UNITED STATES

NUCLEAR WASTE TECHNICAL REVIEW BOARD

TRANSCRIPT

INTERNATIONAL TECHNICAL WORKSHOP ON
DEEP BOREHOLE DISPOSAL OF RADIOACTIVE WASTE

Tuesday

October 20, 2015

Embassy Suites
1250 22nd Street NW
Washington, DC

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P R O C E E D I N G S

8:00 a.m.

EWING: So good morning, and thank you for so promptly sitting down and with the sound of the music. We'll be using the music to signal that it's time to start each of the sessions. So thank you for joining the Nuclear Waste Technical Review Board's Workshop on Deep Borehole Disposal of Radioactive Waste.

I'm Rod Ewing. I'm the Chairman of the Board, and I'll be introducing the other Board members in a moment. But first I want to speak briefly about why we are holding this workshop and what we hope to achieve.

As many of you know, the Board is an independent federal agency in the Executive branch. We are not part of the U.S. Department of Energy or any other federal agency or organization. The Board was created by the 1987 Amendments to the Nuclear Waste Policy Act in order to perform an ongoing evaluation of the technical and scientific validity of DOE's efforts to implement the Nuclear Waste Policy Act of 1982. We are mandated by statute to report the Board's findings, conclusions, and recommendations to Congress and the Secretary of Energy.

So why are we holding this workshop? As part of our ongoing review of the Department of Energy's activities, the Board has had a long-standing interest in deep borehole disposal. The Board's perspective on this subject has evolved over the years, and we have periodically conveyed the Board's views to the Department of Energy.

Most recently, in June of this year, the Board issued a report on the technical basis of the Department of Energy's March announcement that it's going forward with planning for disposal of DOE-managed high-level radioactive waste in a geologic repository that is separate from a repository for commercial waste.

DOE's strategy includes maintaining its flexibility to consider the option of disposing of smaller DOE-managed waste forms in deep boreholes rather than in a mined geologic repository. The Department of Energy has identified, as an example, the cesium and strontium capsules at Hanford as among the candidates for this type of disposal.

Now that the Department of Energy is investigating deep boreholes as a disposal option for some types of radioactive waste, the Board has decided to hold a meeting focused on this deep borehole strategy. We also thought that the workshop format would allow us to hear not only from DOE and its plans for studying or investigating deep borehole disposal, but also we could hear from experts around the United States and international experts who have experience with this technology.

Our objectives in holding the workshops are, first, to identify the technical and scientific issues associated with DOE’s research and development program; second, to assess the viability of the deep borehole disposal concept; and, three, to identify technical and scientific issues that might affect DOE’s implementation of the disposal of radioactive waste in deep boreholes.

Now let me introduce the members of the Board. First, as I’ve said before, my name is Rod Ewing. I am a professor in the Department of Geological Sciences at Stanford University. As I call the names of the Board members, if you’d just raise your hand so that people might identify you.

Jean Bahr is a Professor of Hydrogeology in the Department of Geoscience at the University of Wisconsin-Madison.

Steve Becker is a Professor of Community and Environmental Health in the College of Health Sciences at Old Dominion University.

Susan Brantley is a Distinguished Professor of Geosciences and Director of the Earth and Environmental Systems Institute at Penn State.

Allen Croff is a Nuclear Engineer and an Adjunct Professor in the Department of Civil and Environmental Engineering at Vanderbilt.

Efi Foufoula-Georgiou. Efi is the Distinguished

McKnight University Professor of Civil Engineering and Director of the National Center for Earth Surface Dynamics at the University of Minnesota.

Gerald Frankel is a Professor of Material Science and Engineering and the Director of the Fontana Corrosion Center at Ohio State University.

Linda Nozick is a Professor in the School of Civil and Environmental Engineering and Director of the College Program in Systems Engineering at Cornell University.

Lee Peddicord is the Director of the Nuclear Power Institute and Professor of Nuclear Engineering at Texas A&M University.

Paul Turinsky is a Professor of Nuclear Engineering at North Carolina State University.

And Mary Lou Zoback is a Consulting Professor in the Geophysics Department at Stanford University. I should also say that Mary Lou is the Board lead for this workshop and has played a very important role in assembling the panels and expert speakers.

I also want to recognize the staff, who are seated at the back against the wall, and simply say that the staff have worked incredibly hard to pull all of this together to get you here and handle the logistics, as well as assemble for the Board a tremendous amount of information, literature, and reports on deep borehole disposal.

Related to the introductions, at the back of the room there is a one-page handout, which describes the mission of the Board and also again lists all of the Board members. I think our pictures are there as well. So please take advantage of us during the next two days and to engage us in discussion and to give us your opinions as the workshop proceeds. Also at the back of the room there will be a sign-up sheet if you want to receive Board notifications and information on our meetings.

Now, just to comment on the logistics, if you look at the program, you will see we are shifting back and forth between a lecture, our normal presentation format, and a panel format. This will mean that we'll be moving around so that some Board members and moderators will be sitting on one leg of the "V"; panels will be on another leg of the "V". I'll spare you the details, but just be aware we'll be moving around quite a lot. As an example, the Board members will displace the staff members, who will displace some of those of you in the audience. So we'll try to do that as efficiently as possible.

I want to note we'll be having a noontime speaker, Professor Fergus Gibb from the University of Sheffield. We'll provide box lunches; so as soon as we break for lunch, please go out the back door, collect your lunches--we know who you are in terms of those who have indicated they want a lunch--then come back in immediately and have a seat so we can get started. And if you didn't express an interest in a lunch, I think there may be a few extras, so you're welcome to those.

You should be aware that this workshop is being webcast live. You'll see there are two cameras; and depending on where you're sitting, you may be part of the video. The webcasts are archived and available at our website for about a year after each meeting. And in order to assist those who are watching the webcast, we've posted the workshop presentations on the Board's website, which is www.nwtrb.gov.

Over the next two days there will be four opportunities for public comment. We'll provide an opportunity at the end of each morning session before lunch and then at the end of the day. If you would like to make a public comment, then please sign up on the appropriate list at the table so we'll be sure to get to you. If you don't want to make a public comment but want to submit written questions or comments, that's fine. The meeting is being transcribed. All of the public comments and materials that you submit as part of your comment will be part of that public record, which is posted on the Board's website.

When you want to speak, please get very close to the microphone, and please identify yourself and your affiliation so that that becomes part of the record.

Finally, I want to remind everyone that the Board members will ask a number of questions that you may take to reflect their personal views or impressions of what we're discussing, but these do not represent the Board's position. The Board's position is to be found in our letters and reports.

So that's the introduction. Please mute your cell phones, and I'll turn the meeting over to Mary Lou to guide us through the workshop.

Mary Lou.

ZOBACK: Thank you, Rod.

I want to add my welcome to Rod's, particularly to those of you that have traveled quite some distance to get to this workshop. It's really gratifying to see so many people here, and I hope we keep pulling in chairs as needed, which is a nice situation to be in.

I especially want to thank those of you that are joining us via live webcast. This is the first time for us, so stick with us.

As you've already heard from Rod, the Board's responsibility is evaluating the technical and scientific validity of DOE's work related to the disposition of high-level waste. And as he has also indicated, the subject of this workshop is deep borehole disposal, which means that, in fact, we will be reviewing DOE’s current plans for a deep borehole field test. But we are also going to be evaluating this concept more generally.

When we comment on DOE activities, the Board often recommends the DOE--and they already are in most cases--take advantage of the research and investigations that are being carried out around the world on any given topic and take advantage of the lessons learned by these various investigators.

To that end, in this meeting we have engaged a lot of these international experts; and I am pleased to say that here today we have representatives from Canada, the Czech Republic, Germany, Korea, Sweden, Switzerland, and the U.K., many of the countries that are exploring this option for some of their waste. On the panel we have experts from academia, from industry, consulting fields, and also government and NGOs; so a wide range of experts that will be weighing in.

I want to give you a very brief review of the agenda, which we will be covering over the next two days. To begin with, I am very pleased that this morning we have Dr. Lynn Orr, who is the Under Secretary at DOE for Science and Energy. And he is the principal advisor to Secretary Moniz and the Deputy Secretary on clean energy technologies as well as science and energy research. He will be talking to us--describing for us--right, Lynn?--Lynn is also a colleague from Stanford--DOE strategy for the management and disposal of spent nuclear fuel and high-level waste in general and how deep borehole disposal will fit into that strategy.

Next we’re going to hear from Tim Gunter of the DOE’s Office of Nuclear Energy, and he is going to lay out for us DOE’s deep borehole research program. And we have also asked him to explain DOE’s rationale for considering the deep borehole disposal option and how such an approach might be implemented.

Then following Tim’s presentation, Dave Sassani and Ernest Hardin from Sandia Labs are going to provide us with some of the specifics of this deep borehole test program. And we have asked them to tell us how the deep borehole testing that’s planned is going to provide DOE with a strong technical basis for judging the feasibility of this concept.

After the DOE presentations, which are going to take the entire morning, we’re going to hold the first of our four public comment sessions. Those of you that aren’t familiar with the Board, our meeting are open to the general public and announced a month ahead of time. And this is a rare chance for the general public to have an opportunity to speak to DOE directly.

And I am very pleased to say, as Rod has already mentioned, Professor Fergus Gibbs from the University of Sheffield in the U.K. will be our lunchtime speaker. It’s sure to be a good talk; and I think Fergus, more than any other scientist, has been instrumental in the revitalization of interest in this deep borehole concept.

You’ve already heard the lunch logistics, and you’ll be reminded of them again when the time comes. But basically Fergus is going to be speaking at lunch, so we need to get back in here quickly so we can give him our full, undivided attention.

In the afternoon we’ll begin the open part of the workshop, and that is going to be dominated by panel discussions. And as you’ll see on the agenda, when we constructed the panels we sought the very best experts from around the world, and we tasked them with some very specific questions to address. The panels will have brief presentations by the panel members, and then there will be a discussion moderated by a Board member of what had just been discussed. Then the topic will be open to discussion and questions, any responses by DOE, questions from the Board members, staff, other panelists. We have a lot of experts whose expertise is overlapping, so we hope to hear questions from the other panelists on any given panel and also the audience as time permits.

So Panel 1 is going to discuss previous experience related to deep drilling in crystalline rocks. I’ll be moderating that panel.

Panel 2 is going to be moderated by my colleague, Allen Croff, Nuclear Engineer, and this is going to address the challenges related to emplacing waste in a borehole.

Board Member Jerry Frankel, a materials scientist, is going to moderate the last panel session of this afternoon; and that's going to be related to the technical issues related to the integrity of borehole seals.

And then at the end of the day we are also going to have a chance for public comments again. And if anyone is here that would like to make a comment, please sign up outside. There is a place to do that.

At the end of the day we are going to adjourn the meeting and move to a poster session just across the lobby area. There will be a variety of posters. This has turned out to be a very popular part of our Board meetings. It's a chance for Board members, the staff, and the audience to interact directly; and DOE will have a number of presentations covering aspects that weren't able to be covered in the morning. So we invite you all to join us for that. It's going to be in what's called the Embassy Room, which is, unbelievably, about a quarter of the size of this room. So it'll be a very cozy gathering.

Tomorrow morning we are going to hear from EPA. Dan Schultheisz of EPA is going to talk about their perspectives on the disposal of radioactive waste in boreholes.

Following that presentation, we're going to start again with panel discussions. Panel 4 is going to be examining hydrogeologic conditions at depth, chaired by Board hydrogeologist Jean Bahr. Panel 5 is going to be examining geochemical conditions at depth, chaired by Board member and geochemist Susan Brantley. And then Rod Ewing, our Chair, is going to be moderating Panel 6, which is on waste forms and canister materials. And after those panel discussions we'll have another period for public comment.

Then after lunch tomorrow Panel 7 will also be moderated by Rod. It is going to be discussing the efficacy of deep borehole disposal and risk analysis.

And then following all the panel discussions we are going to have a chance to reflect on what we've heard, what's been heard, and we are going to ask one panelist from each panel to report back on what they feel the key issues are related to their particular area of expertise.

And, finally, we are going to end up hearing from Andrew Griffith, the Associate Deputy Assistant Secretary--there are a lot of adjectives there--for Fuel Cycle Technologies. And he is going to be here to wrap things up for us. And we have asked Andy to reflect back on what he's heard and tell us how this potentially could impact the DOE program.

We're really looking forward to these next few days. I am just delighted to see such a growing audience. This is just great.

And we want to--I have one small request. I hate acronyms; I really do. So whenever possible, I hope that we've cleared the acronyms off the slides. If not, I apologize. And whenever possible, try to use the words you're saying. We've got a lot of non-U.S. people. I am an American citizen. I don't know many acronyms. So, anyway, let's try to do that.

I hope the workshop is going to be--you're going to find it useful. I hope you find it informative, and I hope you find it enjoyable, in fact.

So, with that, let's get started. And I want to say, I've got my iPhone timer set up, so we're going to try to stick strictly to schedule. Thanks a lot. So let's get started. I see we have Lynn's talk right here.

Again, I'd like to introduce Under Secretary Lynn Orr. Lynn has just recently been confirmed the last six months or so, a very drawn-out process. You know the U.S. Congress. Lynn is a petroleum engineer by training, but I would say he has dabbled in an awful lot of things, been involved in providing expert opinion through National Academy studies on all manners of issues related to energy and energy technology. He was the founding director of the center at

Stanford on climate and energy, an industrial affiliation program; former Dean of the School of Earth Sciences at Stanford, now the School of Earth, Energy, and Environmental Sciences. And I am very pleased to welcome Dr. Lynn Orr.

ORR: All right, well, good morning, everyone. It’s actually great to be here. There are some friends in the audience, so it’s nice to see them. And I have to say that, you know, my job has lots of speaking assignments, but every once in a while there is one where I actually know what we’re talking about. And so there’s enough earth science involved in what you’ll be discussing to make me wish I could spend a day here today and tomorrow with you. Alas, that’s not going to happen. But I am going to look forward to hearing from all of you.

I do want to thank the Board and Chairman Rod Ewing for sponsoring this workshop. It’s an important opportunity to delve deeply into questions that we really need to understand better as we go forward. And it has an important bearing on the Administration’s strategy for management and disposal of used nuclear fuel and high-level radioactive waste. So it really is a very important topic.

So my assignment this morning is to talk about the back end of the fuel cycle and what the Administration is doing to meet the challenge of managing and disposing of our country’s nuclear waste. And in particular, of course, this workshop is looking at the questions that will have to be understood for deep borehole disposal of some waste forms.

Now, I know you all know that nuclear power provides almost 20 percent of the electricity generated in the United States, and it's about 60 percent of the electricity that doesn't emit greenhouse gases, except for the concrete and steel that went into the power plants. So it's the largest single contributor to carbon-free electric power generation.

And as we think about the climate challenges that are ahead, that's an important component of the energy mix for the nation, so it will continue to play a very important role going forward as part of the President's Clean Power Plan. And it's hard to see how we would get to the President's goal of reducing carbon dioxide emissions by 32 percent below 2005 levels by 2030 if we don't have nuclear power available as a component of the energy mix.

So if we are going to make that happen, to continue to be able to use nuclear power in the way that we have in the past, we have to take a set of actions to ensure the continued availability of the nuclear-generated electricity in the United States, as well as the continued viability of the industry that supports all this. And then we obviously have, I think, an ethical obligation to future generations to develop a workable long-term solution for storage and disposal of spent nuclear fuel and the high-level radioactive waste. We’ve benefited from nuclear power as a reliable carbon-free source of electricity, and future generations deserve the same option as they make choices about their energy portfolio and management of the nuclear fuel cycle.

So the Administration’s approach, as I’m guessing everybody in this room knows, aligns with the key principles and the core recommendations of the Blue Ribbon Commission on America’s Nuclear Future. It’s not totally surprising since our Secretary of Energy played an important role in that Blue Ribbon panel and had some idea of what they recommended and why, and so the Administration is moving forward on many of the recommendations there. The Secretary, Secretary Moniz, in his remarks before the Bipartisan Policy Center in March of this year, talked about the path forward for defense waste and our parallel efforts for storage and disposal of commercial spent nuclear fuel.

So, beginning in this fiscal year, the Department of Energy will proceed with planning for two types of facilities. One is interim storage for commercial spent nuclear fuel and a separate repository for defense high-level radioactive waste, as authorized by President Obama.

Now, developing a separate repository for defense high-level radioactive waste represents what we think is our best opportunity to move forward with disposal of defense waste, some of which is already packaged and in a form that is ready for disposal.

In 1985 a decision was made to commingle high-level radioactive waste from defense activities and commercial spent nuclear fuel and high-level radioactive waste. Now, at the time it was assumed that production of new nuclear weapons would continue indefinitely. The 1985 decision also assumed more than one repository would be available for the combined inventory of defense and commercial wastes. The first was to be ready in 1998 and a second soon thereafter. I probably don’t have to say to this group that the path to a common repository has been somewhat more controversial, costly, and delayed than was anticipated in 1985.

So the circumstances since 1985, of course, have changed quite significantly. Among other important features, the Cold War is over, and the United States is no longer generating defense high-level radioactive waste associated with weapons production. That’s a good thing. As a result, a known quantity of defense high-level radioactive waste now exists in different forms that are largely defined; and that opens up possibilities to look at separate disposal pathways for these waste forms.

Some of this waste is less radioactive, thermally cooler, and easier to handle than commercial spent nuclear fuel, which, of course, spends a much longer being irradiated. So this can translate into simpler designs, greater flexibility in site selection, and possibly fewer licensing and transportation challenges for a separate defense repository. As a result, a separate defense repository could be made available earlier than a repository including commercial spent nuclear fuel.

Now, earlier availability of a defense repository could reduce the substantial costs to the Department of Energy of ongoing storage, treatment, and management of waste that's currently stored at our facilities. It could also help us meet the regulatory obligations, which would presumably help us avoid other costs triggered by missed milestones prescribed in various legal agreements with the states. It's a complex process, and we do have obligations there as well. Establishing a repository for defense high-level radioactive waste would represent significant progress toward completing the Department's clean-up mission and addressing the federal government's Cold War legacy, as well as meeting our obligation to manage the nation's nuclear waste.

So there are plenty of challenges there. But with the Administration's decision to move forward with planning for a separate defense repository, we have a significant change in our nuclear waste management policy; and we believe it's well justified in light of the changed circumstances, experience gained, and lessons learned over the last 30 years.

So our initiation of activities to do this, to develop a separate repository for defense high-level radioactive waste, does not mean that the Administration will put on hold our efforts to find a solution for commercial spent nuclear fuel. Indeed, we believe that pursuing a separate repository for defense high-level radioactive waste will facilitate parallel efforts to permanently dispose of commercial spent nuclear fuel.

The Administration remains committed to the framework laid out in the 2013 Strategy for Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste for moving toward a sustainable program for integrated waste management systems that will be supported by a consent-based approach to siting that will ensure public trust and confidence in decision-making throughout the process.

So the strategy for developing a comprehensive integrated waste management system reflects the judgment that a one-size-fits-all approach to managing the nuclear waste is not feasible and not likely to be successful. Our goal is to provide current and future decision makers with a range of options by restoring the multiple-path-multiple-facility approach that was embodied in the Nuclear Waste Policy Act before the 1987 amendments.

Now, we are envisioning a waste management system that may contain a pilot interim storage facility, a full-scale interim storage facility, and a geologic repository for commercial spent nuclear fuel, in addition to a separate defense repository and potentially deep borehole disposal of some smaller waste forms, assuming all the questions that you’re considering here are answered satisfactorily.

Going forward, our approach to siting these waste management facilities will be adaptable and flexible. Final configuration of the integrated system will be defined through a consent-based siting process that reflects input from potential host communities, federal, state, and local governments, and other affected stakeholders, as well as the interests of the American citizens, of course. We believe that this approach will put the U.S. government firmly on a path toward a successful process.

So what’s actually taking place? Full implementation of an integrated waste management system will require thoughtful legislation and consensus on several contentious issues and interests. So I don’t mean to minimize the difficulty of that. In the meantime, as all of that goes on, the Administration, through the Department of Energy’s Office of Nuclear Energy, is undertaking activities that are consistent with existing statutory authority, as well as congressional appropriations guidance to plan for the eventual transportation, storage, and disposal of spent nuclear fuel and high-level radioactive waste.

So our current activities are aligned with the Administration's strategy and have focused on several items. One is planning for a separate repository for the defense high-level radioactive waste; planning for an interim storage facility as an integrated component of a waste management system; preparing for large-scale transportation of spent nuclear fuel and high-level radioactive waste with an initial focus on removing spent nuclear fuel from shutdown reactor sites; research and development to further understand the long-term performance of disposal systems in three main geologic rock types--clay or shale, salt, and crystalline rock--as well as R&D in planning for a field test related to deep borehole disposal, the subject of this workshop; and, finally, stakeholder engagement in keeping with our focus on a consent-based approach to siting.

So in all of these activities we are committed to providing analysis and information to inform future decisions on an integrated waste management system.

So let me say a few words about this separate repository idea. Soon after the President's authorization in March 2015 to develop a separate repository for defense waste, the Department initiated technical activities related to the disposal of some Department of Energy-managed high-level radioactive waste. We are currently focused on activities related to characterization and inventory of defense high-level radioactive waste, preliminary design concepts for the inventory in various media, safety analyses, development of a phased approach to technical site evaluation, and planning for the processes related to eventual NRC licensing.

On the interim storage side, we are also engaged in planning activities for siting and development of one or more interim storage facilities. We are initially focused on developing a pilot interim storage facility that could accept spent nuclear fuel from shutdown reactors. Our activities include developing generic design alternatives that could be associated either with a pilot or larger interim storage facility.

We are currently investigating alternatives for a capability to inspect and remediate canisters, an R&D laboratory facility, a repackaging facility, and facilities for the maintenance of the transportation fleet and casks. We are also exploring the costs and potential benefits of implementing a standardized transportation, aging, and disposal approach that would streamline the process of accepting spent nuclear fuel from diverse sites.

And interim storage facility is an integral part of a flexible and resilient waste system, and the Department’s goal is to plan for an interim storage facility that is fully complementary to but not a substitute for a geologic repository. Establishing an interim storage facility as part of a comprehensive system will allow the federal government to begin meeting its obligation to accept spent nuclear fuel earlier, provide flexibility, and improve overall system reliability once a storage repository is in operation.

So what about transportation? No matter how we approach integrated waste management, a carefully planned and developed transportation capability will have to be created to support all components of that system. So in support of this capability, we are continuing to conduct planning activities for transportation of commercial spent nuclear fuel and defense high-level radioactive waste.

As part of this effort, we are initiating work to design and analyze and fabricate railcar equipment; developing a standardized methodology for determining possible transportation routes and the emergency response infrastructure related to those routes; working with interested tribes and states to create policies and procedures that would pertain to the routing of nuclear waste; and studying the unique requirements that apply to accepting and transporting spent nuclear fuel from shutdown reactor sites. No small task those.

