tend to come at late time, especially in the downstream points, because our flow is not that high a flow gradient across the model. It takes however many tens of thousands of years for a few waste packages to breach and actually start releasing anything.

>> BAHR: Right. So that's sort of different from a scenario in which there would be some peak concentration at some time after which the concentrations would start reducing.

>> LAFORCE: I think they will start reducing in the system. They'll flow off the end and get diluted as they go.

>> BAHR: A longer timeframe than you simulated.

>> LAFORCE: Yeah. The peaks, they're not always at the end of the simulation, but a lot of them are towards the end of the simulation.

>> BAHR: Thank you. There were questions from board

members or staff?

>> ILLANGASEKARE: One more question. So in these simulations, maybe I can look at your slides again. The sources are assumed to be continuous, once they're released, then you assume the source to be continuous? It’s not a step, it's not a pulse, it’s a step source?

>> LAFORCE: Yeah. In two of the models, our instant release fraction is .1, and then there's a gradual dissolution after waste package breech. And the other model, in the crystalline model, which is the most sophisticated statistics, the instant release fraction is actually sampled, and I believe the mean is .1, but it's a sampled parameter.

>> ILLANGASEKARE: It's a continuous source? Throughout the simulation, the source is continuous.

>> STEIN: There are essentially two sources. One is pulse, that’s the instant relief fraction, which is immediately followed by the continuous source term as a result of the slow dissolution.

>> ILLANGASEKARE: Dissolution then. Okay.

>> BAHR: I see Bret's hand up. We can bring him

online.

>> LESLIE: Thank you, Tara. That was a nice description of the reference case. This is a question for Emily. And I think for clarification, the other day, Emily, you were talking about concept evaluation and disposal concepts. Could you clarify what you mean by disposal concepts and their relationships to reference cases?

>> STEIN: Oh, okay. That's a great question. And so Tara had the one slide, the grid with all the red and blue colors and the different waste package sizes. So that is the extent really of disposal concept, different disposal concepts we can dispose of 4 PWRs, 12 PWRs, larger waste packages in the same host rock. You could imagine that you could also have different concepts for various engineered barriers or whether you have liner in your tunnel or not. There are other elements that could also create the description of a disposal concept. And then the reference case would be the host rock plus disposal concept. That's what I'm talking about when I say that. I'm not sure if --

>> LESLIE: But that's a helpful explanation. Thank you.

>> BAHR: And I see Andy Jung has his hand up.

>> JUNG: Yes. Thank you. It was very informative. I have just one question for slide number 13. Related to the crystalline reference case, your sensitivity study. Related to the iodine 129, you said that the concentration is sensitive to the rate of spent nuclear fuel dissolution. I understand iodine 129 is supposed to be an instant release fraction, so I don't know why it depends on this spent fuel dissolution rate of this isotope.

>> LAFORCE: Okay. There is an instant release fraction of iodine 129, and it's a sampled parameter. I believe that mean of that sample is .1. And then the other 90% or so comes out gradually through dissolution of the waste form. So if that other 90% of the waste form dissolves quickly, we see more radionuclides downstream.

>> JUNG: So iodine 129 is the most of iodine 129 is incorporated in the fuel matrix, not for the instant release?

>> LAFORCE: Well, some of it is instant release, but most of it dissolves slowly.

>> BAHR: So yes, it is in the matrix.

>> LAFORCE: Yes.

>> Andy Jung: Thank you.

>> BAHR: Chandrika?

>> MANEPALLY: Hi, Tara. Board staff. Very nice presentation. Thank you so much. I had a question, maybe it's you or Emily can respond. This is on Slide 7. you had talked about two concepts of waste packages where the temperature expected was 250C and 200C, but you haven't yet modeled in GDSA. Correct?

>> LAFORCE: Correct.

>> MANEPALLY: To model those cases, do you anticipate you need to put in more capabilities, or do you already have capabilities in GDSA for those range of temperatures?