Our efforts on transportation of spent nuclear fuel and high-level radioactive waste will support the interim storage idea as well as ultimate disposal of both defense high-level radioactive waste and commercial spent nuclear fuel.

On the R&D side, including, of course, deep borehole disposal, the Department is also performing research and development activities to further our understanding of long-term performance of disposal systems. This includes subsurface research related to generic repository designs and modeling that's being led by our Office of Used Nuclear Fuel Disposition in the three rock types I mentioned: salt, granite, and clay or shale. As part of this research, we are initiating a field test to evaluate the deep borehole concept, which, of course, as you know, is the primary focus of this workshop.

So there's multiple potential indications that the deep borehole disposal concept may provide a technically feasible and cost-effective alternative for safe disposal of some smaller Department of Energy-managed radioactive waste forms. To be clear, this option could only be feasible for a part of the waste inventory, and the mined geologic repository would still be required.

So within the FY16 funding request--which I note that the budget has not yet passed even though we have embarked on FY16, so this is in the request--for used nuclear fuel disposition R&D activities, we've asked for 26 million to continue to move forward with plans for a field test on deep borehole disposal. The currently planned test will look at the feasibility of the concept without use of any actual radioactive waste. So this is a small characterization borehole and a second larger research borehole, and the estimated project duration is approximately five years.

Now, the siting and characterization in drilling of a single borehole for disposal--for actual disposal--would likely take four to five years with an additional six months likely required for each additional disposal hole if it's determined that more than one is needed and the hole approach proceeds.

So if the concept proves feasible, further work will be required to estimate the scope and duration of a licensing procedure for a deep borehole disposal site. So the Nuclear Regulatory Commission's licensing process for geologic repositories does not currently explicitly address specific requirements for licensing deep boreholes for permanent disposal of radioactive waste.

So we will continue to refine the cost and schedule estimates for the deep borehole disposal as the work goes forward and data and information are obtained from the field test. Secretary Moniz and I both strongly support the idea of this research to evaluate whether the deep borehole concept has merit. The research from this effort will inform future decisions on whether deep borehole disposal is a feasible option. So this is consistent with our goal that I mentioned earlier to provide current and future decision makers with a range of options to manage the nation's nuclear waste.

Now, let me say just a word about one other thing that's going on here and into which this fits, and that's the Subsurface Technology and Engineering Crosscut program. One of the things that we've done in the last couple of years at DOE is to assemble teams to look at tough, interesting problems that cut across the expertise of the Agency.

And one of them is this so-called SubTER process. This is subsurface research that goes--really, it's done in multiple offices across DOE. And, of course, it applies because something like 80 percent of the current U.S. energy needs involve some sort of use of the subsurface. And it's likely that if we do geologic storage of CO2, play a role there, there is the geothermal side. There is a huge geothermal resource in the upper part of the earth's crust if we had the ability to make the fluids go where we want them to go. And, believe me, I've spent a career trying to understand how to do that, and I know how hard the problem is.

It's also true that carefully selected, characterized, engineered, and operated subsurface sites have the potential to provide storage capacity for large quantities of CO_2 and opportunities for responsible management and disposal of hazardous materials and other waste streams. So that aspect of this needs to be thought about as well. And then, of course, the broad topic of discovering and effectively harnessing subsurface resources, while mitigating the impacts of their development, those are essential components of the nation's energy strategy going forward.

So let me conclude by talking a little bit about stakeholder engagement. As we continue with each of these activities, the Department is committed to pursuing a consent-based siting process for both storage and disposal facilities that will ensure public trust and confidence in the decision-making throughout the process.

The Administration's strategy endorses the principle that prospective host jurisdictions must be recognized as partners; that overall public trust and confidence is a prerequisite to success; and, accordingly, our efforts to achieve stakeholder engagement will continue to inform the Department's activities as we move forward in developing an effective waste management system.

So I'll stop. As you all know the risk when you have a recovering academic standing up here, I mean, you wind them up, you get the 50 minutes; right? But I'm trying to restrain that, so I'll stop and say thank you all very much for participating. The expertise that's gathered in this room and that will be shared over the next two days is an absolutely essential component of thinking hard about the questions that we have to answer going forward if deep borehole storage is to play a role in what we do.

So thank you for participating here, and I'll be happy to try to answer a question or two provided they're not too hard. Thanks.

ZOBACK: Thank you very much, Lynn. And you may realize it's also risky when you finish about 15 minutes early.

We have plenty of time for questions, so I want to first open the questions to the Board members. Do you have-- anyone on the Board have questions? Rod. And please identify yourself.

EWING: Rod Ewing, Board. So, Lynn, thank you very much. That was a wonderful summary of the Administration's plans.

The separation of defense from commercial waste into two separate repositories in a certain sense is consistent with the Nuclear Waste Policy Act of 1982 where we were to have two repositories, one following the other. Thinking about the Waste Policy Act, has there been any thought given to geographic equity? I mean, once you have two repositories, one could imagine that one would be in the West and one in the East, maybe located close to the center of gravity for the different types of waste.

ORR: So that could be one of the things that you would think about in that siting. No sort of pre-decision attempt at that balancing has taken place that I know of. I mean, you can imagine--I know you could write down the list of things that you would want to think about for a particular siting location. And, you know, you could imagine that minimizing transportation distances would be one element of that. But as far as I know, there is no attempt ahead of time to say we should presuppose the answer to that question.

ZOBACK: Paul.

TURINSKY: Paul Turinsky. Two questions, both fairly short answers. For the interim storage are you considering both commercial and DOE-owned spent nuclear fuel?

ORR: As I understand it, yeah, those are both possibilities. What's being considered for the borehole stuff is really, you know, the small waste form kinds of things. So that leaves kind of everything else to be considered. My guess is that there would be presumably separate interim storage for the defense waste and the civilian spent nuclear fuel, but I'm not absolutely sure that's been firmly decided yet. But we're really not thinking at this point about spent nuclear fuel going in the deep borehole kind of setting.

TURINSKY: Yeah, yeah, it was more the interim storage, whether that would be commingled still.

ORR: Well, I think that remains to be seen, but the uncommingling, if that's a word--I'm from Texas, so we, of course, don't bother with the actual English construction. So I think if the idea is to be able to use the perhaps simpler process for the defense waste and there is the Naval reactor fuel and--we'll have to see how that plays out. I don't think it's decided.

TURINSKY: And my second question is--and I know this is way out--you must have some idea of a schedule of when a deep borehole would become available for disposition versus a defense-only repository. What is that schedule?

ORR: You know, I'd like to ask you to defer that question to the folks from the program who really are looking at the details. I think both of them are quite a ways out.

ZOBACK: Jerry.

FRANKEL: Jerry Frankel, Board. So it's particularly heartening to hear the Department of Energy embrace the Blue Ribbon Commission recommendations on consent-based siting. Can you elaborate a little bit on what the plans are for the Department in terms of actually what it means? What does consent-based siting mean to the Department at this point?

ORR: So it’s a good question. It’s actually the kind of thing that we would try to lay out in something about what we would expect from that process this fiscal year. We can do sort of preliminary planning with our existing authority; but for budget to actually do this and staff it in the way that it would need to be done, we need congressional action for that.

But our intent would be to propose a process, invite lots of public comment, and really engage in a stakeholder process that would actually define what would we mean by a consent-based siting and how would that have to go forward. So I don’t want to try to constrain that any more than that at this stage of the game. But it’s an essential first step going forward.

ZOBACK: Sue.

BRANTLEY: Sue Brantley, Board. I just wanted to ask a question. It’s really a clarification. I think you said that the Deep Borehole Field Test project would be a five-year project, but then I think you next said that in the future it would take four to five years for actual disposal.

ORR: Yeah.

BRANTLEY: Can you just clarify that? That seems very rosy if I got it correct--

ORR: That’s--yeah. But, you know, that kind of assumes that everything goes forward as we anticipate at that stage, so obviously you have to refine that as you go forward. But that's kind of overall. If you're looking at the overall time scale, that's a decade right there, assuming that there is no toing and froing on that. So it's a long process.

ZOBACK: Any other questions from the Board?

I'm going to ask one, and I want to follow--this is Mary Lou Zoback, Board--follow up on Jerry's question about the consent-based siting. One of the things the Board's had the privilege of doing the past few years is visiting other countries where they are moving forward with geologic repositories and specifically examining the consent-based aspect of that. And I certainly hope that DOE will consider actively engaging, maybe on an advisory panel, members from these other--engage individuals from these other countries, because there's an awful lot to learn, I think most importantly, from their mistakes.

And I will point out that the Board is releasing a report now shortly that one of our staff members, Dan Metlay, has done, a monumental report that really summarizes the experience and the misadventures country by country in this process. But there is a wealth of mistakes to be made, and many of them have been made already, and it would be really good to try to avoid them.

ORR: Well, that's a good idea. We should try to not be overly inventive in new mistakes, even as well--yeah, of course it makes sense to take advantage of the experience of other places. I think there's absolutely no question of that. And we appreciate the effort that goes into collecting as much of that information as possible.

ZOBACK: Great. Thanks.

Staff, questions. Seeing none, any of our panelists, any questions for Lynn? We have five more minutes.

Yes. Can you please come to the mic and identify yourself?

ION: Hi, good morning. My name is Cristian Ion, and I work for the Government Accountability Office. So I have two questions for you. One of them--

ZOBACK: Excuse me, I didn't hear which--

ION: Government Accountability Office.

ZOBACK: Oh, GAO. Okay.

ION: Yes, GAO.

ZOBACK: U.S. government.

ION: U.S. government. So now that you have this two-repository approach, does that mean that the commingled one-repository option is off the table?

ORR: Well, I don't know that it necessarily precludes some commingling going forward, but we think it makes sense to separate those streams, largely because we have better definition of the defense waste now that we're not producing any more. And it's a smaller quantity, so it gives us an opportunity to test ideas, test the consent-based siting process, and work our way through to provide some experience that would then be useful in the broader siting questions with regard to both an interim storage facility and a mined repository for the commercial spent nuclear fuel.

So the intent for now, I think, is to keep those separate. But we've already seen the things evolve with time, so I wouldn't absolutely guarantee that there couldn't be some version of that.

ION: Right. So the other question is, with the staff levels at DOE being somewhat low, I mean, they were kind of low working on one repository. How is it possible to work on two repositories with lower staff at the same time?

ORR: Well, we would need some congressional budget support to be able to do this in the way that it needs to be done. So--

ION: Okay, thank you.

ORR: --we have proposed that for FY16 for a start, and we have more in the FY17 budget that's wending its way through the system.

ZOBACK: Great. Thank you.

Any other questions? Okay. Well, again, let's give Lynn a big round of applause to thank him.

You've developed Washington-speak very quickly.

I'm impressed.

ORR: --productive.

ZOBACK: Good training; right?

Okay. Now we're going to begin to hear this--now begin our presentations from DOE specifically on their plans. And to start that, we're going to hear from Tim Gunter from the DOE's Office of Nuclear Energy, where he's the Program Manager for Used Nuclear Fuel Disposition Research and Development. And so he will speak directly to the planned research program.

And I just want to point out, any of you that might have come in late, I believe there are copies of all the PowerPoint presentations outside on the table; so please avail yourself of those.

GUNTER: Good morning. I'm Tim Gunter. I'm the Program Manager for Disposal R&D in the Office of Used Fuel Disposition, and it's my pleasure to be here with you today and speak to you on the deep borehole disposal R&D program, including our fuel tests that we have planned coming up.

A bit of an outline of what I'm going to cover; a little bit about the deep borehole disposal concept. I know that most of you in this room are very familiar with the concept; but for the sake of those that may not be, I'm going to just do a little quick high-level summary of the concept, talk about our reference design that we started that we put together to do a lot of our cost estimates and initial planning, and then some details on the field test itself that we kicked off this year.

So in used fuel and high-level waste disposal, our office is focused on really just a number of key issues. We want to provide a sound technical basis for multiple viable disposal options in the U.S. So the multiple viable disposal options is kind of where deep borehole comes in. I have some representations here, figures on the screen of different geologic media, the salt and clay and granite, and then also the deep borehole disposal concept.

Some of the other areas we want to do is increase confidence in the robustness of the generic disposal concepts. So a lot of this work we're doing is on the modeling, performance assessment, how the radionuclides would behave down deep in the earth, how they move through the media.

And then, finally, develop the science and engineering tools needed to support the concept implementation. That would be the science, basically what I just said, how things behave; but also that feeds into your performance assessment. And also the engineering tools would lead you into the hazards analysis and the safety assessments.

So, as most of you know, deep borehole disposal has been a topic that’s been around for a long time. It’s certainly not anything new. It goes back even to the 1950s, and it’s been looked at periodically over the past years on and off. Recently Sandia began looking at it in more detail, because, as time has gone by, the drilling technology has improved. Some of the challenges, particularly in the early days, was the drilling technology may not have been quite there to do what we wanted to do. Also, the cost of the drilling technology was quite high to drill that deep and that large a hole down in the crystalline basement.

But, in general, the concept consists of drilling a borehole--or it could be an array of boreholes, depending on how much waste you want to dispose of--down into the crystalline basement rock to about 5,000 meters. And then you could place your waste packages in the lower 2,000 meters of the borehole. And then the upper borehole would be sealed with compacted bentonite clay, cement plugs or cemented backfill, or a combination of those or other seals.

This is just a representation of kind of a schematic to put things in perspective. You can see the borehole down the 5,000 meters, the lower 2,000-meter disposal zone, and then the upper 3,000 meters would be the seal zone and how that compares with mined geologic repositories as Onkalo and WIPP at 500 meters and 650 meters in depth. And also we just threw in the Burj Khalifa Tower in Dubai at 830 meters.

But one of the keys is that at that depth you're well below any fresh groundwater resources. The communication between that depth and surface, we think, is very low; and that's one of the reasons why we want to set out to do the field test is to show that.

And this is just an example of the sealing system. Currently our sealing system is not yet completely designed, but it shows kind of a concept of the different types of plugs and materials, the cement and the bentonite. And we're going to talk about a lot of the details in the following presentations, so I'm going to focus more on the programmatic issues and not a lot of--not go into a lot of details on the technical issues.

So why did we start thinking about borehole disposal again? Well, there were several factors that entered into this. One is, it could provide a cost-effective alternative for disposal of some smaller DOE-managed waste forms. As was mentioned earlier, this is only a small subset of our total waste inventory. It would be specifically targeted towards those things that would have the right dimensions to fit into the borehole.

But some other things that led us to consider this is, crystalline basement rocks are common throughout the United States in many areas. So there's a lot of areas that could potentially host a deep borehole disposal site. As I mentioned, the existing drilling technology has improved greatly over the last few years. It's gotten more economical. So we think that it should permit dependable construction at an acceptable cost.

And then a couple of other items. Low permeability down at those depths and long residence time of high-salinity groundwater in the deep crystalline basement suggests very limited interaction with the shallow fresh groundwater. You've got reducing conditions at depth that would limit the solubility, also enhance the sorption of many of the radionuclides and slow down your transport times; and then, finally density stratification of saline groundwater, which underlies the fresh groundwater, and that would oppose any induced groundwater convection.

So all those would really lead to reducing travel time and isolating the waste from the biosphere, which is kind of summed up in the first bullet there: Why deep borehole disposal? Well, you have the potential for robust isolation. It gives DOE flexibility to consider options for disposal of smaller waste forms. Potentially earlier disposal of some wastes might be possible then in a mined geologic repository. We think that for a variety of reasons we may be able to implement a deep borehole disposal system quicker and then possible reduced costs associated with projected treatment of some wastes. If the isolation is so robust, you may not have to have as high-integrity waste canisters, exotic materials, and that type of thing.

So this slide kind of shows some undesirable features and then the depth, the crystalline basement chart that I mentioned. I'll start with this. The tan area is all crystalline rock less than 2,000 meters to the surface. The red is granite outcroppings. And then there are some areas that we don't have enough data for. Either it's very complex data--so this is not really showing the depth--but like in the mountainous West, Appalachian Mountains, you have the granite outcrops but not necessarily a good picture of the depth. But even without that, you've got large areas in the U.S. that could be potentially suitable for borehole disposal.

I think I've kind of covered some of these as I went through, but things that we would look to avoid in a disposal site we've also used as siting guidelines for our field test. So we wanted to get something that was representative of what could ultimately be an actual disposal site. So we're trying to avoid things listed here: economic natural resources, upward hydraulic gradients, high pressure/ high heat flow, and then hydraulic connections to the subsurface.

And these are just a few slides that kind of illustrate some of those that I've mentioned: the heat flow, you can see, kind of obvious in the West, the high heat flows; oil and gas drillings throughout the U.S. Some of those areas we would want to avoid. And then recent volcanoes and faulting. And this is going to be going into more detail also later on.

So what kind of waste would we consider to dispose of in a deep borehole? Well, as I mentioned, it's DOE-managed waste. It's going to be smaller waste, which could be spent nuclear fuel or high-level radioactive waste or other specialized waste types.

There was a Sandia report in 2014--we kind of refer to it as shorthand—as the Disposal Options Report. But it went through and identified a number of things that could potentially be candidates for deep borehole disposal. I have a few listed here.

One of the ones I know you've heard about--it's kind of the one we keep talking about most--is the cesium and strontium capsules at Hanford. There's 1,936 of them stored in wet storage at Hanford. It's approximately one-third of the total radioactive inventory at Hanford contained in those 1,936 capsules. They're relatively small, so they would fit easily within a borehole, either singularly on top of each other, or they could be packaged in multiples of three, bundled in three.

Some of the other types of waste: untreated calcine high-level waste at Idaho National Lab. It’s another potential one. There are some salt wastes from electrometallurgical treatment of sodium-bonded fuels. They could be packaged in small canisters as they’re produced. And then finally some DOE-managed spent fuel stored in pools at Idaho and Savannah River site.

So our reference design I mentioned is the next section in my talk. This goes back a few years. I’m going to try to set the stage for how we got started on this, and then the following presentations will take you from our reference design to where we are today, because this is something that continues to evolve.

When we first started looking at this, we had to have designs in order to do initial cost estimates and planning and some analysis. So Arnold et al. (2011) updated some of the past work. What they were looking for was a simple and achievable, internally consistent system for waste disposal that would meet all the regulatory requirements for operational and public safety.

It updated and refined the conceptual design presented in Brady et al. (2009), and it was primarily, like I said, to consider preliminary design alternatives; it provided a reference for performance assessment and risk analysis; also provided a reference design for more accurate cost estimates. So that was one of the things we used to determine whether it was even feasible to move forward with additional work. And I just note that there's numerous viable design alternatives available out there, and many of them could be used as a reference design to do cost analysis and planning, but this is what we chose.

This is just a schematic of a typical borehole that could be used that shows the stepdown from starting out at 36-inch diameter down to 17-inch diameter at depth. It would be cased or lined to ensure unrestricted emplacement of the waste canisters, and also the casing would facilitate potential removal if you had to pull the canisters out before you set the final seals. And then the perforated liner at the bottom would be left in place in the disposal zone, but it would be removed in the seal zone along with most of the intermediate casing so that you could set a good seal.

The reference design for the waste canister is fairly simple. This is just a carbon steel tubing, threaded at each end, and a threaded connection that would be screwed together into strings of the canisters; and they would be designed to withstand the hydrostatic pressure and mechanical load of the overlying canisters, so it would withstand the pressure at depth. And then also you have about a string of 40 canisters, so it has to be able to withstand the weight of the canisters on top of it. And the canisters, like I said, this design is carbon steel, but it would retain their integrity until well after the borehole is loaded and sealed.

Another thing that was done years ago back in the ‘80s is, there was another test at the Nevada test site, now referred to as the Nevada Nuclear Security Site. They actually loaded spent fuel assemblies. They transported them to the site, lowered them down a 420-meter borehole, using a surface vehicle that upended the shielded casks. They had shield doors top and bottom. It was lowered into an underground granite test facility and left for three years, and then later on it was removed to the surface.

And the key point here, I think, is this is representative of some of the surface handling that would be required. Certainly this would not be necessarily a design we use, but it shows that even as far back as 1986 that they could lower very highly-radioactive spent fuel down a borehole and bring it back out. Granted, this 420 meters is not 5 kilometers, but the surface handling facility could be similar.

This is just a schematic of sort of a 1980 design. Again, this is the reference design that we used for our initial studies, the rig that would load the waste canisters, surface handling, rotate the shipping casks. It would move the casks by a short rail system over the borehole, attach the canister to the canister string, and lower the string into the borehole.

As I mentioned, the reference design--a string of about 40 canisters. You would then lower those down. There would be a bridge plug set on top of that so that you don't have a complete length of waste in one, and then you would load in another string of 40. And you keep doing that until you fill up the lower 2 kilometers.

Moving then into the Deep Borehole Field Test, so why are we doing it is because additional research and development is necessary in several important areas to further consider the deep borehole disposal option. Things we would need to look at is: evaluate the drilling technology and the borehole construction to 5 kilometers to make sure that we can actually drill a hole that size at that depth; maintain the hole open while we lower the canisters in; and also that it's cost effective.

We want to verify the deep geological, geochemical, and hydrological conditions at a representative location. So as part of our field test, we would have a series of downhole tests that would be focused on confirming those conditions, that we understand them, and they are what we think they are and that they would meet our expectations in terms of a robust isolation system.

The third bullet, we want to evaluate the canisters, the dummy waste package, and the seals material at a representative temperature, at representative pressures and salinity, and under geochemical conditions at depth.

And then, finally, we want to develop and test the engineering methods for waste canister loading, all of the surface handling equipment. We would mock up some of the shielding that would be necessary for a real waste disposal operation and then actually demonstrate that we can emplace and remove the canisters from those depths.

So we're doing that with our borehole field test. And, as I said, we got started really this year in Fiscal 15. The major steps we want to go through are, we want to obtain a suitable site that's representative of conditions of an actual disposal site that would be desired. We are going to design, drill, and construct the Characterization Borehole. So as we envision this test, there's actually two boreholes. We call the first one the Characterization Borehole. It's an eight-inch-diameter-at-depth borehole, the 5,000 meters. And we're going to do all our scientific tests--or almost all of our scientific tests--in that borehole.

When we started out with our plans, we initially had just planned on drilling the large, what we call Field Test Borehole, the 17-inch bottom hole diameter. And as we were looking at it we realized that we could actually drill two boreholes, one small and one large, for not a huge amount of more money, because you don't tie up the very large drill rig that's necessary to drill the large borehole. And then you do a lot of your scientific testing in the small borehole that's a standard size, so you've got a lot of your tools that are available, and you don't have to go out and fabricate specific tooling and instruments.

So when we have the Characterization Borehole, we would then collect data and characterize the crystalline basement conditions and confirm the hydrologic conditions at depth. Assuming that goes well, we would then construct a Field Test Borehole, which is, as I mentioned, a 17-inch bottom-hole diameter. We would design and develop the surface handling and emplacement equipment systems and then the operational methods and procedures that would be necessary for the safe waste package handling and then demonstrate--as I mentioned, you could actually lower those dummy waste packages and canisters down 5,000 meters into the borehole, take them back out.

So this is, I guess, kind of a summary of why are we doing a deep borehole field test. So it allows further evaluation of the feasibility of the deep borehole disposal concept. And then, in addition, it's consistent with our UFD Mission of providing multiple viable options for the future decision makers.

ZOBACK: UFD?

GUNTER: UFD, Used Fuel Disposition.

ZOBACK: Thank you.

GUNTER: So we're in the Office of Used Nuclear Fuel Disposition. We sometimes refer to Used Fuel Disposition Campaign, which includes not only the DOE office, but also all our laboratory support.

The reasons we're doing it, it implements a recommended near-term action of the Blue Ribbon Commission on America's Nuclear Future; it is consistent with the Administration's Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste that Dr. Orr discussed before me; and then, finally, we think there is economic and scientific benefits that are of interest to local, state, and regional stakeholders. Many have expressed interest in potentially conducting research if they had a borehole at that depth available to them or potentially even taking it over when DOE has completed what we need to do.

So, again, for the people that may not be as familiar with DOE as many of you are, I threw in an organizational chart for the Office of Nuclear Energy, starting with the Assistant Secretary of Nuclear Energy. And I wanted to mention that the Office of Nuclear Energy, it covers a broad range of nuclear-related topics, anywhere from new sources of uranium to advanced fuels, new reactor designs, of course the waste management activities, and then even power supplies for space exploration.

But our office, the Office of Used Nuclear Fuel Disposition Research and Development, is shown here in yellow. We're under the Deputy Assistant Secretary for Fuel Cycle Technologies.

And one more chart, but this is specific to the Deep Borehole Field Test project organization. And it starts--or I started anyway--with our office, the Used Nuclear Fuel Disposition. Bill Boyle is our Office Director, and then there's me, myself. We're both DOE federal employees. Peter Swift, who is here today, he is referred to as the National Technical Director. He's a Sandia employee, but he manages all our laboratory support for the campaign across the board. And then the Field Test Project Lead, we're using Sandia National Lab as kind of our lead lab for this project. Bob McKinnon, he's not listed, but he's the lead at that level.

And then we have many supporting national labs and university partners that are involved in working on this.

And then I've got kind of the major components of the field test, including DOE-Idaho, which are providing our procurement support for the contracts that we need. So I'll just go down that first.

The contract that we are putting in place--and I'll talk a little bit more about them on the next slide--but site management and drilling integration services for the

Characterization Borehole, so we’re going out with Procurements to get not only a site to locate the borehole work, but also a site management company and drilling services. And we also have a contract for engineering services, which are mostly related to the handling equipment, the radiological aspects of the mockup shielding, and that actually has been put in place. That’s AREVA Federal Services. They are supporting us through a task order for a contract we have in place with them. And then the next step would be the drilling integration services for the Field Test Borehole, which would follow.

And then under the laboratory support side, some of the key areas we kind of touched on, site evaluation and data integration; so, in other words, what kind of site are you looking for, some of the guidelines I mentioned that would be desirable or not desirable.

Characterization Borehole design and testing, so Sandia and the other labs are actually putting together an initial borehole design, and then that would be coordinated with whoever ultimately is our drilling integration services and our drilling contractor. They are providing project management services.

And then the bottom two boxes are the test package and emplacement system engineer, so initial designs of the waste packages and emplacement systems, which they’re going to go into more detail later on, and then the demonstration. And this is, again, where AREVA comes in. AREVA will be involved in reviewing and finalizing those designs that we come up with.

So here’s just another view of the participants. As I mentioned, we have six national laboratories involved, Sandia serving as the lead lab, Los Alamos, Pacific Northwest, Berkeley, Idaho, Oak Ridge, and then AREVA Federal Services as our engineering services contractor. And then yet to be determined is our site services and drilling contractor. And then there is also a number of other individual participants, university representatives, or other consultants that are involved.

And here are some examples of the others involved. I’m not going to go through every one of them. I think this is also another slide that’s going to be discussed later on. But we have international participation one way or the other. KAERI, Korean Atomic Energy Research Institute, they’re doing some borehole tracer test in granite. While it’s not specific to deep borehole disposal, it’s borehole characterization in granite, so it might have some interest to us. University of Sheffield was mentioned. They’re providing R&D support, particularly in the seal design and performance criteria.

We have what we call the Nuclear Energy University

Program where we provide grants to different universities to do research topics, one of which is to Massachusetts Institute of Technology, and they're doing some work on optimization of deep borehole system.

Another program we have, Small Business Innovative Research, kind of similar to the University Program, this is money that's provided to small businesses. They propose topics to do research on, and here is a number of them that are related to deep borehole disposal such as--the top two are sealing systems, rock melt borehole sealing, thermally formed plugs for deep borehole waste disposal, a couple of cement technologies. And then, as Dr. Orr mentioned earlier, our subsurface technology and engineering RD&D--SubTER as it's referred to--they're doing a number of things, one of which is also fit-for-purpose cement for rock-cement interfaces.

So the major components of the Deep Borehole Field Test, I kind of covered that, because all these are kind of wrapped up into a science thrust and an engineering thrust. And, as I mentioned, these would kind of feed into your safety assessment and your performance assessment. So a lot of the science work would go into your performance assessment; a lot of the engineering work would go into your safety assessment, hazard analysis, that type of thing.

This was our original concept of a schedule going out five years, selecting a site, initiating a selection process, procure the engineering and science needs, construct the borehole and do the emplacement, and then finalize a demonstration. I have a more detailed schedule coming up. As I mentioned, this is the projected five years, approximately $80 million over the five-year lifetime.

I think we’ve covered that.

So a little more detail of our schedule. You can see we have started really back in ’15, early ’15, and it goes out through September of ’19.

We have issued a draft request for a proposal. We awarded the engineering service task order, which is AREVA, issued a request for a proposal for the Characterization Borehole. And then the proposals were due September 23rd, due and received September 23rd. I can’t really talk a lot about them, because it’s an active procurement that’s ongoing. But it leads us to--our target date on the schedule is February 5th. We’re hoping to beat that if the procurement goes well. Always a lot of uncertainties in procurements. And then in red here I have our key target of--we want to start drilling the Characterization Borehole by September 1, 2016.

So I’m going to talk just a little bit about how we’re working the process for procuring a site. I mentioned that we issued a request for information, so we solicited input from states and local communities, individuals, private groups, academia, pretty much anybody out there that had an interest in either participating in the borehole field test or potentially providing a site that was suitable.

So we posted that to the Federal Business Opportunities website, which is the website the U.S. government uses to announce our funding opportunities. And that was posted back in October of 2014. We gave a 45-day response period and received a number of responses on December 8th. And in general what that indicated was, there was significant interest out there for participating and potentially hosting a field site.

So we followed that in April of this year with a Sources Sought and a draft Request for Proposal. So the Sources Sought basically went out and said, “Is there anybody out there that can do this type of work?” in other words, drill a 17-inch hole at 5,000 meters in crystalline base. And then at the same time or right after it, we issued the actual draft RFP for comment, so we wanted to get the people that were interested and give them a chance to see the RFP that we were going to ultimately issue and get their feedback on, you know, does this make sense for the things we overlooked? Are we asking for something that is not feasible?

So we got a number of responses to that in May of this year. So we took the responses and feedback that we got from the draft RFP. Where appropriate, we rolled those into the final RFP, issued that in July of this year, and, as I said, proposals were due September 23rd and also received. So that procurement process is ongoing right now.

So I think this is the last slide. It’s kind of a wrap-up conclusions. So there’s multiple factors that have indicated that a deep borehole disposal concept could provide an alternative to mined geologic repositories and provide a safe location for disposal of radioactive wastes, and there’s a number of widely available locations that could be potentially suitable, based on the favorable geologic and hydrological conditions.

Implementing deep borehole disposal with a simple reference design could be feasible, could be cost effective, and it would have sufficient capacity for accommodating smaller DOE waste forms.

We think that a deep borehole field test, as I have described and laid out here, is the next logical step in evaluating this waste disposal option and that economic and scientific benefits of this field test could be valuable for local, state, and regional stakeholders.

And then, in conclusion, DOE is moving forward with the Deep Borehole Field Test.

And that is the end of my presentation. I’d be happy to answer questions.

ZOBACK: Thank you, Tim. That was a very nice summary.

We have lots of time for questions. So, again, I'm going to begin with the Board, and everybody remember to identify themselves. Rod.

EWING: Rod Ewing, Board. What I'd like to do is go back to the first question on our list, which is the discussion of the rationale for deep borehole disposal. And the way I'd frame the question is that, of course, as you've described, the emphasis is on smaller DOE waste forms, because that's what will go down the hole.

But I'd point out that all of the smaller DOE waste forms would also fit into a mined geologic repository. And, in particular, thinking about the strontium capsules or cesium and strontium capsules, it wasn't many years ago that the proposed disposal pathway for these capsules was near-surface storage and decay. And that was attractive, because the half-life of the cesium-137/strontium-90 is about 30 years. And at that time, of course, people asked penetrating questions about, is near-surface disposal safe, and the analysis at least supported that--seemed to support that strategy.

So given the short half-lives, the fact that surface disposal or surface storage and decay seemed to work a few years ago, what's the rationale for this effort, which really will take a lot of time and funds?

GUNTER: Okay, well, the deep borehole disposal option is not limited to cesium and strontium; so there's other things that could be viable to be disposed of in that manner. How--well, let me say that the cesium and strontium capsules are owned by Environmental Management, which is another part of DOE. I really want to defer to them as to how they want to dispose, whether they want to dispose of it near-surface or let it decay away in near-surface storage. But we're just trying to provide an option to them if they want to get rid of it, because there are some--

EWING: But is this an option that's relevant to radionuclides that have very short half-lives?

GUNTER: Well, not all of it has short half-lives.

EWING: I know. There's cesium-135.

GUNTER: Right.

EWING: That's why I focused on the strontium-90.

GUNTER: Well, that would be really a policy decision as to whether they want to use a deep borehole disposal for the cesium and strontium capsules.

EWING: Wouldn't that actually be as well a technical decision?

GUNTER: Yeah, and that's what we're focused on. We're trying to provide a technical disposal option, and as part of that we would be developing some cost estimates as we move forward with the design. And that could be presented to them, and they could look at the options available and the cost of disposing it in a borehole or letting it decay on surface.

EWING: But just to be clear, are we in agreement that all of these waste forms, small or large, could be disposed of in a geologically mined repository?

GUNTER: Yeah, we are in agreement with that, if we had one.

EWING: Yeah, right. That's an important qualifier.

And the last point or question I want to raise is, you listed a number of criteria that recommend deep borehole disposal, reducing conditions, old groundwaters, areas where there are no natural resources. Would these criteria be usefully applied to geologic repositories as we search for defense and commercial repositories?

GUNTER: I would say in general, yes.

EWING: Okay. So something like WIPP with natural resources is less attractive according to your criteria.

GUNTER: Well, the one with natural resources, it kind of depends on how close they are, and you have to do--in other words, they're not an absolute. You have to do an assessment of what's in the area and whether it's a potential to--

EWING: Right, right. Okay, thank you.

ZOBACK: Jean.

BAHR: Jean Bahr, Board. Looking at your timeline, the decision on whether to go forward with the Field Test Borehole, the larger diameter one, is going to happen during the process of drilling the Characterization Borehole. And, in fact, my guess is that the tests in the Characterization Borehole probably won't be completed by the time you make that decision whether or not to go forward, award the contract for the larger diameter borehole.

Do you think you'll know enough at the time of awarding that contract to confirm that you have a suitable site? And if you don't have a suitable site, what happens at that point?

GUNTER: Right. So yes is the short answer. I think we'll know enough. We will have drilled roughly halfway through the crystalline basement rock by that time. And the reason we are doing it this way is because of the long lead time for procurement. So we have to get that process started; otherwise, you're going to have a long lag time before you could start drilling the second borehole. I think--

BAHR: But what happens if you run into a highly productive fracture zone in the bottom half of the disposal interval?

GUNTER: Well, you can always not drill the Field Test

Borehole if you made that decision, because you don’t really start drilling--let’s see, you start drilling the Field Test Borehole July 7th, ’17; whereas, you complete the Characterization Borehole February ’17. So you have the procurement in process, but that doesn’t necessarily mean that you would drill a hole if you found something that couldn’t be overcome.

BAHR: Thank you.

ZOBACK: Paul.

TURINSKY: Paul Turinsky, Board. I think this whole program is based on the assumption of homogeneity, that if you go into hard rock, it doesn’t matter where you are in the United States. You’re going to find more or less the same thing. Is there actually scientific data that supports what I think is a very basic assumption?

GUNTER: There is scientific data in some areas where they’ve done other drillings and corings. So they know--you know, they have a better idea of what the rock is like down there.

TURINSKY: And what are they finding? Are they finding that it’s extremely similar in all those characteristics?

GUNTER: I can’t really say whether it’s similar all across the U.S., but what I can say is, based on what we’re seeing, we think that there is enough data there to indicate that this is a potentially viable option. And what we’re trying to do is confirm that with our field test.

TURINSKY: Another question. This procurement, what exactly is going to be included in it, and has the criteria already been established, which I assume it has, for the selection? In particular, is the site part of that procurement proposal?

GUNTER: The site is part of it. And the RFP list wasn't being requested, and it's asking for a company or partnership to come forward and provide a site that would be suitable to drill and conduct the Deep Borehole Field Test. And we provided a number of what we call guidelines. It's similar to the topics that we've talked about on what would be desirable and what would not be desirable. Those are listed in the RFP.

In addition to the site, as far as the RFP, we're asking for a site management company, so someone that would manage the site, manage the drilling, manage day-to-day operations at the site.

And then the third major component of the RFP is the actual driller, either a partner with a drilling company or the ability to get access to a driller that would be willing to drill that to those specifications.

TURINSKY: Okay. So actually embedded in that is the consent-based process.

GUNTER: I would say it's not a true consent-based process in terms of what we're talking about, consent-based siting for an actual waste repository. But there's elements of consent-based in there, because it's a volunteer-type arrangement where it's an open procurement to anyone that's willing to come forward.

TURINSKY: Okay. And if I understand it, so the confidence of whoever is volunteering, they've been assured this is not going to be where waste is actually emplaced; that's a separate process.

GUNTER: Right. And I think we made that statement in the RFP that this test is not going to use any radioactive materials or waste. And if we did go ahead with a disposal site, that would be then part of the consent-based process.

ZOBACK: Efi.

FOUFOULA: Efi Foufoula, Board. So the deep borehole disposal program is moving very fast, in my opinion, compared to the nuclear waste disposal time scale we're used to from the past. In the research program, I think it lacks the urgency in addressing basic research questions; that is, we have seen the time schedule here of drilling and so forth, but the basic research questions include the homogeneity of the deep environment and other things that have to be scheduled pretty quickly.

So is there a research priorities program that you have developed already that goes beyond the time schedule that we have seen here?

GUNTER: Yes. We’ve laid out a draft testing plan, and the folks that follow me in the presentation are going to go into a lot more details on that. But they have their testing laid out, at least in a draft stage.

And I think I mentioned it earlier, but we would then need to finalize that with whoever ultimately becomes the site manager and drilling company; in other words, finalize--we have a drilling and test plan, which lays out all the testing we would do. So we want to work that with whoever is going to actually do the drilling and see what kind of, if any, comments they have or recommendations.

ZOBACK: Lee.

PEDDICORD: Lee Peddicord from the Board. Referring back to Slide 16 and just trying to work some of the numbers you had in there, is it correct that, again, going back to the cesium/strontium inventory, that--well, or let me ask a question: How many boreholes would you need to accommodate that inventory of capsules?

GUNTER: The whole cesium/strontium inventory could be disposed of in one borehole.

PEDDICORD: Okay, because your numbers suggest two, but one, two, it’s approximately the same thing.

GUNTER: I think it’s one. I don’t know.

PEDDICORD: Okay, well, that’s fine. Then on Slide 21 where you talk about NE-53, the used fuel disposition, a couple of questions come to mind and the next one: How many other programs do you have then in NE-53 besides the borehole program?

GUNTER: Well, in terms of program--let's see--NE-53 in used fuel disposition is kind of split in two large programs. One is disposal R&D; the other is transportation/storage R&D. So those are the two large areas. And then within those they're more specific, and it just kind of depends on how you want to break it down.

In disposal R&D we actually have it broken out by geologic media, but it's kind of the similar research on all of them. But we have, you know, like, crystalline and clay, shale, and salt.

PEDDICORD: So I guess I was trying to understand how many more boxes are there across that line.

And then this goes into one of the earlier questions I asked. So in NE-53 how many individuals do you have to give attention to all these programs that you're trying to accomplish?

GUNTER: As far as federal staff in NE-53, we've got 15. And then, as I mentioned, the UFD Campaign, as we call it, is all our national laboratory support. So we use most of the laboratories as necessary. So it turns out to be quite a large number of people working on the campaign.

PEDDICORD: And last question, a little bit different, but trying to build on the WIPP experience, are you going to have some possibility to just kind of look at risk identification, particularly after you've placed materials down and post-closure and so on, so the thing that you don't think of is going to go wrong doesn't go wrong?

GUNTER: Right. We'll do like a risk identification/ risk mitigation type of process as far as a safety strategy. We've done some generic type of work in that area, and particularly Ernie Hardin is going to talk about some of the hazard analysis. But a lot of that we're still yet to come until we have our more final design.

BRANTLEY: Sue Brantley, Board. As a geologist, I'm very enthusiastic about a borehole. We love boreholes. It's really interesting. But when I was reading the--well, in your slides and then the Deep Borehole Field Test, characterization, science objective, some of the wording was interesting to me.

So, for example, the overall goal of the DBFT--that's the Deep Borehole Field Test--is to conduct research, development, and testing to confirm the viability of the DBD concept, so to confirm the viability. And then in your slides it says one of the objectives was to verify deep geological, geochemical, hydrologic conditions. That implies we know it and then we're verifying it. And then another one of your bullets says you want to collect data to confirm expected hydrogeochemical conditions.

So this gets really at Paul's point about the heterogeneity or homogeneity, and your verbiage really makes it sound like we know what's out there, we're just confirming it. And that's important. Words are important.

So what is that based on? I mean, how many boreholes in crystalline rock to 3 to 5 kilometers are you basing that kind of surety on?

GUNTER: I may have to defer that question to our next presenters, but--

BRANTLEY: Well, is it one borehole, ten, one hundred, I mean, just order of magnitude?

GUNTER: Well, there's a lot of boreholes out there. How many they used in putting together their analysis, I don't remember or don't know.

BRANTLEY: Okay. I think it's important when we're using words that make it sound like we know a lot that we could also back it up, you know, hundreds of boreholes or ten boreholes, 3 to 5 kilometers. How many boreholes have been drilled at 17 inches to 3 to 5 kilometers?

GUNTER: Well, that one is, I think, zero.

BRANTLEY: And then the last--

GUNTER: I mean, 17 inches at 5 kilometers.

BRANTLEY: At 5 kilometers, right.

GUNTER: Right. We’re kind of on the--and we did this on purpose, because we want to kind of test the edge of the drilling capability. So we don’t want to--I mean, a lot of this is to demonstrate drilling technology. The larger you can drill, the more economical it can be, because the more waste you can put down, so we don’t want to drill--we don’t need to demonstrate we can drill a small hole, because we know we can do that. We want to demonstrate we can drill a large hole. And there’s a lot of judgment that goes into that, but where is the right diameter that you kind of get to the edge of technology that you’re demonstrating you can do something versus demonstrating something you already know.

BRANTLEY: And then the last question I had is, the characteristics that are emphasized over and over again are geological, geochemical, and hydrological, and microbiology is never mentioned; and we now know that microbiota live to great depths in the earth. So can you tell me why microbiology has not been highlighted in the goals and the objectives and the characterization?

GUNTER: I don’t know if it’s just not listed in the slides or whether it’s not in our current plan, but it’s something we could look at and follow up on.

BRANTLEY: I don’t think it was mentioned at all in the science objectives, unless I missed something. But I just thought that was curious.

GUNTER: And maybe, like I said, some of the following presentations are going to go into more details on the science objectives, so they may have an answer to that.

BRANTLEY: I mean, I'm sure a piece of it is that at 5 kilometers at the temperatures we would expect, we wouldn't expect biota still to be alive. But as you go up to that 3 to 5 kilometers, we don't really know where we'll see them and where we won't.

GUNTER: Okay.

ZOBACK: Jerry. And I'd like to say something, to Bret and at least one panelist, so let's try to--

FRANKEL: Jerry Frankel on the Board. One of the stated objectives of the field test was to evaluate seal materials, and so we have a seal panel later this afternoon that I'm moderating. Just to facilitate that, can you tell us what you have planned, how you're going to test seals in this field test?

GUNTER: Well, some of our seal testing is actually land, and then there's a little bit in the field test. But, here again, we've got a discussion coming up I think next on the sealing, so I'd prefer to defer that.

FRANKEL: Okay.

ZOBACK: Mary Lou Zoback, Board. I just want to make a few points since you're covering the concept in general and the program in general, and now we're going to move into the test specifically. So one point on one slide was regarding your canisters. A requirement is that they retain integrity until they are loaded and sealed. So I take that to mean you claim no credit in performance assessment for the canisters. They could dissolve immediately within the first three months, and that's fine. So that's an assumption, right?

GUNTER: That would be an assumption, yes. I mean, that's what we've done in the past. Whether we use that same--I mean, we could build an argument for how long we think obviously they would--until they degrade.

ZOBACK: Okay. That was the assumption stated. I wanted to clarify that.

The other two design aspects that I think are important, I want to make sure are clear to everyone, because they're not going to happen in the test borehole. And one is that in the disposal interval in this concept--that is, between 3 and 5 kilometers depth--the casing, the metal liner, will be perforated. And that's specifically so when we drop--not drop--place the canisters there in the ambient fluid, as those canisters heat up, the fluid can escape into the surrounding rock, okay?

GUNTER: Correct.

ZOBACK: Good. Then the other point is that once the disposal zone is loaded and the seals put on, then the casing from about 3 kilometers depth to 2 kilometers depth is to be removed so that the seals that Jerry's panel is going to worry about will be sealing directly with the rock in that zone; that's correct?

GUNTER: Right, uh-huh.

ZOBACK: So just going back to the whole concept, we've chosen this method because of the geologic isolation at depth, the favorable geochemical conditions, hydrologic conditions; however, we are putting a hole to the surface, correct?

GUNTER: There is a hole to the surface, right.

ZOBACK: Okay, thank you.

Bret.

LESLIE: Bret Leslie, Board staff. Just one question, and you glossed over. You said there are a variety of reasons why deep borehole would be faster. In your reference design slide you said the concept was assuming that it would meet regulatory requirements. Do you even know what the regulatory requirements are? And if they don't exist, how does that make it any faster?