>> LAFORCE: This might be a bit of a question for Emily. In terms of running PFLOTRAN, PFLOTRAN will go at those temperatures, but when you start getting to very high temperatures, you start having to worry about physics that we do not have in this model. For example, bentonite backfill getting illitized. You get over 200 degrees, it could very well happen then suddenly

your bentonite is not bentonite any more. That is not in the model. So we have been trying to stay away from very high temperatures, because of those kind of concerns. And also about whether that would ever be realistically allowable is another concern.

>> STEIN: I'll add to that. In these reference cases that Tara showed, we're not quite reaching those temperatures. In the recent work that has been done for the criticality consequence analysis, related to direct disposal of DPCs, capability has been developed to at least approximate those high temperature effects. So including there is an illitization model available, they put some effort into creating thermal conductivity models that are -- I hate to use the word realism, but that's all I can think of. So anisotropic thermal conductivity model and also relating thermal conductivity to temperature. So yeah, in the last year or so, some of the capability needed to deal with other high temperature aspects beyond just the equation of state has been added to PFLOTRAN.

>> MANEPALLY: Thank you.

>> BAHR: Do we have any more questions for Tara? Okay.

Well, thank you again for your presentation. And we're going to move on to the final presentation of the day. We're going to go back to Emily to tell us about the DECOVALEX task F.

>> STEIN: Okay. I'm going to try to do a better, smoother job of sharing my screen this time. We'll see how it ... nope. It doesn't -- sorry. I'm so bad at sharing my screen.

>> BAHR: Not quite in presentation mode yet.

>> STEIN: Okay. Now you should see full screen.

>> BAHR: Yeah. Got it.

>> STEIN: Okay. Good. So this talk is about task F in DECOVALEX. And labeled case study in integrating insight and experience from the international community into GDSA. So that's a mouthful. The first thing I'd like to do is explain what DECOVALEX is. That acronym stands for developing coupled models and their validation against experiments. DECOVALEX is an international research and model comparison collaboration initiated in 1992, and it seeks to advance understanding of the thermo, hydro, mechanical and chemical processes that occur in engineered geological

systems. It is supported by radioactive waste management organizations and regulatory authorities around the world. DECOVALEX's tasks run in four-year intervals. Task F is a performance assessment comparison that was initiated in 2020 and will run through 2023. And it is led by DOE specifically, and I'm the task leader.

So this is a brief talk. I'm going to give you a whirlwind tour, first looking at the structure of task F, then within task F, we have two parallel tracks, looking at crystalline reference case and the salt reference case, so I'll tell you about some of the benchmark comparisons we've done within the crystalline track, as well as the crystalline reference case itself and the salt reference case.

So task F is a comparison of performance assessment models and methods. Here is a visual representation of crystalline host rock and a salt dome host rock. Task F objectives are really about capability development, which has been a recurring theme so far through these two days, so capability broadly includes software capability, workflow capability for a probabilistic PA, and people capability. So developing staff competency and next generation really of performance assessment modelers.

We want to leverage this task to really understand how the modeling choices can influence the results of your performance assessment. So different teams will choose different model fidelities. They might choose to include or omit certain processes in their PA. And they will definitely have different methods of coupling those processes.

Once we understand kind of the range of results that can be attributed to different modeling choices, then we have the opportunity to compare the uncertainty introduced by the modeling choices to other uncertainties in the system. And that would include the stochastic fracture network in the case of the crystalline reference case and uncertain inputs, definitely epistemic uncertainties in both cases, and depending how far we get in our reference case development efforts, we might also consider evolutionary scenario uncertainties.

So task F is structured in five different steps to be completed over four years, and we're one and a half years in to the task. The very first step is simply to define the reference cases. Second step is comparison on benchmarks to analytical solutions and some sub-system process models that address a portion of the whole PA problem. Second step is completing a deterministic reference case where we're not yet addressing uncertainty. Everybody is using exactly the same parameters, other than model uncertainty. So this is going to really allow us to address how the coupling between processes affects the solution, how modeling choices affect the solution.

And then step three will be adding consideration of epistemic uncertainty into that, some amount of sensitivity analysis using methods such as correlation and regression that are widely available and that we expect most teams to have experience with, and then step four, we may or may not get there and it's certainly an optional step. Interested teams may also use these reference cases to compare different methods of sensitivity analysis, similar to what Laura showed you in her talk.

So throughout this task, diagram on the right shows you kind of in a pictorial form the steps that are outlined on the left. So first step is to make sure that we are all agreed on the characteristics of the natural and engineered barriers. We all have the same description of that. We've established our performance measures. And we are relatively well agreed on conceptual models. You will see in future slides a little bit of overlap between developing those conceptual models and then development of the computational or numerical models actually used for simulation.

And then these circles off to the side show where we'll do comparison, so process model and benchmark comparison, and then we do our deterministic case, calculate performance measures, do a one-to-one system comparison, and finally include uncertainty propagations, sensitivity analysis, and compare the whole suite of results.

So task F is an atypical task for DECOVALEX. Remember it stands for developing coupled models and validating them against experiments. So most DECOVALEX tasks are designed around perhaps an experiment that is occurring in the laboratory or in underground research lab. They will involve simple benchmarks such as comparison to analytical solutions, and then some simple test cases where people will fit their models to some set of data, and then once everybody has a pretty well calibrated model, then they do blind predictions to compare to a set of data that nobody has seen yet. There may be additional tweaks to models after that step, and then in some cases, they'll go on to then say, well, can I apply this model to a larger question outside of just this set of blind predictions?

In our case for task F, we're going straight from those benchmarks, analytical solutions, simple processes, straight to a performance assessment application. And so it's already been noted that it's not really possible to validate in this traditional sense, a performance assessment model, so tasks like this are one of the methods that can be used to build confidence that a performance assessment model is appropriate for the decision that needs to be made.

There are ten teams from seven countries participating in the crystalline track of this task, and five teams from four countries participating in the salt track. And those teams include implementers, regulators, and some safety and science advisers.

So for DOE and the Spent Fuel and Waste Science and Technology campaign, we expect participation in this task to benefit the program in several ways. The first is it really motivates integration of features and processes into our reference cases. We have already made some improvements to generation and upscaling capabilities for discrete fracture networks. Past year has seen a lot of work on improving the dual continuum fracture matrix diffusion model. And in the next year or so, we will need to tackle implementing a model for crushed salt reconsolidation. This type of exercise definitely is a confidence building exercise through software benchmarking, comparison and modeling approaches, and simply the mutual learning that takes place in this environment. So we are laying out the details of our performance assessment implementation and receiving feedback from other teams on those, and vice versa. We get to learn about the details of other people’s implementations and methods.

And definitely through this task, we are helping to grow the next generation of repository scientists. We have four early career researchers involved in this project helping with reference case development, leading up the numerical implementation and model simulation involved in the software development that needs to take place, and also helping with uncertainty and sensitivity analysis.

So crystalline, we had, you know, steps 0 through 5 laid out a few slides ago, and really, we're running some of these things in parallel. References case development and bench marking in the crystalline case have happened in parallel. We have completed some simple comparisons to analytical solutions, including steady state flow, transient advection and dispersion, matrix diffusion problem, and these are really done, checked out well. We're working on some simple problems that don't have analytical solutions. Transient transport through a four fracture network, transient transport through a stochastic fracture network, these are still in progress, and in the near future we'll likely need a benchmark for the radionuclide source term, and depending where we go with the reference case, we might end up with near field processes that we benchmark.

I'm going to show you results of two of these benchmark sets so that simple advection dispersion and more complicated advection problem. So one of our benchmarks was transient advection and dispersion in a 1 D domain of a conservative here at the top a decaying and adsorbing tracer. There is a steady state flow driving transport from the left side to the right side of the model domain. The source term is just an initial pulse at time equals zero at the inflow face of the domain. And over here you're looking at tracer concentration versus distance in the domain. There is a line in there that is the analytical solution to this equation, and then there are results from PFLOTRAN, COMSOL, in-house code out of the Canadian nuclear safety commission and OpenGeoSys. I'm not sure what the Koreans were using. And you can see that on this simple problem, all the codes can match the analytical solution.