GUNTER: Well, they don't explicitly exist, right? So this would require new regulatory requirements that we would work with the NRC. But to do a repository other than Yucca Mountain, which is 10 CFR Part 63, is also going to require new regulatory requirements more than likely. So either way you're going to have more regulatory requirements that have to be put in place. And we think that a borehole would be--potentially could be somewhat simpler.

ZOBACK: Nigel.

MOTE: Nigel Mote, Board staff. I didn’t hear you say anything about the application in the R&D program of monitoring what would happen if there’s a canister that breaks, potential for contamination of materials, the borehole, how you’d recover. Can you make a comment about where that fits in the R&D program and if there’s anything you can do?

And as a context, Monica Regalbuto two weeks ago in a workshop on the clean-up of DOE sites said we have to get away from thinking we can scale up or apply R&D without doing a real demonstration at the right point to demonstrate that we can do what we think we can do. And in that context, I would have thought this was a good opportunity to do something like use fluorescein or some sort of inactive material that you can detect in water flows, gas flows, to simulate what would happen if there’s a broken canister. Could you comment on what you’re doing, if there’s anything that could be added to the program?

GUNTER: Okay. So you’re referring to if a canister breaches while it’s down in the disposal zone, right?

MOTE: Well, anywhere. It could be--

ZOBACK: Or going down.

MOTE: It could be 2 feet down or 2,000 feet--2 meters down, 2,000 meters down, or when a stringer is placed on top of a stringer below and there's a compression fracture or some other breach of a canister under any circumstances.

GUNTER: Okay, because I know we're--as part of our hazard analysis, we're doing some work on what can go wrong, you know, a canister gets stuck or drops and that type of thing. I don't know if we have any specific tests built into the program that would simulate that and try to identify what would happen. But, here again, the folks that follow me that are going to talk about the testing program probably know the answer to that.

MOTE: Thank you.

ZOBACK: Okay. Would you like to identify--

PUSCH: Yes.

ZOBACK: Yes.

PUSCH: My name is Roland Pusch. I come from Sweden, and I have two questions. And the first one you have already touched on, and I've read all the recent papers prior to the presentations here. But that concerns the selection of the suitable position for a very deep hole, second deep hole, including also preparing preceding holes for investigation. My question was, this is, according to modern techniques, something that you easily can predict, approximately at least, what the stress conditions are, I mean, what the variations, how homogeneously horizontal primary stress conditions are, because this is the only really difficult thing, I think, with the--to guarantee stability of the borehole in the construction phase and in the phase when the waste is being placed. So that was one thing. Have you any direct comment on that? You didn't mention that, I think, in your--you have listed some sort of major things that have to be considered. No, I didn't hear that.

GUNTER: Well, the drilling of the borehole is going to be one of the challenges, that diameter and that depth, keeping the borehole open as you're drilling until you get the liners set. And that's one of the reasons we're doing the test is to try to confirm that this is a feasible proposal. And in our discussion with drilling companies we don't get the impression that we're too far out in left field, so to speak.

PUSCH: The thing I think of is that we have higher up from the--in the upper part 2,000 meters we can have rather large differences in the primary stresses in two major horizontal directions, and this could be investigated and determined well before you would select the point where the test hole should be made. I mean, it should belong to the pre-pre-study of finding a good position for the testing.

GUNTER: Right. And some of the guidelines for selecting a site, stress at depth or in between depth and surface, is listed in there, based on what data is available. So we would want to, if possible, avoid areas of high stress.

PUSCH: The question I have or is rather a note, with the experience we have from mined repositories at 400- or 500-meter depth in granite in Sweden, we know that there is an extreme risk that monitoring controls and gives the results. So that is a big fiasco, actually, when all the seals, the clay seals, were equipped with thermostats, with the pressure cells, with practically anything, because the engineers love to have as many sensors in as possible—the use of cables.

And it turned out that water from the surrounding at this depth went along the cables and gave the indication that wetting of the clay was much quicker than it should be, using a theoretical estimate. And it turned out to be so. So you can see for yourself. Be very careful with putting in instrumentation even in the test hole with no radioactive waste. In a repository with radioactive waste, don't put any monitoring instruments inside.

GUNTER: Thank you for your comment.

ZOBACK: I see we have many more questions, but I also see that we've run into our coffee break. And since this is being webcast, I think we have to try to stay on schedule. So many apologies we didn't get to the questions, and I hope you'll take advantage of the break to ask them directly.

Thank you. And we'll be back at 10:15 to stay on schedule.

(Whereupon, the meeting was adjourned for a brief recess.)

ZOBACK: Okay. If you could take your seats, we'd like to get started again. A lot of empty seats in the front.

Okay. After our general introduction to DOE's deep borehole concept and program, we are now going to focus in on the deep borehole test program. And we're going to have--the next hour and a half we have two speakers that are going to be tag-teaming. And I think to be efficient we're going to keep the questions toward the end, and I hope we can get through all the questions, questions of the panelists, other panelists, and the audience as well.

So let's try to keep the questions crisp, concise, and if we don't know the answer, "I don't know" is okay.

So now we're going to move into the, as I said, Deep Borehole Field Test, a site characterization and design requirements. As I mentioned, there will be two speakers. We're going to begin with Dave Sassani. His background, he is a geology--it is in geology and geochemistry, and right now he is the lead on the site evaluation and data integration for the deep borehole test. He's from Sandia.

And he will be joined by Ernest Hardin, also from Sandia. Ernie has a geophysics and hydrology background.

He’s done modeling on coupled hydrogeologic-geochemical-mechanical processes, and he’s the lead on the engineering development for the deep borehole test.

So, again, they’re going to both be speaking, and we’ll have the questions for both of them at the end. Thanks.

SASSANI: Thank you. Am I all turned--oh, there we go. Very good.

Well, good morning. I want to thank the Board, congratulate them on pulling together such a wonderful group of individuals from all around the world so we can have this discussion here today. I look forward not just to providing a little bit of information in terms of what we are doing with DOE’s Deep Borehole Field Test project, but I also look forward to actually becoming connected and getting myself to learn from a lot of the individuals that are here who have some of the largest amount of expertise in some of these areas in the world. So I’m really happy about that.

As introduced, that’s me. Later on I’ll be handing off to Ernest Hardin. Initially we decided that we wouldn’t, like, alternate each slide so we had to get up and sit down all the time. So I think we worked it out a little smoother than that.

So just to go through, I’m going to talk a little bit about the team for the field test in a little more detail based on Tim’s intro. I’ll then go in a little bit through the concept again, a little bit more on the hydrogeologic and geochemical information, and I do at least touch on the geomechanical aspects, which are very important from construction of a borehole, keeping it open, and actually successfully fielding either a test in the field of this nature or also a deep borehole disposal borehole.

I’ll talk about how we are assessing the concept feasibility, and a large part of that is, to start with, the field test; talk about the site characterization approaches to the geohydrologic, geochemical, geomechanical aspects of the system that have been laid out; and I’ll talk to how we’re going to use that information from the characterization in terms of assessing the feasibility of the concept as well as how do we roll that into safety assessments that you would do for something that is actually a disposal system.

After all that, I will turn it over to the more entertaining portion of our presentation today, because Ernie will be doing a multi-media presentation. So if you haven’t gotten your popcorn yet, you know, I think there’s popcorn in the back? No, Rod?

EWING: For sure.

SASSANI: Okay. So there will be a couple of videos that Ernie will also show in addition to the presentation, and those will be very fun as well as enlightening.

So, in terms of site evaluation characterization, also the engineering component and the data integration, our team members: Tim Gunter, who just spoke, Federal Program Manager at DOE; Lam Xuan is the Program Lead in the technical area; and at Sandia we are the DBFT, the Deep Borehole Field Test.

I will try not to do that, Mary Lou. Please yell at me if I read them as letters.

ZOBACK: Thank you.

SASSANI: Project Technical Lead at Sandia National Laboratories, Bob McKinnon is our Manager; Geoff Freeze is Project Lead and Safety Assessment Lead. This is myself; I’ve been in charge of laying out the site evaluation work that’s ongoing, and we’ll be doing data integration once a site is chosen and we actually put together a full-blown geologic framework model of the system.

Kris Kuhlman, who I have to give lots of kudos to, is our Site Characterization Lead. He is here in the audience. And if there is extremely detailed questions, Kris is actually the person that would be addressing those. I don’t know if we’ll have him get up or get down unless we really need the additional information. Kris put together the attachment that was with the RFP on the science requirements and objectives for the Characterization Borehole for the field test project.

And then Ernie Hardin is Test Package/Emplacement Engineering Lead on this, and you'll hear more from him on all of that.

In addition, we have other laboratory participants. At Los Alamos, covering regional geology, geoscience, and site characterization, Frank Perry is the lead there, and he's been helping us very much in that region; also, Lawrence Berkeley National Lab with Jens Birkholzer, Jim Houseworth, and now Pat Dobson, since Jim has just retired, for geoscience and site characterization.

We have support from Oak Ridge National Lab on surface site characteristics. They have a very nice GIS (geographic information system) tool called OR-SAGE that they've used for evaluating siting of various reactor facilities and things like that. Idaho National Laboratory also provides a web visualization interface support for geoscience data, and they interface pretty much directly with Los Alamos and Frank on the regional geoscience databases. Pacific Northwest National Laboratory has been helping us with the engineering design support as well, and we continue to look for getting them involved in other aspects of the site.

So this is our team, but by no means is it everybody that works on it, not even at Sandia. We have other folks in the audience like Pat Brady, who has worked on this for at least five years at this point. Pat’s been a lot of the conceptual driving force behind the geoscience aspects; Payton Gardner, who was a Sandian up till just this past summer and is now at the university up in Missoula, Montana, so he is one of our technical leads or was one of Sandia’s technical leads on tracers and groundwater provenance and interactions. So Payton is also here. And Steve Pye is a drilling expert that we have contracted, who is also helping us with our understanding in those areas.

So I didn’t even know that was in there like that. Anyway, so here’s a disposal concept in terms of safety and feasibility considerations. This came up a little bit earlier, long-term waste isolation (hydrogeochemical characteristics). So we’ve seen a disposal zone crystalline basement within 2,000 meters of the surface. That at least is relatively common. We have a pretty good understanding of depth at crystalline basement. It’s one of the few parameters where maybe we have a lot of data, but that’s pretty well known. So our idea is that it would actually be fairly easy to go pick areas with at least that characteristic.

But in addition to that, the deep groundwater in the crystalline basement, well, it can have long residence times. There are studies that show million-year-plus ages for the waters, waters coming in pre-Pleistocene, and looking very old. It also can be highly saline and geochemically reducing, or I would say geochemically reduced or reducing, depending on what the minerology is in the host rock, which is where most of your capacity for doing reduction lies. And those things enhance sorption and limit solubilities of many radionuclides.

It also can have density stratification in that salinity. You can see in some studies from the Canadian Shield work that's been done by some of the folks in the audience here you get to 50,000 parts per million within a couple of kilometers and possibly up to greater than 300,000 parts per million deeper into the crust. And those salinity stratifications also have a little bit of a compositional variation, become more calcium-rich brines at depth, at least from the little bit of data we have. Kola Peninsula also shows that.

So, in any case, that's important for a few reasons, but one of them is that that stratification can oppose any thermally-induced upward groundwater circulation, which may drive diffusion and possibly slight advection of radionuclides in an actual disposal facility.

And then the crystalline basement can have very low permeability, which can limit flow and transport out into the host rock; and, in fact, these can be down on the order in crystal and granitic rocks of 10^{-19} m^2 to about

10^{-7} Darcy, I think. And those have been measured. But they are also in many cases--the work that's been done in some of the boreholes, the sites that have been chosen are not--although some of the geothermal ones--some of the sites that have been chosen and worked on, many of them are not all of the types of characteristics we would choose for this system. Some of them have--there are a lot of structural complexity, things like the KTB hole in Germany and also the Siljan Ring.

And then there's other aspects for the geothermal exploration drilling that's been done very deep in the granitic rocks. You have very high geothermal flow. You have a lot of heat. That's what's being looked for. We want to stay away from those areas. But looking across the board at these, each of them has some of the components that we would be looking at.

So this Tim covered a little bit. I'm just going to go through it real quick. It's sometimes better to look at what are the types of conditions you don't want for one of these deep systems. And for us, we don't want interconnected high-permeability zones, shear zones and fractures, from the lower portion, the waste disposal interval, to the shallow aquifers or the surface. In many cases it may not be readily observable to know those things until you drill the hole. But there's methods for even looking down the hole, geochemical methods that may tell you if there's something even close by that you haven't intersected that could affect that. So we'll be looking at those kinds of things.

You don't want a high degree of heterogeneity in the crystalline basement. I like to say it this way, because I am a geologist, and we're not going to go find some big, vast, 50-kilometer, a homogeneous piece of rock. We're going to look for rocks that have the least heterogeneity. That's what we're focusing on.

At depths of greater than 3 kilometers in the disposal interval you don't want to see young meteoric groundwater. That's not a good sign. You don't want to see low-salinity oxidizing groundwater. These things indicate that you've got flux that's getting down deep into this crystalline basement rock. That is not what you want to see. Those are observations that you would say this is not where we would choose to put an actual disposal hole.

You don't want economically exploitable natural resources. You want to be away from any kind of ore deposits. You'd like to find a really barren granite that has maybe a little bit of magnetite and a little hematite in it, but nothing else of any viability.

You don't want to see any significant upward gradient in the fluid potential. You don't want overpressurized conditions, because you don't want flux going upwards. And you don't really want any high geothermal heat flow, not just because it's a natural resource, but also because it makes it very difficult to drill the hole and to do things in the system, and it can also generate a thermally-driven upward flux.

So, additionally, high differential horizontal stresses, as was brought up by the gentleman from Sweden, those are very undesirable for borehole completion and disposal operations. This is an area--and Mary Lou knows much better than I do--there are vast portions of the country where in the crystalline basement rocks you don't have an enormous amount of information directly to evaluate this.

And so this is one area where we have to do our best. And, in fact, the Characterization Borehole gives us an opportunity to characterize explicitly what's going on here, and that would be part of making this decision about whether or not you would proceed with putting in a Field Test Borehole.

You know, there's a lot of ways that you can have success in a field test of this nature. It doesn't have to be every particular aspect. There can be aspects that are successful and aspects that--you know, maybe we do have young meteoric groundwater at the site. Okay, well, we can characterize that, and it's not a disposal site, so it sort of takes off the table looking at these salinity gradients in explicit detail, but it doesn't invalidate the rest of the testing. However, if we had a Characterization Borehole that we could not keep open, that was unstable, that would definitely be something that would tell us we're not going to put a Field Test Borehole here.

So absent these unfavorable conditions, the potential scenarios for radionuclide release to the biosphere in the deep borehole disposal concept would be thermally driven groundwater flow from waste heat or simply diffusive flux through the borehole seals and/or along the disturbed rock zone annulus. This is important, and we'll get to talk about this more in Panel #6, which I'll be on, where we talk about the different amounts of reliance put on different barriers in the system. These barriers, the borehole seals, are part of the engineered barrier system which is relied upon in this concept. They aren't the primary reliance, but they are part of it.

So geologic conditions, what do we like? Well, we like reduced or reducing conditions in the geosphere, rock and water system included, not just looking at the water. Water sampling to see if the water is actually reduced at these depths could be very tricky and could be very difficult and a very big challenge to get uncontaminated samples. So we will not just simply sample fluids, but we're going to have rock samples, because if the fluids in their major element chemistry show they are largely rock equilibrated, then we can rely on the minerology in the rock to give us information about how reduced or reducing is the system.

In addition, steels in the borehole will provide some reduction capacity either directly through reaction with radionuclides once they're in solution or through generation of hydrogen gas, which can also be a reductant in the system.

Rock-dominated system at depth is what we'd like to see. We'd like major elements at depth increasing with brines at depth--again, stratified--evolving to these calcium chloride fluids, which will look like they are dominated by rock equilibration; reactions of the feldspars at depth under low-grade metamorphic conditions; forcing the fluid to evolve to a more calcium fluid; generating things like zeolites and clays even in the granites; and then also affecting things like stable isotopes, radiogenic isotopes, and noble gases, looking at those to try to get some indication of the isolated nature of the fluids in the system.

For a subset of the waste forms and the radionuclides, a subset of those, which are redox-sensitive, this can generate very much lower degradation rates; it can lower solubility-limited concentrations for some of those radionuclides; and it can increase sorption coefficients. So those are some of the performance aspects that we would get out of this kind of a system.

The stratification of salinity, in addition, that gradient opposes the upward flow, as I said, but it also reduces or eliminates consideration of colloidal transport. As you go to very high ionic strengths, colloids become--well, they're metastable, unstable. They actually flocculate out, and so your load is very, very small, if any at all. So those are very good things.

In addition, the overall aspect of this system, if we see it as such, if it is this isolated system where you don't have a lot of fluid influx, that also provides a good constraint on solubility limitations, because if you have a diffusive environment, a calm environment, that's exactly where you're likely to hit your solubility limits, even for elements that are not redox-sensitive, as long as there's phases in the bulk chemistry that can precipitate and have a low enough solubility limit.

Geohydrologic considerations, again, no large-scale connected pathways. So we will look for these in the Characterization Borehole. We look for these things as site selection criteria also, what's the regional structure look like, and what's the local structure look like, and what do we think in terms of whether or not we would be seeing any of this--again, we're seeking lower heterogeneity in the crystalline basement--low permeability of the crystalline basement at depth; and, again the evidence that these fluids are ancient and isolated in nature within the crystalline basement groundwaters. The salinity gradients, to do what they do, provide that density resistance to upward flow and then major element and isotopic indications of compositional equilibration with the rock.

So if this system is dominated by that equilibration with the rock and we can demonstrate that the fluids are isolated and are ancient based on isotopic work and noble gases, then we have an idea that there is minimal recharge going on in this deep crystalline system. So you have a system which is primarily diffusion-dominated.

So somebody asked earlier how many boreholes. Well, you know, are there thousands of them in deep crystalline rock? No. But what I'm showing here is a plot, which was taken from Beswick 2008, and this is the plot upon which the selection of a 17-inch diameter at 5 kilometers depth is based.

So these red dots are all boreholes, deep drilled in crystalline rocks. The numbers you can't read at the top here are diameter of the borehole in centimeters, so that's half a meter right there. And the numbers that you can't read on this side are depth in meters, and that is 6,000 meters right there. That's 6 kilometers. So 5 kilometers depth and 44 centimeters is right here, which is our target deep borehole concept for the diameter of the hole at 5 kilometers. And you can see there's a number of them. Below about 5 kilometers there’s fewer.

Here’s the Kola Russian borehole, which went to 12.2 kilometers, the deepest in the world. That was 8-1/2 inches in diameter at 12.2 kilometers. Pretty impressive.

You can see these guys in here include the KTB borehole in Germany, and that’s an acronym, and that stands for Kontinentales Tiefbohrprogramm der Bundesrepublik. It’s much easier for me to say KTB hole. That’s the hole in Germany, and that is another very deep one. That’s 9.1 kilometers, and it’s 6-1/2 inches in diameter at depth.

So that gives you some feel. Now, that’s Beswick 2008. There was a Beswick et al. 2014 recently published that indicated that you could probably go--our concept is 44 centimeters. He was saying, yeah, you can probably go to 60 centimeters at 5 kilometers with current drilling technology. So, in fact, within that six-year period, we are now within the envelope, not on the edge of it.

So I don’t know much else about drilling holes. Steve Pye does, though, if we have questions about it. So, in any case, that’s some of the previous work.

And what are we going to do to actually evaluate the feasibility? And, hence the word “evaluate,” not confirm--not confirm our assumptions, which is, I think, where some of that wording came from. But this is actually evaluating the feasibility of this concept. Well, we want to select a suitable site. They occur everywhere, right? It's all over the place, all over the continental U.S. There's all kinds of rocks that we can put this in, so we ought to have a fairly straightforward time selecting a site. That's a little tongue-in-cheek. We'll see how successful we are. We're in the process of doing that currently with the RFP procurement process.

Part of it is to design, drill, and construct the Characterization Borehole to its requirements. These holes are being conducted and put in place for research purposes relative to the deep borehole, but to look at targeted science and then the possibility of doing some other R&D associated with it, as long as that gets fit in with the targeted science for the project.

We want to collect the data in the Characterization Borehole to find all those--and, again, here it says "confirm." That shouldn't be confirm; that should be evaluate or quantify--with acceptable uncertainty what we expect would be the hydrogeological conditions for the site we select. So, in this case, once we select that site, we have all of the background information about that site. It doesn't mean we have all the data you might like to have, but we've looked at as much as exists.

So then you want to design and develop the surface handling and emplacement systems. You want to verify hazard analyses that--you want to verify through hazard analyses that you can do this in a safe manner with sufficiently low risk. There is no radiological materials in the field test. You want to demonstrate that handling, and you want to do emplacement and retrieval/removal operations in the Field Test Borehole.

We have laboratory studies that we're looking at engineered materials under representative downhole conditions. Once we get those conditions, we'll be putting those in place. We're starting some of those up this year on some of the seals materials to look in general at what can be done for something like clays, altering the zeolites at these slightly higher temperatures, and cesium incorporation into those.

We want to do subsystem analyses and a post-closure safety assessment to quantify uncertainties, to demonstrate the understanding we have of the key processes, and to evaluate the safety of the concept.

Cost analysis is in here. This was mentioned earlier. Ernie will talk a little bit about this. I can't tell you anything about it.

And we want to synthesize all of the above elements into a comprehensive and transparent evaluation of the feasibility of the concept.

So those are the primary aspects of actually conducting the field test.

This block diagram, I was going to walk through those. I'll just point out, here is the Burj Khalifa Tower in Dubai. This is not part of the surface facilities. It's just on here for scale. It's 830 meters tall. It is not actually only half as tall as the drill rig. These guys are not to scale.

So there's design aspects. We want to evaluate a site. We want to characterize the basement fluids. We want to characterize the overlying sediment fluids and hydrologic conditions, although those are a lower priority, because the techniques for doing that are very, very well understood by tens of thousands of holes that have been worked.

We want to characterize the disturbed rock zone all along the borehole. This will probably be the most likely pathway for any kind of radionuclide transport.

Design and test waste packages; develop and handle and emplace and remove waste packages; do emplacement hazard analyses about packages getting stuck in the hole and having to be fished out; evaluate the waste package, the waste form, the casing, cement, and seal materials; design a seal system; do an in situ thermal test as part of the characterization; and assess the post-closure safety.

So those will all be synthesized, and no nuclear material will be used or disposed of in these holes.

This characterization is very different from mined waste repositories. There is more isolation, so you do less site mapping, although you could view the downhole camera recording as the mapping of the borehole. There is single-phase fluid flow, less steep pressure gradients.

In terms of oil and gas or mineral exploration, there's a much lower permeability, generally crystalline basement versus sedimentary rocks. We're avoiding mineralization, avoiding overpressure, and for geothermal systems we are avoiding high heat flow.