So then when we get to the four fracture network, it becomes a little bit more complicated. Again, we have a fairly simple model domain with an inflow face and outflow face, steady state flow, and a pulse source term at the start of the transport simulation.

There are several ways that teams have chosen to model this problem. Some are modeling using the discrete fracture network. Others have upscaled that to the equivalent continuous porous medium. Some people are using particle tracking and others are using the Eulerian advection dispersion equation. So if you look on the right you're seeing results generated with a mix of those different transport methods. And what we're looking at is the cumulative tracer mass across the out flow phase as a function of time. So just for reference in red here is the particle tracking solution in the dfn, and you can see that particle track is a very sharp arrival, just before one year. Some of these other solutions using the equivalent continuous porous medium and the advection dispersion equation or even advection dispersion in the dfn. Numerical dispersion becomes apparent in those solutions, and then a few of these lines are really a bit separate from the rest of the pack. And I would say these are preliminary calculations and there is still some digging to do in these simulations to understand why they're different and if they can be brought more in line with the others.

So then somewhat quickly through the two reference cases. Very high-level view. We have put considerable effort in both projects into developing a reference case that will be useful for all the teams for the simulation tools that they have on hand and also for the types of performance metrics that they are accustomed to working toward. And so this crystalline reference case, I'll tell you about natural barrier system, followed by the engineered barrier system. The natural barrier system is loosely based on the Finnish repository site, including the description of the brittle fracture zones, the large deterministic features that you see here in magenta. And also the stochastic distribution of fractures within the intervening blocks of rocks. There are three depth zones, each with three fracture sets, and you can see that in the color from blue to yellow to orange and red.

There's the possibility later in the project of relating fracture transmissivity to the normal and shear stress on the fractures, which would be of interest, for instance, if you're thinking about a system with a glacier advancing and retreating. We're going to use a very low relief topography at the top surface of this domain, and the effect of the associated pressure at the top surface is to drive flow downward at the slightly higher elevations and upward at the lower elevations.

The engineered barriers system that we've chosen for the reference cases is the KBS-3V emplacement concept, which is the emplacement concept, the reference design for both the Swedish and Finnish repository concepts. It is for disposal of spent nuclear fuel. You're looking at a blowup of fuel pellets here. Those fuel assemblies are placed in a copper canister with a cast iron insert and then that canister is emplaced in a disposal borehole below the floor of a tunnel and which is backfilled with bentonite, both in the bore hole and in the tunnels or the drifts.

The depth of that repository is approximately 500 meters. So for initial simulations, I'll point out dealing with spent fuel or any of the details of the near field, too complicated. We are simply going to look at tracer source terms in each of the deposition holes, essentially in a steady state flow field.

So later, as this reference case develops, we'll have to see how it goes. There's the possibility of adding more complicated canister failure mechanisms or feedbacks between different parts of the systems, and very early in development of this reference case, we did a survey to see what teams were interested in, and so over here it's priority number 1. The teams' top priority in terms of canister failure mechanisms. Some people were very interested in looking at the corrosion of the copper. Others said as long as you put a glacier on top of it, I don't care what the failure mechanism is.

In terms of feedbacks, we might look at fracture flow, the feedback between that and buffer erosion and there is additional feedbacks there to the canister corrosion. Others were interested in looking at the influence of glaciation on boundary conditions or on fracture transmissivity.

And then briefly through the salt reference case. So our salt reference case is a salt dome. It is based on a German salt dome, but then very, very highly simplified in terms of geometry and the number of geologic units that we're considering. The salt, of course, has very low porosity permeability, high thermal conductivity. We expect the openings to be closed and that the crushed salt backfill would heal the intact salt.

And designing the engineered barrier system, we borrowed features from Germany, the Netherlands, and the United States. So we will have some drifts with a glass waste form in them. Others with spent nuclear fuel. We've chosen a cast iron canister for the spent nuclear fuel, which is a German design. Crushed salt backfill in the drifts. Gravel in the infrastructure area, which provides a reservoir for accumulation of excess fluid or gas pressures. And then there will be a length of drift seal between the disposal area and this infrastructure, the shaft area. And also shaft seals.

So in this reference case, we've got a little bit further in terms of staging our model development. We've chosen a what if case. What if the shaft seals fail in a thousand years? Which is a very early failure time, chosen because that timescale is coincident with the time scale of backfill reconsolidation. We're going to start simply with flow and transport, move on to adding drift convergence, so creep closure and reconsolidation, and then hopefully we'll get to adding heat flow and temperature dependence of those salt consolidation processes. We may model uncertainty in the backfill consolidation model down here in parenthesis. This may be aspirational. We might get to considering gas generation.

There are diverse modeling approaches proposed for this problem, including very detailed representation of the repository with completely neglecting the impermeable host rock. A more geologic representation of the repository and the units surrounding it, and also this code out of Germany, LOPOS, which stands for loop structures in repositories, and is a segments model.

So just in summary, what we're doing in this task is a comparison of performance assessment models and methods on both the crystalline and salt reference case. This is a means of building confidence by addressing uncertainties introduced by the modeling approach, by becoming cognizant of what's going on in other international programs, and also, of course, we will be developing capability through participation in this task. And that's it. Questions?

>> BAHR: Thank you, Emily.

I see Lee Peddicord's hand is up. Go right to him.

>> PEDDICORD: Thank you. This is really interesting and really is a great project. We kept apprised of this by Chandrika, who is our local enthusiast for Decovalex. The question I wanted to ask is kind of a broader one, and to use a good nuclear term, is there any flux of countries, new ones coming in or even countries dropping out of it? I can't see any existing, but I can see maybe more countries coming in overtime. Does that work? Because you're pretty far along in what you're

doing.

>> STEIN: Yeah. So we have, in fact, had a pretty stable set of teams since the beginning of the program. We did have one team drop out of the crystalline performance assessment because they had only that loop structures model and said we cannot do stochastic fracture networks. We had one team who had been slow to find the actual technical support to do the simulation. So that person just got hired, and they will be joining us at our meeting next week. I think they'll be able to catch up, because we haven't started the reference case simulation yet, and the benchmarks are really simple.

>> PEDDICORD: It occurs to me this might be an opportunity to engage countries with, I don't know, DECOVALEX, DECOVALEX, Jr., or the brownies or whatever would be the entry level for this to kind of get new countries that ought to be thinking about this, and even some of the newcomer countries that are thinking about nuclear for the first time, but you know, we all say, you should think about disposal at the beginning. Incorporate it into your strategic planning from day one so you're not playing catch up like all the rest of us. And so you've got a really attractive framework here.

Maybe reaching out and engaging and saying, come on in it. Let's kinds of look at this and think about just to stimulate their thinking. I don't know. It's really impressive what you all are doing. And I think you ought to push it outside the tent somehow. I don't know how, but I think you've got something really great here that could have a big impact.

>> STEIN: Yeah. Well, thank you for that. That's an interesting idea.

>> PEDDICORD: Thank you.

>> BAHR: Emily, I had a question about the results that you showed for the four fracture model. And you had a large number of results that were fairly consistent with each other, and then you had several that you noted didn't match. There seemed to be an implicit assumption in your discussion of those that didn't match that the ones that matched must be somehow better representing the process than the ones that didn't. Maybe you can expand on that a little bit. Is there one of those models that's being used that you see as the most physically realistic representation of the system?

>> STEIN: No, no. I would not say that through this

exercise, I would not say that we're evaluating what is a physically realistic representation of the system. Rather, we have already chosen the, essentially, the conceptual model that flow and transport is occurring in these discreet fractures. And so having made that choice, then through kind of an extension of that is, okay, when I model flow and transport in the discreet fracture network, that is kind of the thing that I want to compare all of the other representations back to.