So this is a summary of what we would be doing in the Characterization Borehole, kind of as an overview. This is the diagram of the borehole shown here. Here's the 2-kilometer mark where we would have crystalline basement starting at least by 2 kilometers. This is from Kris Kuhlman's 2015 report that is attached to the RFP. It was sent out on July 9th or put out by DOE on July 9th.

And there's a number of tests indicated here at various locations throughout the disposal zone and the seal zone, but we'd be looking to be doing downhole borehole geophysics. We'd be coring, getting cuttings and rock flower analysis, virtually continuously or semi-continuously every 3 meters as the mud came out of the hole. And we'd be doing minerology and petrology on those rock samples and rock flower samples, XRD for quick mineralogical analysis, and we'd be collecting fluid samples from some of those cores as well, looking to get bulk composition, things like salinity, look at the composition of the fluid for how rock-equilibrated it is.

And then there's sampling-based profiles, things like fluid density, temperature, major ions. This is all, like, from the drilling fluid to take a look at what's going on as you drill the hole; pump samples from high-permeability regions to do water sampling; and then samples primarily from core water samples in low-permeability regions.

Drilling parameters and logging, the mud fluids, the solids, the dissolved gases, continuous monitoring of those, looking at things like torque on the bit, weight on the bit, etc., just to keep monitoring the drilling, because we want very straight holes. We want very little deviation in these holes. And then testing-based profiles, things like static formation pressure, formation hydraulic/transport properties, and then looking at the in situ stress via things like doing hydrofrac tests and looking at breakouts and mapping those in the hole.

And then a little bit more detail in terms of environmental tracers. This diagram just shows you some of the ways these tracers can either be formed in the atmosphere via cosmic rays and come into groundwaters, which penetrate down into portions of the crust, but they are also generated in radioactive decay throughout the crustal rocks. Particularly in things like granite, you can get a lot of these building up and particular helium-4, which is a very good indicator.

So what we would be looking to do--and the colors over here, the red colors basically indicate what I would say is our low-hanging fruit. These are the pieces of the puzzle that we would hang our most reliance on being able to get good measures of and can tell us the information about do the groundwaters look like they're isolated, rock-dominated, very ancient waters or not. But we aren't just going for the low-hanging fruit here, because part of this whole test is to look at characterization methodologies and then at some point come up with what is the most bang-for-the-buck, cost-effective way to do the characterization of the site and get the data that you need as easily and comprehensively as possible.

So noble gases, again focusing on helium, stable water isotopes, oxygen and hydrogen, some atmospheric radioisotope tracers, things like krypton-81 has been used. It's got about a 230,000-year half-life or 250,000-year half-life, one of those two, and it's usually indicative of meteoric fluids. But, in fact, in systems where you get a lot of formation of this in highly radioactive systems, they are nucleogenic reactions; they're not radiogenic reactions.

If it’s well sealed, you can build up krypton-81. It’s been sampled, and if it’s waters ran--waters from deep in the mine where huge values have been found much, much higher than atmospheric. And those indicate waters that have been isolated in that host rock for at least the lifetime of the krypton, anyway, things like uranium-238/234 ratios, strontium ratios, and the long-term data where we want to try to map out what the water provenance is, look at flow mechanisms and isolation, evaluating the minerals or fluids in the pores, the fluids in the fractures, and effectively come up with an assessment of how leaky is this deep crystalline basement system.

So the fluid sample quality and quantity will be a focus. The ones in red tend to leave much smaller fluid samples to get good analyses from.

So for hydrogeologic testing, we want to get hydrologic property profiles. We want to look at the static formation pressure, measure permeability or compressibility, doing pumping/sampling in high-permeability zones or pulse testing in low-permeability zones, and then doing some borehole tracer testing. Single-well injection-withdrawal or vertical dipole, kind of shown here. You can do single-well injection-withdrawal, or you can set up a number of packers, introduce a tracer here, and pump it out here to get measures of how permeable primarily is this disturbed rock zone around the borehole. That'll help us understand the transport pathways.

Hydraulic fracturing tests, again, to look at the stress magnitudes and try to determine what is the differential horizontal stress that would go along, again, with mapping of breakouts, which give you some of that information in terms of directionality and magnitude.

And then we have a borehole heater test that we would look to field with a surrogate canister with a heater in the crystalline basement to try to get after the thermomechanical properties and the thermohydrologic response of that system. That would be over about, I think, a 5-meter interval.

So, going back to this slide, I'm just going to pull all these up, because what will we use all this data for? Well, there's a number of things we would use it for, specifically to look at those particular properties of the system, but also to then inform the post-closure safety assessment of the entire system and to build a safety assessment, a performance assessment, of the site that is actually based on the properties of the site and evaluate it quantitatively.

In addition to that, there is a large amount of these demonstration and design aspects, evaluation of the emplacement hazard, design of seal systems, which we are not going to field seals in these holes at this point, but that may be a follow-on project that we are going to be doing laboratory studies in terms of sealing materials. And the in situ thermal test would be down in the disposal region.

So at this point I'm going to hand it off for Ernie Hardin to talk much more about these design aspects, and I'll be around for questions.

HARDIN: Well, good morning. There really are a lot of luminaries of nuclear waste disposal technology in this room, and I'm proud to be here. And I'm also happy to have the opportunity to talk about work we've done in the past year on the engineering side of the Deep Borehole Field Test.

So my slides are more in the burst mode.

So these are the elements of the big picture that I'm going to talk to you about: Developing and testing systems for handling and emplacing and retrieving waste packages; performing emplacement hazard analysis to understand the risks involved; work towards a reference design or improvement of the reference design for a seal system; to actually design and test the waste packaging concepts; and to evaluate seal materials for use in that seal design.

So I put this--this is a schematic of the Field Test Borehole depth and casing plan. It's entirely consistent with the one that Tim Gunter showed you earlier this morning, redrawn, and the message here I wanted to give you was something Tim also said, which is that I cannot understate the importance of a continuous casing pathway for emplacing waste from the surface all the way down to total depth. And, in addition, this upper section, 3 kilometers, is a tie-back, meaning that it’s hung from the surface, and it’s not cemented at all, and it could be removed if we were to stick one or more waste packages in it. It’s a method of last resort available to use for recovering from that condition.

So this is what I’m going to talk about. We’ve gone through objectives. Next I want to present to you some emplacement system options and particularly starting with the Spent Fuel Test-Climax; I want to talk about wireline emplacement, which is based on that, and then go on to drill string emplacement, which is where we’ve been for the past 20 or 25 years; and then briefly touch on some packaging concepts and then describe a cost-risk study that we performed with the intent of justifying a recommendation for one or the other of these emplacement methods. And our recommendation is that the wireline could be, in fact, favorable. And, finally, I’m going to identify some remaining questions in the conceptual design process and also present where we are with the sealing technology R&D program.

So this photograph is from the Climax site, circa

1982, I guess. And Wes Patrick wrote the final report on this project, and he's here as a panelist. What you see here is the flatbed-mounted shielded transport cask. It's double-ended, and there is a waste canister inside of it. And the wireline then has engaged the canister.

This gadget sticking out is a special cable that was developed for that project. It is a load-sensing device; and if for any reason the canister were to go into free-fall, spring loaded arms would come out and arrest the canister against the inside of the casing. So this method, I don't think, was ever needed and in practice of the test.

The wireline was interesting on this. This is sort of a relic of the test site days. It's a 36-conductor wireline with about 9/10 of an inch diameter. In other words, it's similar to a wireline that's used in the petroleum oil and gas logging business.

So, based on that, these are some little screen shots that show some of the major features of the wireline emplacement concept as we understand it. So we start with a headframe. It's safer to use a headframe than a crane, so we're trying to eliminate possible modes of failure that could contribute to dropping the package or otherwise producing a hazard. And this pillbox affair here is our rendition of a shield that would be needed.

Now, the borehole will probably have a blowout protector stack on it. Blowout protectors are going to be required for our drilling by the state regulatory authorities. Even though the circumstances of hydrogeological conditions that we’re looking for would never require--they’re not going to have an overpressure condition; so, in principle, a blowout protector is not needed. But we need to design our emplacement system so it can accommodate that if it’s required.

So, with that said, we conceivably are lowering gamma-emitting waste packages down through the blowout protector, which is not designed for shielding purposes, so we need some sort of shielding. If necessary, we could reconstruct the wellhead so that those were subgrade.

So, Jason, could you roll video number one, please?

So we did these primarily for the benefit of an expert panel that we convened to review and go through all of this. So it shows a waste package arriving in the double-ended shielded cask. This could be either a multi-purpose cask, or it could be one solely for transferring from a transportation cask to the wellhead. You saw the impact limiters disappear as if by magic.

This lift right here is up about ten feet and, in fact, could be the riskiest part of this entire proposition, what you just saw.

We actually started, Wes, by simulating the spent fuel test. Our graphic artist made a video of that if you should ever require it. That's why some of the components look familiar.

So that's a shield plug right there, and we're going to engage and lift slightly so we can open sliding doors. And we see the need for a redundant closure mechanism here. It prevents a number of different single-point failures. So here we've labeled some of the components I've told you about. The upper cask door is a pop-top variety, because it can be actuated externally and therefore repaired, and it's obvious when it's open.

And now we lower away. Now, one of the reasons why this concept works, I think, is because there is a relatively new wireline technology available from a major vendor--I won't specify who that is--but it's an iteration, an evolution, of the classic double-armored steel design that's completely blocked with a high-temperature polymer, and it eliminates many of the problems with conventional wireline.

And now the video shows that we're stacking waste packages one on top of another. And the limit of forty is a soft limit. We could do ten or we could do a hundred, but it's mainly to protect the condition of that lowermost package under the static load of the others.

So that's it. And now you can kill it anytime. There we go. And put me back in control. Good. So I think that’s it. All right.

So the alternative that we evaluated is a so-called drill string emplacement method, and this is a schematic of a drill rig that shows kind of what we’re talking about. This is just like the schematic that you saw from the Woody-Clyde report from 1983 this morning in one of Tim’s slides.

So we start with a drill rig which is large enough to do the job. It’ll handle triple pipe stands. It’ll have a hook load limit of at last a half a million pounds, maybe a million pounds. So it’s a fairly large rig. It’s going to sit up off the ground on a substructure that’s maybe 25 or 30 feet tall. And we need that room because the game plan here is to assemble a string of waste packages threaded together, and they come in in the cask. They need to be assembled below the cask obviously. So we don’t want to lift the cask up onto the rig floor. There would be some horrific shielding issues down here if we did that.

So, anyway, the geometry sort of draws itself. And so what you end up with is a sub-basement here where you’d have the blowout protectors stacked and also this other equipment, tongs and slips and so forth that would be used to assemble or disassemble, if necessary, strings of waste packages.

And these screen shots here, similar to the others. I may not have a chance to show you in the video that we need some sort of a device for translating the upended waste package under the rig and depositing it over the wellhead, and there are various ways of doing that. We didn't get into the details.

This picture here shows a machine or device on the rig floor that's called an iron roughneck. It makes and breaks out joints between drill pipe, so it's an automated feature of many modern rigs. And the rig basement will look like this. And I think we're probably shortly ready to roll the video. Here again we would opt for using some of the blowout preventer apparatus to provide a backup in case a waste package was dropped somewhere near the surface, and we'd have to deal with the mud. I won't get into the details, but the mud equipment is all going to be on the surface, and we're going to have to evacuate the annulus down here below.

So, Jason, I think it's time.

So this video is quite a bit longer.

(Pause.)

So that cask there would have to have a--to handle the cesium capsules we would probably have to have a wall thickness on the order of 10 to 12 inches of steel, and that makes it weigh in a configuration like this more than 30 tons, but it would be road legal.

Now, we imagined waste packages being delivered to a remote site at the rate of about one per day. I'll talk about that a little bit more in the assumptions on the study that we've done.

I think being a graphic artist would be fun. He makes a whole bunch of the substructure disappear right here.

Okay, now we're located below the--directly below the drill rig. We go down and engage the waste package with a pipe string. This string right here would be engineered so that it didn't have the strength to pull the package out of the cask against its restraints. That's real important. We call that the breakaway sub in our report.

So we have to lift it slightly in order to get the sliding doors open. There's another set of doors that would have to open into the basement. And right here could be the limiting drop for the drill string method, dropping it in air, having the package accelerate through 10 or 15 feet.

So this would be an integrated system that the package would have features that engaged one or more of the blowout preventer rams as a backup gripper. Most of the gripping would be done by a set of tongs here, which is just an elaborate wedge affair. The power tongs are based on hundred-year-old drilling technology.

(Pause.)

I misspoke. I said the power slips are. What you just saw was the tongs engaging the package string. Now we’re going to unthread the pipe string above it and get ready for another package to be added to that string.

So, again, we made the videos for the benefit of our subject matter expert panel, and I wanted to make sure everybody had a common understanding of the complexity involved in some of these operations.

So at this stage of the emplacement process, dropping something is the principal hazard.

PEDDICORD: Would there be extreme radiation coming up?

HARDIN: There would be--there would be some. And with that shield plug there, you limit a whole lot of that, but there would still be some. That shield plug idea is, of course, what’s done with packaging spent fuel in pools.

So my graphic artist was perfectly willing to extend this so that all forty packages were threaded together. I think we got him down to three. He really worked hard on this. He told me this is the hardest project he’d ever done.

So then you’ll see the--the complete string will be captured in the basement there, and we’ll start threading in not more packages but drill pipe. Now, with a triple-stand rig, the stands of pipe are about 90 feet long; and so it’ll take on average 138 of them to lower the waste package string into place. So that’s 138 pipe joints that have to be made up, and that’s 138 lifts.

Now, the oil drilling business knows how to do lifts reliably. What you see here is a device called a J-slot that is used to engage an assembly and lower it in the hole and then disengage. There are other devices with potentially more reliability and more capacity, more strength.

As I said, the lifting on a drill rig is a well-understood process, and they use something called an elevator, which is what you see here. The drill pipe has upset ends so that the elevator gets a real good grip, but there is a potential single-point failure there. You go through the entire system and find all the single-point failures and see what you can do engineering-wise to mitigate them or eliminate them. The pipe joints would be made up automatically. This is actually much safer from an occupational safety point of view than having men on the rig for slips and gauge, elevator releases. So this is exactly the process that would be repeated 138 times.

You know, there are numbers out there for the hazard and reliability associated with lifts, and we think that if you have a standard rigging setup, you’re doing repeated lifts, you could probably get 10^{-5}. And if you have a piece of equipment like this, which is highly engineered and has an inspection schedule, you might be able to get

10^{-6}; that’s drops per lift. Whereas, if you just go into randomly lift a large, heavy object up, some particular size, but you have to make up the rating for it, the reliability is more like 10^{-4}.

So there you have a package stream being lowered into place one stand at a time. So you’ll see the J-slot device disengaged and then the string withdrawn the same way it was inserted.

So I think you can kill that.

Okay. So let me touch on some of the packaging questions that we looked at. The reference packaging design that Tim showed you this morning was done as a straw man to see just how easily it could be done, how cheaply and easily could we package certain waste forms for borehole disposal. And so that design relied on off-the-shelf American Petroleum Institute schedule tubing and connectors.

The safety factor on something like that is fairly low, so we set about to understand if we could do that with a higher safety factor. API safety factors are typically on the order of 1.3 or 1.4 against crushing or burst. And so in our case we were principally concerned about the crushed strength of the package at the bottom hole pressure, which we calculate to be around 9600 Psi.

And so we want a factor of safety--I mean, you want it as high as you can get it. We wanted an FOS of 2. That’s comparable to a value that’s used in certain pipeline regulatory applications. If you go too high, of course, it gets too heavy, and the material thickness replaces your waste, and so you get less efficient disposal.

The concept that you see here then would use a higher grade or higher strength of API tubing friction-welded to subs that are machined. So this material is called P110. It’s really one of the 4140 series steels. It’s medium carbon. It’s not very friendly to work with, so we’d have to be careful about how we did that. You want the welds to be separated from some of the more sensitive components like threads in a package like this.

But the advantage of the concept you’re looking at here is that although there are welds in the load path, they can be heat treated. They can be stress-relieved before you load the waste in the package. This is about the maximum size that we think we could get into the 17-inch borehole with the 13-3/8 guidance casing. So it’s a roughly 11-inch OD, is what you have to work with.

And this version here is a little bit different in subtle ways. First of all, it’s the slim version. This is the one that we would propose for the cesium/strontium capsules, which look like this. They’re about a half meter long, they weigh about 8 kilograms, and they’re about--sorry about the units here--they’re about 2.3 inches in outer diameter. One thing when you start mixing up science with drilling, the units get completely out of control.

This one has an internal flush concept, so you could take waste forms that were already canistered, and you could slide that canister into this overpack. That's the idea here. And they could be constructed in any length. You could do 2s, 4s, 8s, what have you. We regard 5 meters to be a practical limit, because if you go much longer than that on the packaging, then you're talking about a huge shielded transport cask.

And the other thing to say about this is that we could also bundle these. And the DOE-EM, Environmental Management, has a program, which they call their Universal Canister program, that is looking at what is the next step in packaging the cesium/strontium capsules and other waste forms. And we're involved with that, and we're cooperating with them.

And one other thing about these, for the study to date we've regarded the package from here to here to be the same for wireline and for drill string. So we're not letting that degree of freedom enter into our comparative analysis right now. So they would both have threads on the ends. They'd have some sort of API-type thread. But for the wireline, what we'd do is we'd have a sub or an insert that would thread into the top. It'll have a wireline latch on it, protected by a skirt, and at the bottom we could put an impact limiter. And this is really important, because if you have the right impact limiter, it may very well be that you can never get a package to breach if you drop it. So we'll see more of that.

So I've described the two methods of emplacement and shown you what sort of waste packages would be used. Now we've set about to make a recommendation as to which method of emplacement should be used for the Deep Borehole Field Test, and that recommendation's got to be based on how we view the performance of an actual disposal system.

And first I point out that the DBFT has zero radiological risk. So in the risk discussion that follows, we're really talking about the disposal system that will, of course, trickle down to the DBFT selections. So that's what I'm saying here. We're looking for features of the two different methods that discriminate and we don't get hung up and spend time on features that don't discriminate at this point in the conceptual design process.

And then we've thought about what sort of off-normal events or accidents could occur, and we identified a few that found their way into our risk study. If we drop a single canister, there may be zero consequence. We could also drop a pipe string plus a waste package string, and there's another one in here where we just drop the waste package strong. Now we're talking about dropping assemblies that weigh something like 150,000 pounds for a string of packages; and then if you add 138 stands of pipe to that, it goes up to about 450,000. So there's really a lot of potential energy that has to be dealt with there when you look at the potential for drops.

And then if we emplace a string of waste packages with pipe, when we pull out we have 138 more opportunities to drop the pipe string onto the packages. And then there's this other problem of potentially getting stuck in the hole, and we've treated that a little bit differently for wireline versus drill string operations. But it's in the model that we have for risk, and it actually is important in certain places.

We didn't look at external hazards, feeling that for this point in the conceptual design process that they would not be discriminating.

So, given this, what is the safest emplacement method given the possible range of accidents and off-normal events? So we embarked on this cost-risk study. And this slide attempts to put a boundary around that study. First of all, if we're making a recommendation at this point, we're going to get much more input to the DBFT engineering work package before we get as far as a final decision on this.

We're making some assumptions here. I should first point out an assumption that’s not on the list, and that is that we’re not looking at the post-closure performance of the system. We’re looking at what evolves from the time that the shipping cask is parked on top of the wellhead until all of the packages are emplaced and the borehole is sealed. So we’re really looking at just the emplacement operation.

Now, we might have taken on a conceptualization of the whole field of boreholes for disposal of some waste stream that required five, ten, twenty boreholes. But, instead, we said that, really, we’re going to learn so much from the first that what we need to focus on here is the prototype borehole, so a single borehole with 400 packages in stacks of 40, separated by cement plugs, which would help bear the load of the packages.

And they would be delivered to the site at an average of one per day. That’s because you have a certain turnaround rate on the system that delivers the packages to the remote site, and that turnaround rate is on the order of three days, which we learned from WCS, Waste Control Specialists, in Texas. They have a similar operation.

Occupational hazards. Well, these are the things that happened mainly on the drill rig, so these are the falls, drops, equipment failures, things like that, things that can hurt people. They are important. The hazards are fairly low. The drilling industry, at least the high-dollar drilling industry, has improved safety a lot in the last 20 years; and we don't think that they discriminate those hazards between the two options that we're evaluating. And that's based on oil field experience.

Now, worker radiological exposures are also important. It's very important that we not dose our workers inordinately, but we think that those exposures would be low and also do not discriminate the emplacement options. And that's based on industry experience with nuclear material handling. And that's the benefit of having a contractor to support you like AREVA, where they have vast experience in handling spent fuel and other types of nuclear materials.

And, finally, we're assuming that we would apply a functional safety design approach, which is jargon for a system of sensors, cameras, and actuators that is integrated with programmable logic and really backstops human error. So you can really improve the reliability of your system if you can get people more or less out of that loop, at least the loop that leads directly to accidents. And these subsystems are used extensively in your car and people movers, you know, any cable-driven system that you might encounter at an airport. Anyway, they're fairly common. So it's not a stretch for us to invoke them here.

So the first job in the cost-risk study was to develop an event tree for what could happen. And what we have here are four major types of off-normal events. We’ve got dropping a string during assembly--this is the drill string method here--dropping the whole thing during the trip in; we could get stuck during the trip in; and we can drop just the pipe during the trip out. So each of those is quantified by a fault tree, which I’ll talk about shortly. So this is fairly standard methodology here.

Then we get down to the branches, and there are a couple of events here which are conditional on getting stuck. And they required expert judgment from our subject matter experts to try to get our arms around what’s the probability of different kinds of resolutions once you get stuck.

And all of these lead to a set of outcomes over here, which we costed. So, in principle, you could take this tree; once you had all the probabilities, you could calculate it out and multiply on the right-hand side to get probability-weighted cost and then sum that to a common numeraire. You could do that. We planned to do that. We don’t really need to, because once you see the risks, you’ll see the basis for our recommendation.

And we have a similar tree for wireline emplacement. This one’s just a little bit more complex in the middle, because it turns out that getting stuck is a little trickier with the wireline. You don’t have quite the feel or the power that you do with the drill string. And, furthermore, the drill string is already connected in the best way possible for getting unstuck; whereas, with the wireline, once you're well and truly stuck, you need to disengage the wireline and bring in a drill rig. So that's reflected in the additional complexity in that part of the tree.

So these represent fault trees. They actually are fault trees, and I'll talk a little bit about them. But we've populated fault trees for each of these major off-normal events, and the top event then is calculated from these basic events below. So this slide just gives you a feeling for the full scope of the risk model.

And this slide is somewhat tutorial, so I won't really get into it. But I will say that we used a program called Sapphire, which is sponsored by the NRC, Nuclear Regulatory Commission, which accounts for the peculiar graphic character of these plots. What you have here are a set of AND & OR gates. And when you have events stacked like this with an "and" sign, it means that they both have to occur and their probabilities multiply, for example.