>> BAHR: I guess I wasn't meaning physically representational of a particular system, but which of those mathematical models do you believe is best capturing the process of flow and transport through those four fractures? It seemed to me that you were assuming that the models that seemed to agree relatively well with each other were the ones that were best capturing those processes and that the other three were somehow not capturing the actual processes, but could it be that the other three are actually capturing the process and the rest of them are off base? I mean, do you have an idea of what I think is most realistic?

>> STEIN: Okay. Good question. So all of these models, let's begin with they are all using Darcy's law.

They all have the same underlying equation that they're solving. And so then the question is almost one of grid resolution. So when you simulate on the discrete fracture networks and refine those, at least I know when we are creating ours, the grid cell sizes are pretty small on those discreet fracture networks, I know that I do not have any false connections in there. I know that my pathways along the fracture exactly correspond with the slope of the fracture, and I know that my grid resolution is pretty good.

Uh-oh. Am I still lost?

>> BAHR: You’re on. I think it was my problem.

>> STEIN: Okay. So just numerically I know that the dfn is capturing the correct path link, the correct connections, and we’re able to have good grid resolution in there. When I go to the equivalent continuous porous medium, I run the risk of introducing false connections. I have a larger grid cell size and I also have stair-steps instead of a direct pathway. So there are ways of correcting for some of those things, but those are the types of problems that you introduce. So the question is not really not that we are trying to you find the best or most correct model, but which models,

like how is the uncertainty introduced? How is that variance introduced by using the other methods? How does that compare to the overall uncertainty introduced by the stochastic nature of the network itself, by the epistemic uncertainties? Because there can be real benefits to using the equivalent continuous porous medium, and one of those is that you can introduce heat into it. We'll deal with heat conduction, whereas the discreet fracture network will not. Another of those is that you may really reduce the number of grid cells in your problem, so it's much less computationally expensive. Right? So there are benefits to doing it. So how well can you do it. Is it an adequate model? Which is really the question that we're trying to get here. Not which model is exactly right or the best physical representation of the system, but do they all give us a close enough answer that we're confident that that answer is good for decision-making in this completely hypothetical decision?

>> BAHR: And when you do those comparisons, those are really, in a sense, an equivalent porous medium model is a surrogate model for the discrete fracture network model. When you do those comparisons, if you do them for

just one realization of a fracture network or for one distance from the source area from one outflow boundary, you know, you may be able to tune all of those surrogate models to match your highly discretized fracture model. But the same tuning may not give you a good match to another network of fractures or to another outlet boundary one that's 5 kilometers away instead of 1 kilometer away. Are you worrying about those kinds of issues?

>> STEIN: So for this benchmark, we are all using the same fracture network. And even for the one that we're calling stochastic fracture network, which I didn't show you, has a lot more fractures in it, that is still just a fracture network. When we move to the reference case, it was a group decision that we are going to consider that stochastic variation right away. So the instructions that come with the reference case are everybody needs to create ten realizations of their fractured rock, and so everybody will be generating an envelope of results or horsetail plots, and then what we want to compare is not a direct comparison on fracture networks, but a comparison of that envelope of results to the next team's envelope of results.

>> BAHR: Okay. Thank you. I see Tissa's hands up. Let's go to him. We still have some time.

>> ILLANGASEKARE: [Indiscernible] I like the modeling part and of course the international part is very good. Basically, you're looking like you in this type of studies, you are not in this particular study, but in general when you have model comparisons, you look at the numerical issues, conceptual issues, and some constitutive models in one way or another. But you are not going to the constitutive models, sophisticated ones you need for multiphase flow at this stage. So my question is more like supporting what Lee was saying, whether we can build on this idea. So can we think, in terms of the long term, of going to more process, the constitutive models, based on these comparisons, can you come to some recommendation to say that certain constitutive models may or may not work and there's some recommendations? Can you make research recommendations based on this comparative study to be able to say that based on this study, we have learned these are the areas more science is needed? I’m not talking about this particular study you are doing, but I'm talking in terms of more future work, where this type of concept of

international collaboration, including DOE models, can go to the next stage?

>> STEIN: Yeah. So I mean, this is good question, because DECOVALEX, as a whole, generally deals in a very detailed fashion with constitutive models, which is the appropriate one to describe the data or what are the processes I need to include in my models to describe that data? So definitely that's kind of in the -- there is a thing that DECOVALEX deals with. And then your question is more, okay, so you have a variety of constitutive models. How does that affect the performance of the system? Does it even matter?

>> ILLANGASEKARE: Yeah, yeah.

>> STEIN: And I would say that with the salt case, we hope to get there. So I am not an expert in salt reconsolidation, but there are some people participating in that project who are, and I know that they bring multiple backfill consolidation models to the table, and one of the things that we would like to be able to do within this project is incorporate those multiple reconsolidation models and exactly see, do they make a difference to the performance of the system and how does the variants introduced by those different models

compare to the variants introduced by some of the other things that we're working on.

>> ILLANGASEKARE: My question was an extension of that. My question was at the same point that the two comparison consistently find that certain models don't match, certain models don't match, then you'll find that it probably has to do with the constitutive models. So are you in a position to make recommendations that you don't know which constitutive model is good or bad, the comparison, unless you go to real experimental data, you know? So until that happens, can you, as a product of this type of work, can you come up with a recommendation and say, these are some research - a good example is the constitutive models, you look at the dry state. If you find that your comparison with the international collaboration, the model doesn't match, all together, can you come up with a recommendation to be able to say that maybe you guys in Germany should be doing this research and we should be doing this research and it is something [Indiscernible] or joint research on these type of things which are common interest?

>> STEIN: Well, I think that the situation that would allow you to see something like that is if you can

observe and demonstrate that the uncertainty introduced by the different constitutive models exceeds the uncertainty introduced by your performance assessments modeling approach or your other epistemic uncertainties.

>> ILLANGASEKARE: Yeah, yeah, yeah, yeah. I can see that being the scope, yeah. Thank you.

>> BAHR: Do we have other questions from board members or staff members? I'm not seeing any hands raised. So thank you, Emily, and thanks again to all of the presenters, both from today and yesterday. The final thing that we're going to do now is we have a period for public comment, so Bret Leslie of the staff is going to come online and he will read us the comments that he's received.

>> LESLIE: So thank you, Jean. I am Bret Leslie, a member of the board's staff. Before I begin with the submitted public comments I would just like to let those listening know that the meeting transcript will be available on our website by January 3rd. I will be reading the comments in the order they were submitted. I will identify the approximate timing of the comments, and then I will identify the commenter and any affiliation they gave before I read their comment. The

transcript will include the following comments:

First, yesterday as we were signing off, Sven Bader from Orano Federal Services asked or commented, in the FMD model, degradation appears on the timeframe of hundreds to thousands of years. What sort of time steps were utilized in the model and are these coarse or fine enough to capture the phenomenon?

Today associated with Caitlin's presentation, Sen U Tong from the Environmental Protection Agency commented or stated while incorporating the biosphere model in PFLOTRAN, are you planning to include an automatic triggering mechanism during simulations? For instance, there's an accidental drilling through the waste at a 500 year, during a 25,000 year simulation. The biosphere model automatically starts the cancellation for the individual over the 70 years since the drilling event and PFLOTRAN is still progressing for the simulation?

Next we got a couple of comments during the NRC's presentation. Sin U Tong from the U.S. Environmental Protection Agency stated, the WIPP-PA covers over a 10,000 year period starting after closure of the repository. This is the PA that EPA reviews every five years for recertification. The 2014 release incidents in this case is not a good example for discussion about FEPs in a PA.

Barbara J. Warren, RNMS from citizen's environmental coalition stated, excellent presentations by Tim McCartin and Dave Esh, thank you so much.

Sven Bader from Orano Federal Services stated, in the potential process of developing a consent based siting process, can the PA be used to eliminate potential sites for a repository or can engineered barriers be created that are likely to bring any site into compliance/acceptable result?