And the question then really is, once you've come up with--you characterize all the basic events, all the things that can really go wrong. What then do you assign as a probability? And what we did was we took a fairly simple approach where we identified it as either one of two kinds of human error or an active equipment or passive equipment error and assigned these order of magnitude probabilities that you see. This is sort of approximate. But the only reason for drilling down further on this would be if you had some close call, if you had some matter that was emerging from your model that required more resolution.

So some of these events are actually failures of the safety system, that functional safety system that I talked about. So everywhere in those fault trees human error is backed up with some sort of engineered measure.

And we constructed all of that and then took it to a panel of subject matter experts. There are some people from within Sandia and also from outside of Sandia here, and their purpose was--their instruction was to review and update the preliminary input that we had developed on engineering concepts, on the hazard analysis, and on the cost.

So this slide is sort of a top-level summary of the risk insights that we gained from the study, and it begins with the overall probability of an incident-free emplacement of 40 waste packages. So for wireline it’s a little lower than for drill string. And that’s really because with wireline there are these--first off, it’s easier to get stuck with one package. But, secondly, it’s possible in wireline, when you’re lowering a heavy package, that it could hang up somehow momentarily and then put a dynamic load on the wireline; and ultimately that will be the thing that breaks your wireline. So that's reflected in these probabilities.

But, importantly here--this is really important--the probability of a radiation release is much lower, about 55 times lower, for wireline emplacement than for drill string. So on that alone, I could recommend that we pursue wireline emplacement.

And there are some other insights that fall out here, the probability of a failure that does not cause a radiation release but terminates disposal operations. So in the costing of this, we have assumed that if you get anything stuck in the hole, that you would decline to put any more--try to emplace any more waste in that hole. You're going to move on. So that comes in here. And we see that it's a little higher for wireline, and that's basically because there is a higher chance of getting stuck.

Then we have this one, which is a probability of a failure that leads to extra costs and delays but does not terminate disposal operations. So that's essentially zero for the drill string. So there's an interesting, sort of, risk-cost trade-off here.

And, finally, we look at the nominal cost, the cost of normal operations, about 40 million for drill string--that's 400 waste packages--and about 22 million for wireline. And then the expected cost, which brings in the probability weighted costs of all the outcomes, is very similar. What does that mean? It’s similar because the likelihood of an off-normal event is low.

So those are the insights. How can we use those going forward? One of the things we can do, we can use that model to actually design the Deep Borehole Field Test demonstration. Now, do we need all the bells and whistles of a disposal system in the demonstration? Maybe not. But if we’re going to eliminate something on cost or schedule or because it’s an engineering task that’s well understood, then we need to know what we’re doing to our risk model, so we’re prepared to do that. Our report has an example.

And, lo and behold, there are a few remaining conceptual design questions. They’re probably far more than I listed on this slide, but I wanted to go through a couple of them just to give you an idea of where we are in the process. AREVA is on board and coming up to speed. Working with them, we’re going to deal with some of these. These are the, sort of, near-term ones that I consider to be of importance to the field test itself. So we need to work on concepts for the disposal interval completion.

So this might include things like just exactly what perforation scheme we’re going to use in the casing down there. That was brought up a little earlier. And the primary reason given for having perforations is to control fluid that would be expelled from the disposal zone during heating by the waste. And the goal there, of course, is to keep that fluid from developing the pressure that could drive past your seals and/or potentially damage your seals. So we understand that. But at the same time, the perforations affect the behavior of a package if you drop it in the hole. So it’s coming down, it’s viscously damped until it gets to that zone, and now it has less resistance.

So we need to understand the relationship between the geometry of the package in the casing, the number of perforations, and the viscosity of the fluid, look at eccentric arrangement of the package in the casing, things of that nature, so we could really make a definitive statement about the potential for package breach if you drop one.

ZOBACK: Ernie, just a time check. You guys have been speaking now an hour and 12 minutes, so we want to leave time for questions.

HARDIN: No problem. Okay, yeah. I was working to a quarter of 12:00.

ZOBACK: That’s including questions.

HARDIN: Oh, that’s the limit for bumping up against the stop, so, okay, very good.

ZOBACK: No, that was to allow questions as well.

HARDIN: Okay, well, I won’t go through these in gory detail. Some of these have already--have been tasked to

AREVA to think about, and some of these Sandia will work on in the next year. So hopefully the next time I see you we can have more new information to share about what we've learned on sinking velocity and other topics.

In addition, there are some more global topics that will need to be addressed. If we go to a complex set of equipment in a shielded basement, we're going to have to figure out how to fix it, because the conventional means of repair are simply not going to work in a radiological environment. That gives you an idea of the kinds of challenges that are there.

And there might be a few things we can do to prevent packages from getting stuck, and we'll look at those also. And ultimately the drop at the surface where there is no fluid to dampen the dynamics could be the limiting drop for us.

Finally, the seals technology R&D program, this is a reference depiction of the seal system. It also includes API-type plugging that would be done near the surface. I won't get into it in too much detail. We've already talked about the fact that we're following up on different materials, so bentonite swelling clays, other clays, different kinds of cement.

And the work on those materials has been going on for almost a generation in the field, but we're trying to evaluate some of the materials we'd like to use against the environment, which is chloride brine and elevated temperature, plus we have to emplace these materials at depth, which, for most of them, means we have to pump them down a couple of miles, and that requires a retarder. And so all of these things might affect the properties and the longevity of cement.

I should point out that some of the programs, for example, the Japanese program, is planning to use cement and rely on its integrity for many thousands of years. So I think we might be able to do something similar.

And this, of course, summarizes those materials and also mentions that we are supporting work by Olympic Research on their fused plug idea and that University of Sheffield is working on rock melting, which would be done electrically. And we can talk about that more later, I guess, when Professor Gibb is up here. The cartoon just decorates this slide, but it's one of SKB's very early demonstrations of how their borehole sealing apparatus would work.

And so these are studies underway. And this slide also is more or less exactly consistent with the one that Tim Gunter showed you earlier. So we are supporting projects at RESPEC, Olympic Research, at MIT in using millimeter wave technology to melt rock, and also some advanced work on selection of cement for grouting and sealing.

And then we have our partner labs and subcontracts. The University of Sheffield contract has just been let. But this one is a maybe. We are involved with the KAERI in their URL, Underground Research Lab, on a set of experiments that may include sealing. We're talking about that. And then Los Alamos is involved in the laboratory work on smectites. And then we are starting to participate in the SubTER program, which is a priority for the DOE.

So that is it. Most of what I've presented here you'll find in this 2015 report right here. Thank you.

ZOBACK: Okay, thank you very much. A lot of ground has been covered, and I know we're going to have lots of questions. This is a chance for everyone to question DOE directly on their plans, so I'm going to start with Board members. Jerry.

FRANKEL: Jerry Frankel, Board. So I'm going to come back to the question I asked Tim Gunter. You know, all of your cutaway slides say that the field test, one of the objectives is to evaluate and test seals. But it seems like all of your seal work is laboratory-based. So is there any testing of seals going to be done in the field test?

HARDIN: My answer is maybe later, maybe later. We're talking about a heater test, and that's part of the scope of the Characterization Borehole. It would be at some point later in that program to do a heater test. And the heater test may very well have a seals-type component to it. We’ll see. Don’t know yet.

FRANKEL: But you’re using this field test to come up with the assessment of your safety case, your post-closure safety case. I mean, is there going to be some--I mean, it seems to me you would need to use this opportunity to develop the safety case for the long-term survival of seals for these large boreholes.

HARDIN: Right. You know, it’s a tricky problem, because the behavior of the sealing materials that probably concerns some of our folks the most is longevity.

FRANKEL: Right.

HARDIN: So that type of experiment needs to be started in the laboratory.

SASSANI: I’ll just add a little bit to it. There’s two aspects of that. One is, you know, the aspects that we’re looking at directly, if we can’t demonstrate that we can do this, well, you don’t have to do any sealing work, right? So that’s why it’s a little bit on the back end of the whole R&D program. But we do have--and was the KAERI work up here? We do have a field borehole that’s going to be going on in South Korea that’s not at 5 kilometers depth, but it will be a fairly deep borehole starting from their Underground Research Lab. And we’re looking at that to plan maybe some in situ seal testing.

ZOBACK: Okay, Sue.

BRANTLEY: Sue Brantley, Board. Am I working now? He tells me I'm working now. I didn't have a microphone this morning. I wonder why. Thanks for--

SASSANI: I had nothing to do with it.

BRANTLEY: Thanks for trying to answer my questions from this morning. That was great.

I just wanted to talk about the straightness of these boreholes. In your images and movies they're all perfectly straight. Can anybody tell me whether these boreholes that go down 5 kilometers in crystalline rock are perfectly straight?

SASSANI: There are people who can speak to that better than I, but given--

BRANTLEY: And why don't we let them.

SASSANI: I was just going to say, given the scale you were seeing them at, that's probably how straight they are. But I don't know if Steve Pye would like to talk about--

BRANTLEY: Well, I think Mary Lou wants that to be--

ZOBACK: We're going to touch on that.

SASSANI: Okay. There are directional drilling technologies that can keep you very straight, for the borehole anyway.

BRANTLEY: Okay, that's to scale, but then as you send something down there, that's where we get worried about something getting stuck. So I think it's, you know, a little bit confusing.

The other thing I wanted to ask about, I think you've said--did I get this correct?--that you're not going to be cementing in the casing so that you could pull it back up if you had to. Did I get that right?

HARDIN: Part of it, yes. Hardin, Sandia. So that borehole would be lined--we're talking about the Field Test Borehole here, so the large-diameter hole would be lined down to a station just above the crystalline basement contact. It would be lined with steel and cemented. And then everything else that went in the hole would--the guidance casing and the casing that was hung in the disposal zone would be uncemented.

BRANTLEY: I guess I'm getting confused in the details. I mean, you know, as I understand that, with boreholes, say, in Pennsylvania, which are much shallower, the casing is what--I'm sorry--they like to think that the casing keeping the movement horizontally from happening, but the cement keeps the vertical from happening. And when the cement problems happen, we get gases coming up along our boreholes.

Are you planning to have cement so that they wouldn't have any gas movement up along your borehole?

HARDIN: Okay, Hardin, Sandia again. Frankly, I don't think we're going to need it. The point of the casing plan is to isolate the overburden interval and then leave the basement accessible. And that's particularly true in the Characterization Borehole, which will essentially be an open hole completion in the basement interval.

So, no, I don't think that gas movement is going to be important in the basement. That remains to be confirmed, let's say. That's one other reason for drilling a characterization hole.

BRANTLEY: Test it, test it.

HARDIN: Yes, it would be tested.

ZOBACK: Rod.

EWING: Rod Ewing, Board. Ernie, I'd like to go back to the fault tree analysis. Certainly it gives one a lot of insight into the possible types of accidents, so it's very useful, and I appreciated your presentation.

But I'm always surprised at the end of the fault tree analysis how low the probabilities are of accidents, right? For the drill string, 99 percent of the time you'll get 400 waste packages down the hole without--it's called incident-free. So that's fine, that could be, but can you draw on actual experience to test your analysis?

I mean, in the oil patch there are lots of accidents on drill rigs, lots of different types of accidents. Certainly there are fault tree analyses. They go with those. So have you looked at what the actual experience is on drill rigs?

HARDIN: We're doing that now.

EWING: Okay.

HARDIN: We have an effort to pick a few databases and see whether they help us. The tendency when you do that is you're going to bring in more detail in the conceptualization of the system that you're describing, so there's a phenomenon that occurs called disaggregation. So you break a process down into subprocesses and so forth, because you need the subprocess level conceptualization to match the industry data. Disaggregation comes--a distortion in the overall top in that probability. So it--

EWING: Yeah, I understand that, but a more fundamental question would be to look back at the fault tree analysis before the accident and analyze the approach just to get an idea of whether generally with the fault tree analysis you get a high or low number. I don't know the answer, but it seems like accidents occur more often than our analyses would indicate.

HARDIN: You could turn that around and say that, really, some of these drops that we're talking about here, which would be almost catastrophic, are quite rare in the oil business. I mean, they don't drop pipe streams very often. And you could back out of that--and we have--in the scoping manner, what the event-wise probability of it really is. And that’s how we can justify something like 10^{-5} or 10^{-6}.

EWING: Okay, thank you.

HARDIN: It’s a point well-taken.

ZOBACK: Jean.

BAHR: Jean Bahr, Board. Another question related to the fault tree analysis. One of your categories was probability of a failure that does not cause radiation release but terminates disposal operations. And my question is, over what time scales is that not a radioactive release? Does that mean that it doesn’t cause an immediate radioactive release to the surface; but if it terminates operations and hence precludes good sealing, perhaps could it lead to a long-term release or something that would lead to a long-term release not in that category?

HARDIN: Okay, so we are on our second or third choice of words for that statement. And by “terminate” what we meant was that you have just lost the use of that borehole for any further disposal activity, but you can still complete it according to plan.

BAHR: Okay, thanks.

HARDIN: There are some outcomes on those trees where you really lose it, but we think we’ve found a way to avoid most of them.

ZOBACK: Paul.

TURINSKY: Paul Turinsky, Board. Just a point of clarification. What exactly is going into the test hole?

HARDIN: One or more test packages. I think that's the answer; right? We don't know exactly how many test packages will be built for the demonstration yet. It's going to be some number probably greater than three and less than ten. We'll build enough for destructive testing, and hopefully we'll be able to drop a few of them down the hole and see what happens. Does that answer?

TURINSKY: Okay, yeah, it does. And seals--are seals going to be placed to see the process?

HARDIN: No, there are no current plans to run a seals emplacement-type experiment in either of the boreholes, currently.

ZOBACK: Any other Board questions? Efi.

FOUFOULA: Efi Foufoula, Board. I'm sure you're familiar with the concept of probable maximum flood that is used for the design nuclear power plants and so forth. And this is based on a similar kind of probabilistic theory and so forth and some concepts that cascade of probability of failure. And the end products are probabilities then to the minus 7 of failure and so forth.

But probably you are also aware that in the last two years the National Weather Service has updated this probabilistic maximum flood, probabilities of failure, because events have happened that they were not anticipated before or, you know, we have seen extreme events, much more than we knew 60 years ago and so forth. So in every probabilistic analysis of that sort, there are the unknown unknowns and the known unknowns and so forth.

So talking about such low probabilities, if there is one thing that we would say is unanticipated and not accounted for but would just break the whole concept, what would that be?

HARDIN: I haven't found it. But I want to say that this is not the last word, the safety of this system. If and when we ever get to go ahead to do a disposal system, we have a site and so forth, there would be a much more extensive probabilistic nuclear safety analysis done on the order of what was done for Yucca Mountain, maybe not in all of that complexity, but--yeah, the requirements are there, and they're much more rigorous than what I've showed you today.

ZOBACK: Any other questions from the Board? I have one myself--Mary Lou Zoback, Board--and that is, you didn't discuss things such as what if a weld was faulty and when you went to join two packages you literally sheared the top off the weld. How does that get captured? You know, no one was going to substitute organic kitty litter in the waste packages going to WIPP either, but it happened. And every accident in a nuclear power reactor has been a human error.

So it seems to me there's many more sources of errors than you've captured.

HARDIN: Right. So that's a good point. And the methods used to inspect and verify the package fabrication are really important. And that's going to be part of the scope of the engineering services that are provided to the Deep Borehole Field Test. I mean, I look at it a little bit differently. I don't want the package to crush in the hole for any reason at all during the test. How do we make sure that doesn't happen?

EWING: Can I ask a follow-up?

ZOBACK: Rod.

EWING: Just on this issue of inspection and reducing the probability or the possibility of accidents, so with the cesium and strontium samples, they're not pure cesium chloride, strontium fluoride. There's transportation effects; the chemistry is changing; if you read the reports, some of them slide up and down in the canisters; there's been volume expansion.

So will you inspect or in your strategy will you be checking carefully the material you put down the hole?

HARDIN: Don't know. I would assume that some necessary level of inspection would occur. We haven't addressed that in our study. That's kind of a vacant answer, but that's exactly where we are with it.

ZOBACK: We appreciate honesty.

I’m going to pause right now, because we have run into our public comment period, and I know panelists have indicated there’s a number of questions there. But we also always invite members of the general public that have signed up. So my question is: Has anyone signed up on the sheet?

Since we don’t know that yet, I can’t remember--I think you were--no, behind you gentlemen, right, first to come up and, again, identify yourself. Thanks.

SRIDHAR: Thank you. Narasi Sridhar, DNV GL. In your fault tree or risk analysis, you mainly focused on what I would call instantaneous failures, things drop, things break, and so on. But you have 400 waste packages. And assuming one a day if everything goes well, you have more than a year, but not everything will go well. So you’ll have a time-based risk where these things are hanging by threads or whatever.

So have you considered time-based events where things are degrading due to exposure to whatever, you know, downhole environment?

HARDIN: Hardin, Sandia. I think we have considered that. We have a specification for the corrosion lifetime of the packaging simply because we have to accommodate some unforeseen delay. And we’ve also talked about what happens when the string is hanging for 40 days from the surface. Are there some sort of unforeseen conditions that might result? Thermal is one of them. So what happens if two systems break down, your mud circulation goes, and something happens to your chain of supply, and now you have a thermal problem in the hole? Yeah, we've considered that, but we haven't dealt with it explicitly.

SRIDHAR: May I ask a follow-up question?

ZOBACK: Quickly.

SRIDHAR: So in the fault tree analysis one of the major issues is that the basic events don't interact, cannot interact. They are independent. But, really, in these kinds of time-based events, you need to consider interaction of some of the basic events. Have you thought about that a little bit, for instance, where you have a creep of something hanging and then some other weld problem occurs, for example, things like that?

HARDIN: Since we're dealing with instantaneous events, I don't think there's much overlap in that way. So that would be a topic for a future analysis.

ZOBACK: Thank you.

We have no one signed up for public comment, so I invite anybody that has a question to come up to the microphone, and we'll try to get to as many questions as possible before our noon break.

Yes, go ahead.

GARWIN: Richard Garwin, IBM Fellow Emeritus, Panel 7. I certainly welcome evaluation rather than confirming. Very difficult to maintain that as the program goes on.

In particular, what is known about hydrogen bubble generation and creep to the surface from the test wells? Because you’ve got a casing which will corrode, and you have a path all the way to the surface, you block it macroscopically with bentonite or whatever, but there are still rock fractures close to the borehole. So what is known and what is the test for such things in the program?

SASSANI: That's a good question, and it’s one of our active areas of discussion and research. But it’s very similar to what’s been done in the European FORGE program looking at the fate of repository gases in the EBS system, where they were concerned there with generation of hydrogen and actually disruption of their engineered barriers, things like blocks, clay bentonite barriers around the packages.

And, in fact, they have a little bit--it’s a little different, because we have a lot greater depth, so we can have higher pressure. And we have materials that are corroding that are also in reduced conditions or reducing conditions in most saturated repository systems, so you’re getting the same kinds of reactions going on. Hydrogen under these systems, we expect that it will migrate in solution. It diffuses fairly readily.

But in terms of overpressuring these systems, I won’t say it’s likely impossible, but you could--if you generate hydrogen gas continuously from a large enough mass of metal, you might generate separate gas. You'd become-- basically, your hydrogen partial pressure equals your total pressure. So in those systems in our case, our bentonite buffer, the permeabilities of it I don't think will approach the low permeability of the intact crystalline basement rock. So that's why we expect that to be the pathway.

And then there's the disturbed rock zone that's in the annulus, which, depending on how invasive the seals are, that may or may not be as well sealed. So we would figure on having at least orders of magnitude permeability deltas in there, one, two, three orders of magnitude, and still have substantial performance from the system. But I think it will actually provide also a fairly direct pathway for any gas to move out.

I think it was the Kola borehole where hydrogen was observed to be escaping. It wasn't doing anything substantially bad. And we're looking right now at kind of the oil field industry and the experience from oil wells, which have been out there for decades with casing in them that should be undergoing degradation reactions and generating hydrogen, to see if, you know, do you generate migration and seepage of hydrogen out of the system, or does it do something that's substantially different than that.

ZOBACK: Okay, next question. And, again, come on up;

and if you line up, then we can get questions as quick as possible.

PUSCH: Yeah, I have a question to the Sandia representative concerning the--

ZOBACK: Identify yourself again.

PUSCH: Is that louder?

ZOBACK: No. Identify yourself.

PUSCH: Oh, my name is Pusch. I am a professor from Sweden. I have been working with these things for 40 years, I think almost a hundred years. I'll come back to that later in the afternoon, and that will touch on a number of questions that have come up here lately.

The question I have concerning the investigations into boreholes, when we are down there at the bottom of the hole, we have 150 centigrade. That means that the creep property is changing. Have you considered the creep and creep-related risk of failure of the rock?

SASSANI: I'm not sure we've looked so much at creep of the rock at this point. At 150 degrees, I'm not too concerned about the rock creep. The materials creep may be more substantial, but we're--you know, we would be emplacing over less than about a year and then sealing the borehole and going away. And so at that point, particularly with the way we do our safety assessments and not taking any post-closure credit for the canisters--

PUSCH: No, creep is not in the crystal matrix. It is in the fissures that have chloride in them and things like that. You get movements, and this can generate failure of the hole.

SASSANI: Yes.

PUSCH: I have two other questions.

ZOBACK: Make them quick, because it’s lunchtime.

PUSCH: Very quick. And that was concerning the concept of having the respective container units connected to each other. It’s a series; is that correct? It’s a series of connected containers?

SASSANI: Yes.

PUSCH: And they make up a set of maybe three, four, five containers?

SASSANI: Or more.

PUSCH: And when you put one down there and you come with the next, how do you connect these two?

HARDIN: So the packages are stacked, not threaded together in the hole. So they are simply emplaced one on another without connecting the threads.

PUSCH: There can be some slight displacement. You cannot guarantee that they have complete connectivity between each individual package. That’s all.

HARDIN: That is correct, yeah. There is no effort in this concept to center.

PUSCH: I don’t think that matters very much, but it’s important with respect to the quality assurance. You need to know where each individual canister--where they are. And that would speak in favor of the drilling technique. Use the drilling logs to put them down, to keep them there for a few minutes to make sure that they stick there, and then go up with the drilling strings again and bring down the next set. I think that is an important thing, quality assurance. You know where the things are.

ZOBACK: Okay, thank you.

A quick question? Both of you have been waiting, and I’d like to let you get in. Go ahead.

BRACKE: Guido Bracke from GRS Germany. I think it’s a quick question. Is the recovery or retrieval of the test packages possible? If yes, how it is done; if no, could it be done?

HARDIN: Hardin from Sandia. So retrieval is always the question that comes up with borehole disposal. For the Deep Borehole Field Test we will retrieve--we plan to retrieve all the packages. And for a disposal operation, I would say that’s not really determined. We know that we’ll be able to retrieve them for a period of time, for some months, for years; we could retrieve them. And then after that, after the borehole is sealed, we don’t know at this point whether that could be done practically. But we also don’t know if it’s required. So in the U.S. regulatory context, it may not be required even if it could be done.

GRUNDFELT: Grundfelt, Sweden. A very quick question, pick up from where Rod Ewing was. He said it was a very low probability for radioactive release. You had about .121 percent probability per 400 canisters. That means about 1 to 10 percent per borehole. That sounds pretty high to me.

HARDIN: I think you might have the numbers wrong. So the results I showed in that summary table were--

GRUNDFELT: 10^{-4} to 7 times 10^{-3} per were on the canisters.

HARDIN: For the entire operation.

GRUNDFELT: For the entire. Okay. I thought it was per 400 canisters.

ZOBACK: Okay. We need to be organized for lunch. So I’m going to ask that everyone exit through the back door, pick up their lunch, and come in through this middle door and get your seat as quickly as possible, so we have Fergus Gibb’s speech. Thank you. We only ended a couple minutes late, but I wanted to let the four visitors speak.

(Whereupon, a lunch recess was taken and the lunch presentation by Fergus GF Gibb was transcribed by another firm.)

UNITED STATES NUCLEAR WASTE TECHNICAL REVIEW BOARD

INTERNATIONAL TECHNICAL WORKSHOP ON DEEP BOREHOLE

DISPOSAL OF RADIOACTIVE WASTE

LUNCHTIME PRESENTATION:

INTERNATIONAL PERSPECTIVE ON DEEP BOREHOLE

DISPOSAL

FERGUS GIBB, UNIVERSITY OF SHEFFIELD, UNITED
KINGDOM

TUESDAY, OCTOBER

20, 2015

Embassy Suites
1250 22nd Street, N.W.
Washington, DC 20037

Reported by: Christine Allen,
Capital Reporting Company

P R O C E E D I N G S

12:14 p.m.

ZOBACK: Okay. It looks like everybody followed the directions on the doors and got their lunches. I'd like to ask you to take a seat if you could. We would like to get started.

We are very fortunate to have a very distinguished lunchtime speaker today. For our lunchtime talk, we're going to have Fergus Gibb from University of Sheffield in the U.K. give the talk.

Fergus got his Ph.D. in geology from St. Andrews and went on to lecture in geology at various universities. He ended up at Sheffield in 1973, became a senior lecturer there.

Interestingly, after being in geology for many years, in 2001, he actually switched over to material science and engineering, and has been working in that group since. He now has a Chair in the Material Science Department that is partially funded by the Nuclear Decommissioning Authority in the U.K. He is working in the immobilization lab there in Material Science.

As I mentioned in my introductory remarks, I really credit Fergus more than any other scientist for really revitalizing providing scientific credibility to the deep borehole disposal idea, and today, we are very lucky to hear from him on the international perspective on deep borehole disposal.

Fergus?

GIBB: Thank you, Mary Lou. Well, when I started working on deep borehole disposal, about 25 years ago, I could never have envisioned I would be standing here today, and very grateful to the Board for their invitation and opportunity to give this presentation.

I am going to give this in four parts. I am going to give a brief history of deep borehole disposal, followed by a few comments on some of the potential benefits of boreholes. I shall then look at how boreholes have featured in international programs, excluding the USA, of course, and then for the remainder of the time, I am going to look at some important differences between the various types of deep borehole disposal schemes that have been put forward, and the technical issues these raise, the options they provide, and the challenges they present for implementation.

As we heard earlier, the idea of putting radioactive waste down holes in the ground is not new. What I am going to do is just list some of the key milestones that have brought us to where we are now. Inevitably, this will be a rather subjective list.

Deep borehole disposal, which is also sometimes referred to as very deep holes, particularly in Sweden, or very deep disposal, which we used to call it in the U.K., has been around since the early 1950s. It was suggested both in the United States and the Soviet Union.

The first serious consideration of it was in 1957 when the U.S. National Academy of Sciences considered it as a possibility but rejected it in favor of mined engineered repositories largely on the grounds, as we heard earlier, that the technology did not exist at that time.

However, the idea did not die. It resurfaced in a number of reports through the 1970s. In 1983, Woodward-Clyde produced a seminal report in which they presented a reference system for deep borehole disposal. This called for a 20-inch hole to a depth of 6 kilometers.

This report was largely speculative because it was based on a projection of what would be technically possible by the year 2000. But, it was remarkably prescient. It has been influential in many of the subsequent borehole disposal schemes, including the one we heard about this morning.

In 1989, Juhlin and Sandstedt produced a very detailed two-part report on disposal in deep boreholes for SKB, the Swedish nuclear waste management organization. As I said, this was in two parts. The first part looked at the geological situation, geological benefits of deep borehole disposal, albeit in a Swedish context, and the second part actually presented an engineering design.

This report was obviously influenced by SKB's work on mined repositories, and it was based on a 50 centimeter diameter titanium container that would take four boiling water reactor assemblies or 1PWR and two boiling water reactor assemblies. Obviously, it needed a very large hole. In fact, it called for an 80-centimeter hole.

Throughout the 1990s at the University of Sheffield, we were investigating the geological feasibility of deep borehole disposal and produced a number of reports and papers like this one here.

Our initial focus was on what we called "the high temperature version" of deep borehole disposal, in which the waste packages would generate sufficient heat to partially melt the host-rock with subsequent cooling, re-crystallization, encapsulating the waste packages in the sarcophagus of solid granite, which would be continuous with and virtually identical to the original host-rock.

By 2003, we had realized that while the high temperature version of deep borehole disposal was scientifically feasible and it might indeed be the best possible version from the long term safety perspective, implementation would be a step too far, particularly given the realities, the political realities, of the industry and the waste management organizations.

So Neil Chapman and I published this paper in which we set out the case for low temperature versions of deep borehole disposal, which is the type we are all familiar with now.

At the same time as we were working on the geological feasibility of borehole disposal, there was a group at MIT led by Michael Driscoll, who was working on the engineering aspects. This work, and I strongly suspect Michael's influence, fed into the report in 2003 by a group of very distinguished academics, including Secretary Moniz, into the future of nuclear power.

Among their recommendations was the Department of Energy should broaden its long-term waste program to include deep borehole disposal.

Now, opponents of deep borehole disposal had always argued that no one had ever drilled such big deep boreholes before, and therefore, they were beyond the capability of the drilling industry.

It was a major step forward when in 2008 the Nuclear Decommissioning Authority in the U.K. commissioned this report on the "Status of Technology for Borehole Disposal," written by John Beswick, who was mentioned earlier, who is an international expert on deep drilling in crystallized rocks.

He concluded that boreholes up to 50 centimeters in diameter could be designed and implemented more or less there and then. Larger boreholes, up to about 75 centimeters, could be done but would require some technology development, and he also advised that even larger holes like a meter or larger should not be considered at that time because they were outside the envelope of experience.

Well around this time, Sandia National Lab became very interested in deep borehole disposal, and the appearance of this report marked a step forward because it was the first real quantitative performance assessment of the concept. Although it was rather simplified, and used very conservative assumptions, it did confirm that there was an exceptional degree of safety to be gained from deep borehole disposal.

A couple of years later, Sandia produced another report giving a reference design for deep borehole disposal, which was the one that Ernie and David were talking about this morning, and this called for a 17 inch hole, which is quite a bit smaller than most other deep borehole schemes, but they were putting it down to five kilometers. At that time, it was kind of pushing the envelope a bit.

Of course, as I'm sure everybody knows, in 2012, the Blue Ribbon Commission reported to the Secretary of Energy. They identified deep borehole disposal as a potentially promising technology, which merited further research and development.

The rest you know, last year, the Department of Energy's assessment of disposal options committed to a program of research on deep boreholes, and called for a practical demonstration of the technology. The rest of the story, we know all about. We have heard it. It is going ahead.

Around the same time, we demonstrated that deep borehole disposal would work very well for very high heat generating waste, such as the MOX or high-burnup spent fuels likely to arise from the next generation of reactors that are going to be used in newly built power stations.

This has a lot of advantages in that particular scenario because it could eliminate the need for over 100 years of pre-disposal cooling, which you would require for disposal in a mined repository. So, deep borehole disposal is not just safer and better, it can do some things that normal mined repositories would struggle with.

The state-of-the-art is kind of summed

up in this report by Beswick, et al, which identified some very interesting engineering issues and discussed them at some length. If anyone would like a copy of that, we have got some of them with us.

Moving on to the potential benefits of boreholes, it is often argued how many benefits there are potentially, and I'm not going to go into these in detail because they are pretty well known, particularly things like safety, which we heard a little bit about this morning.

I'll comment just briefly on one or two of the less frequently mentioned ones. Most borehole disposal concepts are aimed at spent fuel, unlike here in the U.S. The rest of the world was looking to get rid of spent fuel. When it comes to disposing of spent fuel, it is about an order of magnitude more cost effective.

To dispose of a ton of heavy metal in a borehole, it would cost less than 20 percent of the cost of disposing of it in SKB's planned repository. The environmental impact, of course, is much smaller because not only are the surface facilities for a borehole much less than a mined repository, but the key thing is it is transient.

It would take less than three years to drill, fill, and seal a borehole. Once the rig is moved off the site, the environmental impact is effectively zero. Contrast that with a mined repository, which could remain open and operational for over 300 years.

Now dispersed disposal is an issue. Rather than having one or two very large facilities, you can have any number of small ones, even down to an individual nuclear installation disposing of its own waste on a near site given suitable geology. That, of course, could reduce or maybe even eliminate some of the transportation problems, which can be quite particular, particularly in a large country like the U.S.

A small disposal program using boreholes could be expanded as and when required, and a large one could be terminated at any point without any significant further costs. Again, contrast that with a mined repository where most of the investment is up front before any waste is disposed of. It is effectively a "pay as you go" system.

Fukushima reminded us all, of course, of how important it is that nuclear facilities can withstand the effects of a tectonic event. Seismic shear waves will not disrupt the gravity-stratified groundwater in the crystalline basement. Even if an earthquake ruptured the canisters and damaged the other barriers, the groundwater into which any radionuclides might reach out is going nowhere. It would not disturb the isolation, and therefore, it would not threaten the overall safety of the disposal.

Very few countries have seriously looked at deep boreholes. The U.S. is now setting the pace, but it is very difficult to interest governments and waste management organizations in a concept like deep boreholes. Of course, this is largely because of the huge investments they have made in time, money, and effort already in mined repositories.

There is also a growing alarm among the supporters of repositories that deep boreholes could divert attention and resources from repositories, could damage public confidence in them, and delay their implementation even further. There is a lot of resistance to getting deep boreholes into anybody's plans. Nowhere is this more true than in the United Kingdom.

Back in 2004, Nirex reviewed the deep borehole disposal concept, highlighted the fact that there was no practical demonstration of it anywhere, and considered that the investment in time, money, effort required to bring it up to the technical readiness level of borehole disposal was prohibitive.

A couple of years later when the Committee on Radioactive Waste Management reported to the government, they recommended for the U.K. high activity waste that the best option at that time was geological disposal in a mined and engineered repository, but they added the rider that any decision making should leave open the possibility that other options such as deep borehole disposal could emerge as a practical alternative.

Nevertheless, a couple of years later when the government did announce its policy, boreholes were more or less forgotten about, and all they said is that the Nuclear Decommissioning Authority would also keep options such as borehole disposal under review.

In 2011, political pressure at the highest level was brought to bear on the implementers to accelerate the geological disposal program, and in response, the NDA reviewed options, and they did identify the use of deep boreholes to bring the first disposal of high-level waste forward from 2075 to 2040, which at the time was the plan.

However, last year when the government updated its policy, yet again boreholes fell through the gaps, and the U.K. has made no change to its commitment to a mined and engineered repository for its high activity waste - to if and when they can find a willing community and a suitable site.

Earlier this month, the implementers, the waste management organization, kicked the whole thing further down the road for another 10 years.

Sweden is the only country that has seriously considered deep boreholes. In the late 1980s, a series of reports for SKB culminated in this seminal work by Juhlin and Sandstedt that I mentioned earlier, and was followed a few years later by SKB's Project Alternative Systems study, in which they compared their own very deep hole concept with their KBS-3 mined repository concept, and a couple of other repository schemes.

They concluded that the long term safety of very deep holes was potentially as good as the long term safety of a repository, but it was much more difficult to demonstrate. At the end of their analysis, perhaps not surprisingly, deep boreholes were ranked last.

Ever since then, SKB's position has been that it would take 30 years and a massive investment to bring the technology for deep borehole disposal up to the readiness level of their KBS-3 mined repository, and the KBS-3 concept remains their preferred option.

However, the Swedish government and the regulators pressed them to carry on looking at alternatives, and they did so, and they produced a number of reports, which were not unhelpful to deep boreholes, like this one by Harrison in 2000, which showed that the borehole could be drilled.

In his report, Harrison modified the original deep borehole concept slightly by replacing the titanium containers with steel and enlarging the disposal zone from 80 centimeters to 84. He basically concluded that the well could be drilled with currently existing technology, although it would be a bit difficult.

Also, reports like this one, which looked at the groundwater and said even for an array of 45 boreholes, which would take care of the whole of the Swedish spent fuel inventory -- I switched it off.

This concluded that the heat output from the spent fuel in this array of boreholes would not jeopardize the stability of the saline groundwater system.

In Sweden, the law requires that SKB consider all the possible alternatives and then justify their choice of disposal concept. In 2010, they commissioned a report that compared the KBS method again with their own very deep hole disposal system, and this formed the basis for their rejection of deep boreholes when they applied in 2011 to the Environmental Court for permission to start constructing a spent fuel repository at Forsmark.

The application was challenged by a number of organizations on various grounds, but including the rejection of deep boreholes, and the suggestion was made that the argument was flawed, not least because they had compared the current version of the KBS-3 repository concept with the 20 year old very deep hole concept that they had commissioned earlier.

In 2014, under advice from the

Environmental Court, SKB submitted a revised and reduced case against deep boreholes. I think a decision is fairly imminent, and we just wait to see whether or not the Environmental Court accepted that.

Germany is the latest country to show an interest in boreholes. Germany has about 10,000 tons of spent fuel and about 300 canisters of vitrified reprocessing waste. Most of this is in storage, either in fuel forms or dry storage. It is awaiting disposal, but of course, three years ago they abandoned their plans for a mined repository in salt in Gorleben, and essentially like many other countries, it now has nowhere to go.

In 2013, the German government set up a 33-man commission to look into finding a final disposal site for the high level waste. This commission has until 2016 to select the criteria it will use and then to find or at least begin the search for a site.

Last year, a group of individuals,

academics, nuclear industry employees, government employees, came together to form a group to promote deep boreholes. They were very successful. They are based at Karlsruhe Institute of Technology, and they managed to persuade the commission that it ought to look at alternatives to mined repositories in their deliberations.

Last June, they organized a very successful conference in Berlin, and the outcomes of that conference have been fed into the commission in its subsequent meeting. We just have to wait and see what they made of it.

There are not many other countries that have looked at boreholes but among those that did was Russia, where they actually got as far as putting forward a proposal to dispose of spent boiling water reactor fuel in deep boreholes at or near their nuclear power plants, and to the best of my knowledge, nothing came of it.

In the late 1990s, representatives of the Czech Republic approached us at Sheffield and asked for information about deep borehole disposal because they have a fairly small inventory of spent fuel. Basically, they were interested but they decided they could not afford to develop the technology.

More recently, as we heard this morning, South Korea is interested, and some of their scientists are involved with the Sandia program and have attended and participated in the workshops on deep borehole disposal. Similarly, China is interested and scientists from Sandia have been across to China to participate in discussions.

But basically, the list is pretty short. There are not a lot of countries that have done much apart from Sweden, and I think it is safe to say that if someone developed successful deep borehole technology, there would be a pretty good market for it.

What I'd like to do for the rest of the talk is to look at issues, options, and challenges for deep boreholes. Within the generic concept, there are many different versions that have been put forward, and these differ considerably in detail and approach. These differences are quite important because they give rise to technical issues and create options that really need to be considered very carefully in any practical borehole implementation.

Three of the areas in which the options and challenges need to be particularly considered are waste package deployment, near field safety cases, and of course, the sealing of the boreholes, which has already raised its head this morning.

Before I get into these and talk about how you would select options, there is an important point that is worth reiterating. Drilling and casing the borehole and construction of any wellhead facilities is just a large engineering project like any other. It will inevitably encounter problems. These can be tolerated and dealt with and remediated by all the usual methods, but only with the normal operational safety requirements of any large engineering project.

However, the arrival of the first active waste package at the wellhead changes the whole situation because it now becomes a nuclear facility, and this means any unplanned intervention could be very difficult and potentially hazardous.

So, the success of all subsequent operations and procedures must be virtually guaranteed.

I conclude from this that the criteria for selecting from any possible options is they must be simple, they must involve minimal risk and maximum reliability. They must be as fail safe as humanly possible. They must be as fail-safe as humanly possible. This might seem like stating the obvious to this audience, but it's worth remembering.

When we come to the issues themselves, starting with waste package deployment, there are two areas in which significant options are available. One is the way in which the packages are deployed, and the other is the question, which Ernie addressed this morning of whether you deploy them singularly or in multiple strings.

When it comes to the method of deployment, there are four ways that have been suggested for doing this. First, is free fall. This is not as bizarre as it might seem.

(Laughter.)

DR. GIBB: Descent rates can be managed by the hydraulic damping effect in the borehole fluid, and terminal velocities can be kept down to like 1 or 2 meters per second, which would effectively eliminate any damage to the packages, even if one fell down the hole, it would still hit the bottom at 1.5 meters per second, which is going to do nothing to an two inch thick steel container.

Unfortunately, while it does allow for the fastest way of getting the packages down the hole, there is a horrible lack of control, and it's very difficult to get them back. I think we would happily kick that out.

Drill pipe is of course the method that most borehole disposal schemes would advocate. It is a tried and tested method of downhole intervention, and it is well within the capabilities of the oil and gas industry, the drilling industry.

Unfortunately, the need to screw the sections of drill pipe together, as we saw this morning, makes it quite slow, and realistic run trip times are probably in excess of 18 hours. It also requires fairly skilled operators to achieve any sort of reasonable run trip time, and of course, the drill rig to be kept on the site until end of the deployment program.

Wireline is the traditional method of speeding up downhole operations, but while it can be run very fast, it does have problems. There are load limits. The wirelines can stretch, control is difficult, and fast running carries the risk of entanglements, which necessitate that the early part of the running on the down trip has to be done very slowly and carefully, which means realistically you would be lucky with wireline to get the run trip time down to about six hours.

Coiled tubing is a relatively recent method of downhole intervention, which has been successfully developed and used by the oil and gas industry. It is fast, reliable, and you can have electrical conductors inside the tube, which opens up all sorts of possibilities for remote operations, monitoring, and various other things you might wish to do. It is a very good way of doing it because it is more reliable than wireline and it doesn't have the complications of drill pipe.

That is a typical coiled tubing rig, which would replace the drilling rig at the wellhead once the casing had been set. The tubing comes in various diameters and wall thicknesses, and therefore, strengths. It has been successfully run to over 10 kilometers. It can take loads up to and even beyond 40 tons, and it can make between 100 and 200 run trips before the coiled tubing requires replacement. It is quite cost effective.

Most deep borehole schemes, of course,

have suggested that the packages be deployed one at a time, but in 1983, Woodward and Clyde raised the possibility that packages could be assembled into strings and lowered in a single operation. This idea was carried through much of the MIT work, and into the Sandia reference design where it has evolved as we heard earlier into 200-meter long strings of 40 packages weighing just under 70 tons.

This raises a number of issues that we need to think about. Obviously, with that weight, they can only be deployed by drill pipe. The combined weight of the drill pipe and the drill string would require a very big rig. Our experts tell me they would need at least a 300-ton capacity rig to do that, and Ernie gave probably a more accurate figure this morning.

Running rigidly coupled strings of packages also brings up the issues of the limits to well tortuosity. If the clearance between the string of packages and the casing, particularly with offset couplings, if these are used, means the well tortuosity has to be minimal, and it raises serious issues.

As we saw illustrated beautifully in the previous talks, it requires very complex wellhead engineering. You have to have a lot of hardware beneath the shielded facility. You have to have the remote operation of tongs, slips, collars, et cetera. It also involves very elaborate package design, with all the screw threads, ways of connecting them, which of course, are not required for single package operations.

Assembly of strings of packages at the wellhead increases the time the packages spend at the wellhead, and therefore, the time for things to go wrong, the probability of things going wrong because of so many complicated operations, and bits of engineering, and of course, that brings in the workforce dosage problem, and of course, serious cost implications.

For high heat generating waste, like spent fuel, the protracted time at the wellhead to assemble strings may not be advisable. It might carry an increased risk and it could require the addition of extra safety measures.

If we go back to the original rationale behind multi-package deployment, it was, quite simply, to save time on a large number of individual run trips, at a time when the only real way of placing the packages was by drill string.

The appearance of a fast and reliable method like coiled tubing could completely negate this rationale, and so I would suggest that before anyone considers multi-package, we really look carefully at the justification for it, and the exercise we heard about earlier was discrimination analysis between drill pipe and wireline seems to me to be going in the right direction.

Now one of the benefits often advanced for deep boreholes is that they can use almost any type of solid waste, and they can cope with almost any amount of heat. The emphasis is on the geological barrier, but it is still a multi-barrier concept. The near field barriers still consist of the waste form, the infill, the container, and the annuli between the package and the casing and the casing and the rock.

When it comes to the role of these barriers in the safety case, there are two completely opposing views. One says that once a disposal zone is sealed off, any escape of radionuclides from the near field is irrelevant because the isolation is ensured by the geological barrier.

The other view argues that irrespective of any of that, the safety case should be maximized by making near field barriers as robust as reasonably achievable.

If we look at the individual near field barriers, taking the waste form first as I have just said, boreholes can cope with almost any sort of solid waste, but most of the candidate waste forms that have been put forward, like spent fuel and vitrified reprocessing waste and so on, are already in a fairly suitable form, or a very suitable form, for borehole disposal. Others, like the Cesium capsules we have been hearing about, are already packaged.

It might be quite difficult to justify

the risks and the costs of trying to process the waste forms into something that was a bit more durable when it is already good enough.

The only possible exception to this might be where a substantial volume reduction could be achieved, for example, by consolidating fuel pins to get three or four times as many into the container.

The waste form needs to be surrounded by some sort of infill in order to prevent deformation and damage to the containers by the hydrostatic pressure down the hole and the axial load stresses. Lots of materials have been suggested for this, cement, glass, lead, and so on. Really, these need to be properly evaluated along with other materials. It is essential that the container is in-filled.

The container itself offers a range of possibilities, from the relatively economic carbon steel, mild steel, as we saw earlier, drill pipe, right through to the very expensive pure copper and titanium containers suggested by some people. A possible compromise would be to copper plate stainless steel.