During Sarah Vine's presentation, Karen Bonome with no affiliation had two comments. The first is a long one, so bear with me. The explosion at WIPP was on Valentine's Day, 2014, 2/14/14, about 7-and-a-half years ago. The facility had been operating for only 15 years. It is informally known as the kitty litter accident. Packaging of americium nitrate and plutonium nitrate waste at Los Alamos was apparently done without adequate supervision. The wrong kind of kitty litter was purchased and used in the packaging process. An EPA staffer informed me during a break at a post-accident presentations that LANL had asked New Mexico Tech for advice on packaging materials. The advice was to use, quote, inorganic kitty litter, closed quote. Clay based. Someone at the lab mis-transcribed quote inorganic kitty litter, unquote, to, quote, an organic kitty litter close quote, or cellulosic. Nitrates interacted with the cellulose, creating the explosion. Why was there apparently no supervisor with basic knowledge of nitrate chemistry checking the purchase inventory and packaging process. What model could possibly capture this level of improbability? Not only was LANL remiss for not providing adequate supervision, but the New Mexico environmental department was too short-staffed, thanks to the budget cutting zeal of our previous governor, to provide the degree of oversight that could have provided backup to LANL's inadequate supervision. What model could have captured that development? Moreover, the radioactive release resulting from the explosion brought about an in-depth investigation by EPA which uncovered multiple design and operational flaws at WIPP which required a three year shut down of the facility to be addressed. I think this, quote, perfect storm of mostly improbable, inadequately monitored, and unpredictable events is a stern reminder of the extreme difficulty of creating models that account for human error, which is the largest factor in nuclear accidents, including Three Mile Island, Chernobyl, and Fukushima. At least the spent fuel baskets at Fukushima survived the tsunami and earthquake, thanks to being constructed of extremely thick steel, over 8-inches thick, as opposed to the 5/8th inch steel used in American made casks, for example Holtec. I would hope that the NWTRB will recommend using thicker-walled casks, like those used by the U.S. Navy as well as Swiss and German repositories in any spent fuel or high-level waste disposal plant to allow for unforeseeable human error caused eventualities. Safety cautions must be extra redundant, not merely what models predict based on predictable factors. Human beings are unpredictable.

Her second comment, again, Karen Bonome, no affiliation. How thick is the steel used in disposal casks in the United Kingdom?

During Laura's presentation, Karen Bonome, again, no affiliation, stated, another WIPP anecdote that illustrates unpredictability of human behavior in nuclear waste facilities with unfortunate consequences.

A worker who is very fond of smoking discovered a small window in a ventilation shaft which he was able to open. Smoking by this window sucked the smoke from the cigarettes into the shaft and thereby removed any tell-tale evidence. It also caused him to inhale dangerous substances and he died. Perhaps it was a sampling window. Why was it left unlocked? Design flaw or operational flaw?

During Emily's presentation, which we recently completed, Kalene Walker, with no affiliation, had the following statement: Question, what is a short or long-term plan for radioactive molten salt waste such as what is at Oak Ridge?

Sven Bader from Orano Federal Services: Emily, under the DECOVALEX program, are there geologies other than crystalline and salt media modeled/benchmarked? Are there any models for deep borehole?

Ken Bayer from Metatomic Incorporated also commented during Emily's presentation. He stated: Last presentation. DECOVALEX, it looks like India, Russia, and Japan are not participating. Will they be joining the testing groups?

Now I need to check the in-box to see if there's new comment. There is.

Sven Bader from Orano Federal Services. Emily, the DECOVALEX program should be commended for bringing together the global GDSA modeling community and this program should provide the opportunity to coordinate R&D activities and share results to improve future modeling efforts.

Jean, that's the end of the comments that I received today and people have submitted.

>> BAHR: Okay. Well, thank you, Bret. Again, thanks to everyone who participated in this meeting. And it's certainly given the board a lot to consider, and so thanks again for your participation, and I'm going to sign off now.

[Event Concludes]