The main criteria for selection of a container for borehole disposal are the mechanical strengths required and the extent to which it needs to resist corrosion. The mechanical properties are easy. They are a simple matter of engineering calculation. The corrosion resistance issue is more difficult, and it ties into the next thing, which is what happens in the annuli between the package and the wall rock.

If these annuli are simply left with water or drilling mud in them or even if they have an incomplete well cementing job done, the groundwater will have ready access to the casing and the containers, and this could raise issues of corrosion and of gas migration of corrosion products up the annulus.

If on the other hand, these annuli are filled with what we refer to as a sealing and support matrix, this will prevent access of the groundwater to the casing and the containers, at least for quite a long time, maybe not indefinitely, but long enough to greatly reduce any corrosion effects, and it will block off any gas migration path up the annulus.

Among the things that have been suggested for this are special lead-based alloy high-density support matrix or a specially formulated cementitious grout. The usefulness of this and other options really need to be examined and considered. The borehole annuli should not be left unfilled.

Now we come to the big issue of sealing. If the isolation provided by the depth and the geological barriers is not to be compromised, it is imperative that the borehole itself does not provide an easy route back to the surface than the enclosing geology.

ZOBACK: Fergus, excuse me, just a time check. You have about seven or eight minutes left.

DR. GIBB: That's okay. I am near the end.

Most people would agree that the

disposal zone should be permanently sealed, but if once the activities cease and the hole is sealed and backfilled, the groundwater, the saline groundwater gradients will reestablish themselves in the borehole, and if they do so, they will act as a deterrent to upward flow, just as they do in the surrounding rock.

It may be that the disposal zone only needs to be sealed off for long enough for these salinity gradients to reestablish themselves in the borehole, and this could be as little as a couple of hundred years.

We really need to resolve this issue of how long does the borehole really need to be sealed for. Obviously, the answer to that will be site specific, it will depend on the local conditions and on the permeability of the backfill, but it is something which really needs to be resolved because it has important implications for sealing the boreholes.

Most borehole sealing is done by conventional methods. Most borehole disposal schemes have looked to the oil and gas industry for ways of sealing the wells, and this, which is the Sandia reference design, probably represents the peak of sealing a borehole disposal by a combination of conventional methods.

The problem with conventional methods, which is to use materials like cement and concrete, clays, asphalt and so on, which are simply pumped down the hole with or without removal of the casing and allowed to sit. Alternatively, mechanical devices like swell packers can be used.

The problem with these is no matter how durable the material; the interface with the rock is always a zone of potential weakness. It could develop into the path of least resistance for any fluid seeking to flow up and down the hole.

We have to conclude that such conventional seals are unlikely to retain their integrity for the sort of times we are looking for.

Recognizing these problems, particularly with clay-based seals, Roland Pusch and his colleagues in Sweden have developed more advanced seals in which they use perforated super containers made of copper or bronze, filled with compacted swelling clays. These are pushed down the hole into the drilling mud or deployment mud, and as they hydrate, the clay swells out through the perforations and creates a sealing pressure in the annulus.

Another attempt to produce a better seal is Olympic Research's ceramic plug, where they emplace a charge of metal oxide, based on the thermite principle. They grind away a bit of the casing, ignite the charge, which self sinters progressively, and leaves behind a robust and durable oxide seal.

Unfortunately, the problem with all of these seals is the existence of the disturbed rock zone around the borehole. The fractures and micro fractures of this disturbed rock zone can extend into the wall rock for 10s of the permeability of the disturbed rock zone by a centimeters and their interconnectivity can increase couple orders of magnitude. This will remain as a potential bypass of any conventional seals for a deep borehole disposal, and it would be identified as the dominant release pathway in any performance assessment or safety case.

As a response to that, we are working to develop a method of permanently sealing the borehole by rock welding, which will also eliminate the disturbed rock zone. We cut away or grind away part of the casing, and emplace some crushed backfill, host-rock, and then follow it with an electrical heating device attached to the surface by an umbilical cord, and then top it off with more crushed host-rock to bury the heater. We then apply power to the heater sufficient to partially melt the rock, the backfill, and the host-rock for a reasonable distance beyond the borehole wall.

Subsequent cooling allows when the power is switched off or reduced, allows it to recrystallize under controlled conditions to generate the correct size, avoid tracking, and annealing any fractures.

These seals could be repeated at intervals up the hole with spaces between filled with other sealants, and the big questions, I think, that we really need to be addressing are how long do we need to seal the borehole for, and how should we do it.

Undoubtedly, this workshop will identify many such issues and hopefully resolve some of them. They will almost certainly identify areas where the technology is not yet in place.

I would just like to leave you with a final thought, which is a quotation from the President of the Institution of Civil Engineers at the awards ceremony in London last week, and it was this, "When you hear about a new idea, don't ask yourself what's wrong with it, ask what can we do to make it work."

Thank you.

(Applause.)

ZOBACK: Thank you very much, Fergus. That was a really great review. We are just about at 1:00 on break.Are there any really quick questions for Fergus? Otherwise, you can catch him at the break.

(No response.)

ZOBACK: Okay. Let's take a break, and we will start again promptly at 1:15 with the first of our panel discussions on drilling and drilling experience.

(Whereupon, the meeting was adjourned for a brief recess, and the rest of the meeting was transcribed by another firm.)

CERTIFICATE OF NOTARY PUBLIC

I, CHRISTINE ALLEN, the officer before whom the foregoing proceeding was taken, do hereby certify that the proceedings were recorded by me and thereafter reduced to typewriting under my direction; that said proceedings are a true and accurate record to the best of my knowledge, skills, and ability; that I am neither counsel for, related to, nor employed by any of the parties to the action in which this was taken; and, further, that I am not a relative or employee of any counsel or attorney employed by the parties hereto, nor financially or otherwise interested in the outcome of this action.

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CHRISTINE ALLEN

Notary Public in and for the

District of Columbia

AFTERNOON SESSION

ZOBACK: If we can regroup now, please. We've shifted some of the staff into the audience seats, so I hope we have enough seats. If not, we can bring in more chairs.

(Pause.)

Okay, everybody, regain your seat, please.

I want to begin by thanking DOE and Sandia presenters this morning. I think they gave us a really good overview, a concise overview, of the program that we're going to be focusing on for the rest of the workshop. And, again, thanks to Fergus for that excellent international and, I would say, very balanced perspective on deep borehole drilling or disposal.

We are going to begin with sort of the first obvious step of a program like this, and that is with the drilling of the hole. And, in particular, we have assembled a series of international experts with vast experience in deep drilling in crystalline rocks, and that's the title and topic of the panel. And we have three speakers.

And just as way of background, we're going to have a series of panel discussions. The speakers have all been asked to make brief ten-minute presentations. They're going to go one after the other. And then we'll have 40 to 45 minutes for discussion, so hopefully ample discussion time.

And I'd like to begin by introducing the first panel. I will be the moderator of that panel, Mary Lou Zoback, member of the Board. And the three panelists in the order that they'll be speaking--and in all cases I have been giving really brief biographies, not to slight people, but you all have written biographies in the materials handed out.

So staying with brief introductions, the first speaker will be Steve Hickman. He's from the USGS and Menlo Park, where he is a research geophysicist. Steve is currently the Director of the Earthquake Science Center there at the USGS. He has extensive experience working in boreholes drilled for scientific and geothermal purposes, and his particular area of expertise is looking at stress fractures and fluid flow in the subsurface.

Next we'll move to Claus Chur. He is a petroleum and drilling engineer by training. He worked a number of years in industry. He then went on to become eventually the Technical Director of the German Deep Drilling Program, which is commonly referred to as KTB. I won't try to say that in German. He is now a private consultant, but, again, extensive field experience.

And, finally, we have Eric van Oort. His background is in chemical physics. He is now a professor at University of Texas at Austin; however he worked 20-plus years in industry for Shell. He was very involved in both continental and offshore drilling, wellbore stability, real time analysis, and, again, bringing to the panel extensive experience, none in the nuclear area, but with drilling in general.

So without further ado, I am going to ask Steve to come. And, again, we'll have all three brief presentations back-to-back and then questions.

HICKMAN: Thank you, Mary Lou, and thank you for an opportunity to speak to you today. My talk could just as easily be entitled "Geomechanical Consequences", to drilling, casing, and disposal of radioactive wastes in deep boreholes.

This is a brief cartoon illustrating one of the concepts I want to get across, and that is the crust is in a state of incipient frictional failure. This is looking down on a fault here, the two horizontal principal stresses, a maximum and a minimum principal stress, creating a shear stress and a normal stress on that fault. The fault will start to slip if you raise the fluid pressure or increase the stress to such that the shear increases. And we know from many observations--and Mark Zoback will be talking about this later in Panel 4--that much of the crust is near critically stressed for coefficients of friction to 0.6 - 1.0.

Also, when a fault slips, it creates permeability, especially in low-porosity crystalline rocks, which is the foundation of enhanced geothermal systems. In a critically-stressed or near-critically-stressed crust, stresses will increase as you go deeper.

Shown here from the KTB well--and I won’t try to pronounce it--differential stress as a function of depth down to about 9 kilometers, result of an injection experiment done in this well, which shows, first of all, stress magnitudes are near-critical all the way down to about 8 kilometers, and then small perturbations in fluid pressure cause slip along faults and fractures, producing earthquakes, further demonstrating that the crust is in a state of incipient frictional failure at KTB.

This is, again, a common observation that Mark Zoback will be discussing later.

How do breakouts and tensile cracks form? We mentioned borehole failure in a couple of the presentations today already. This just shows a diagram of a borehole drilled in rock, vertical borehole, impinged upon by maximum and minimum principal stresses. Both stresses concentrate around the well and cause brittle failure called breakouts along the minimum principal stress direction and tensile cracks along the maximum.

This is a plot showing the circumferential or hoop stress around the well that causes the breakouts and causes the borehole to fail. And one of the main points I want to make this morning is that when you drill a well, you perturb the stress field, it causes failure that has consequences for the damage zone around the well, including breakouts, which have been mentioned before. The width of the breakouts is determined by the magnitude of the stress concentration when it exceeds the compressive strength and the tensile cracks form 90 degrees away. It’s possible to use these observations to produce complete *in situ* stress models, which would be a part of any project to do a pilot waste disposal effort.

Very importantly, when you increase the borehole temperature, which might happen after you emplace a canister, that causes an increase in sigma theta-theta, or the hoop stress, around the well, cause the breakouts to get bigger and wider, and that’ll increase the damage zone around the well. So there are thermal consequences in terms of borehole failure.

This is a couple of examples of drilling-induced borehole failure from the San Andreas Fault Observatory at Depth project near Parkfield that Mark, Bill Ellsworth, and I led. You can see breakouts here in an acoustic image. This is essentially like you would take in the borehole and split it and then unrolled it along the north direction. You see breakouts very clearly there, tensile cracks 90 degrees away, in an electrical image log, a different kind of imaging log, and then a cross-section of the breakouts here showing what they look like. They’re rather large tensile cracks at 90 degrees.

You can characterize stress regimes in the earth relative to the magnitudes of the principal stresses in relation to the vertical stress. Relatively extensional stress fields are normal faulting; as you get higher and higher horizontal compression, you go into strike-slip and then reverse faulting. It all depends on the relative magnitudes of the two horizontal principal stresses and the vertical stress.

Very importantly, most of the U.S. is in a state of compressional failure, a combination of strike-slip shown by these arrows pointing together, a combination of strike-slip and reverse faulting. And most of the areas being discussed for nuclear disposal in boreholes are thus in a compressional stress regime, either strike-slip or reverse. This has important consequences for failure around a well.

How deep do you have to go to see breakouts in a well depends upon the stress regime that you’re in. This is a theoretical calculation from Moos and Zoback, showing the depth to the initiation of breakouts, depending on rock strength for a pure strike-slip environment, strike-slip transitional to normal faulting, strike-slip transitional to reverse. As you can see, you get breakouts at much shallower depths in highly compressive stress regimes than you do in extensile stress regimes. Thus, in most of the areas discussed here at this workshop, you should get breakouts forming at relatively shallow depths.

If you take the range of strengths for granite, typically 100 to 200 MPa, this tells you that for a pure strike-slip you'd be getting faulting to start at a depth--I'm sorry--breakouts to start at a depth of about 1.5 kilometers; and the deeper you go, the bigger the breakouts become.

In some cases--this is an example from a well in Russia--the stresses are so high--this is transitional strike-slip to reverse faulting--the breakouts at about 3 kilometers, which is shown here, become extremely large. This is a cross-section of the borehole taken from an acoustic borehole televiewer log. Circles just show the drill pipe joints and drill bit sizes for reference. You can see the breakouts go out extremely far away from the borehole. This is an extreme case, but it's something you should be prepared for in any project like this when you drill to these kind of depths in the compressional stress regime.

Next point I want to make is that rocks don't fail all at once. They fail progressively. So although you may see a breakout in a wellbore, what's behind the breakout is a lot of damage; it's called the damage zone. And that damage consists of microcracks. And this is illustrated with this very nice series of laboratory experiments done by Dave Lockner and his colleagues where they tracked the failure of a rock under compression by monitoring the acoustic emissions; think of them as ultra-ultra-small earthquakes as the rock progress to failure.

So here is the stress strain curve during those experiments. The rock starts to dilate at about 60 percent of the peak stress. That’s where the rock actually breaks and fails, so only 60 percent up to failure, you’re already getting dilatancy and damage. This is important to keep in mind. When you see acoustic emissions starting to show up, those are all grain-scale fracturing events. When you get to this point, peak stress, and then start to roll over and fail, you get coalescence of those damaging events into throughgoing faults that eventually result in macroscopic failure. So the failure process occurs gradually; and when it does, it accumulates a lot of damage.

And one of the important things to realize about this damage that in low-porosity crystalline rock, that damage creates permeability. This is an experimental result from Wong and Zhu, showing permeability for low-porosity rocks and high-porosity rocks from the onset of dilatancy to peak stress. Rocks over here are granites and gabbros, the kind of rocks we’re talking about disposing of waste in here. You can see that in that interval from onset of dilatancy to peak stress, there's a considerable amount of permeability gain up to a factor of 8, and the permeability gain keeps increasing as you roll over and the sample fails.

Now, damage zones aren't the only way to get fractures around a breakout that create problems with seal integrity. Another way is by just the tensile cracks and the interaction between tensile cracks and natural fractures in the borehole itself.

This shows some examples of a borehole televiewer and Formation MicroScanner log from a geothermal well in granite, the Coso Geothermal Field. You can see tensile fractures here in green of various kinds interacting with natural fractures, which show up here as sine waves, and that produces fluid pathways that could carry you past seals. So when you worry about seal integrity, you have to worry about not only microcrack damage, as I showed in the earlier slide, but also these more macroscopic tensile and cooling cracks interacting with these preexisting natural fractures to create fluid pressure bypass, fluid bypass.

This slide is very complicated, and I don't want to spend too much time on it, but the important point is here, we've done a lot of work in geothermal fields, characterizing natural fractures with image logs in relation to the stress field. One thing we see very typically is a great number of fractures. Here each dot represents a fracture on a particular kind of lower hemisphere plot. If you're a geologist, you'll understand this. But each one of these dots is a fracture of different orientations. We can then see that only a few of these fractures, six in this case, have enough permeability to actually make this well a producing geothermal well. These are extremely permeable fractures. A number of other fractures shown here in blue are slightly permeable. They're shown as--they're indicated to be permeable by perturbations and temperature logs.

The important thing here is that these fractures can exist in granitic rock in geothermal fields pretty much anywhere; and when you're drilling, you don't know they're coming. So you can drill and drill and drill and hit nothing, and all of a sudden you hit a fracture, and it's a surprise. Two or three of those fractures, you have a geothermal-producing well.

What happens if you don't hit them and you're a couple meters away? How do you know you're safe? And that's one of the concerns I have in the context of this project. There are a lot of fractures in the crust. Some of them are very fast fluid pathways. And unless you intersect them with a borehole, how do you know they're nearby and could create a problem?

So, in summary, extensive wellbore failure will complicate drilling completion and seal installation and could compromise long-term integrity of the seals. Breakouts become more severe with depth and can even lead to complete circumferential failure, especially in reverse faulting stress regimes. Severe breakouts could pose major challenges to drilling and completion.

Breakouts could pose operational challenges when cementing casing and setting multiple seals in long open-hole interval above the waste canisters. And high-permeability damage zones produced by breakouts, drilling-induced tensile fractures, and dilated natural fractures could provide short-circuit pathways around seals. And it is important to point out that when you drill through a fault, sometimes you actually trigger a slip through the stress perturbation from drilling or the excess fluid pressures from the drilling fluid. So this is a real concern.

Increasing temperature after canister emplacement could lead to an increase in the compressive hoop stress around the well, promoting more breakout growth and borehole enlargement. Thermal pressurization of fluids, which hasn’t been discussed, could reactivate nearby faults, increase fracture permeability. Hydrothermal convection is a potential problem that needs to be evaluated; and microcracking due to differential thermal expansion, which has been demonstrated in the laboratory, especially in quartz-rich rocks, has to be taken into account when thinking of melting in the borehole or high-temperature rock behavior around a canister. This can lead to a three-order-of-magnitude increase in permeability. We know this from tests on granite, so it has to be taken into account when talking about melting seals.

And last but not least, we knon when drilling in geothermal wells we can hit fractures suddenly and without warning that have a lot of permeability. How can we be assured in this project that these high-permeability fractures or faults will not be so close to the borehole that they'll cause a problem and compromise geologic containment?

Thank you.

ZOBACK: Thank you, Steve.

CHUR: Well, good afternoon. And, first of all, I would like to thank the Review Board for having invited me to this conference. Professor Gibb already pointed out during the lunch presentation that the issue is also at the moment actual in Germany as well, and we will see how that will proceed.

I will briefly show you--share some experience in drilling projects in crystalline rocks, specifically on the drilling performance, directional control, borehole stability, and the value of a characterization hole. And, of course, during the discussion we can address much more issues like casing scheme or other things.

This is a similar slide you've seen this morning from David. It just summarizes some of the wells which have been drilled over the last couple of decades in crystalline rocks. And I show that basically--that's the second slide on this--to show that there is quite significant expertise in drilling in crystalline rocks. I just feel obliged to say a word on the KTB approach, because several times there was questions how it is pronounced in German, so it was called the Continental Deep Drilling Program of the Federal Republic of Germany.

So this shows some of the drilling performance you typically can expect in crystalline rock. And, as you see, it more or less varies between one and three meters per hour.

ZOBACK: The ROP; right?

CHUR: The ROP is the rate--thank you--I forgot about--the ROP is the rate of penetration here measured in meters per hour. And probably the figure from the geothermal project in California was eight meters; it's a little bit unexceptional. And, of course, at the end of the day it just depends, of course, on the local situation on the compressive strengths and compactation of the rock.

So this shows you the drilling performance of the KTB main well; in green the rate of penetration, the red is the bit life, and the blue the footage. And for this project probably the two diameters on the left side are of interest to 17-1/2 inch and 4-3/4. 17-1/2 inch was drilled down to 3,000 meters, 4-3/4 down to 6,000 meters--that’s something you talk here in this project. And, again, you see the ROP, of course, is significantly less than in oil and gas.

Directional control has been addressed several times today and generally addressed in context with crystalline rock drilling. You see here on the left--you must not read the figures. It’s more to get an impression. On the left side you see the horizontal plots of the Kola well, and on the right side you see the horizontal plot, which is a bird’s view of a driller if you were looking down the hole from the KTB well.

It’s important here to realize the different scales. On the right side this (inaudible) all happens within a diameter of 10 meters down to a depth of 7.5 kilometers. So the well has been drilled in a cylinder with a diameter of 10 meters; whereas, on the Kola well on the left side the distance is 5 kilometers.

So how can that be achieved? It was achieved by applying what we called at that time the vertical drilling system, which was at the time basically the prototype for all automatic drilling systems which are applied today primarily, of course, for drilling directional holes, drilling horizontal holes, but you see on the right side down to a depth of 7.5 kilometers. Even at that time we were able to drill a technical, absolutely vertical borehole. That also refers to some concerns of the morning on tortuosity, which I think, if you do it right, is not a problem.

You also see below 7.5 kilometers, which is down here, the systems couldn’t be used anymore due to temperature limits of the electronics. And you see how quickly the well deviates, so I strongly recommend that the wells we are talking here during the workshop certainly should be drilled with the proper directional control. Let’s put it that way.

Borehole stability, already addressed by Steve. It’s probably the challenge in crystalline rocks. And, to me, next to the slower rate of penetration, which is only an issue at the end of cost, the borehole stability is probably the main difference to know drilling in sedimentary rocks. And what you see here is the caliper log from the KTB well from top to 9 kilometers depth. And you see here, of course, the caliper, and you can see that the caliper or the size of the breakouts reach sometimes more than double the size, the nominal size, of the bit.

However, just the practical experience in the upper part of the hole that’s here, the first 3,000 meters, the breakouts didn’t cause a real drilling problem. They were there, but they didn’t cause a real drilling problem, where in the lower parts, actually, they caused huge problems and more or less were the predominant factor next to money that the project has to be finished at 9 kilometers.

But in my view--but there are much better experts here in the room--that is, among other issues, very much depth-dependent. So, from my experience and from the depth regime you're talking, you're down to 5 kilometers, if there are not other, let's say, special stress fields, the normal stress fields, things like that, that should be at least--can be controlled.

Of course, next to the borehole stability issue, it is fair to say that we find a lot of fluids and gases in crystalline rocks. And that can be quite sufficient amounts, as you can see in the KTB well, for example, in the pilot hole in a depth of close to 4 kilometers. We did a four-month production test, producing over 700 cubic meters of fluids. And this is basically reported, at least in most projects I am aware of or I have documentations on, that you find throughout the wells influxes of fluids, primarily in the KTB case where there are sodium and calcium chloride fluids, gases, mainly nitrogen and methane.

This is a core from the pilot hole in 3-1/2-kilometer depth. And, of course, you see that there are quite some significant pathways for fluids. And a very nice piece.

The value of a characterization hole cannot be underestimated. I would strongly recommend to do such a characterization or pilot hole. It will, of course, deliver a lot of important data for planning the well for the drillers on the rocks. It will deliver data on where problem zones are, influx zones, breakout zones. It will also give you the opportunity probably to test specific tools, not only for drilling, but also for the geological or, let’s say, scientific interpretation.

There was one example--it has been mentioned before, the rock flower--the KTB people, the scientists, they developed a method using the underflow of the centrifuge, which is the rock flower, dry it, put it into tablets, and then analyze it with an x-ray analysis and diffractometry analysis. And this gave basically a perfect lithologic and mineralogic profile, much better than the cuttings, because the cuttings are not so easy to put them into the right depth. So these are very nice tools.

You can test also the people who will then work at the rig site, the geologists who have to interpretate the cuttings and the logging of people from the service companies. Normally, of course, they are not used to or experienced in interpreting crystalline parameters, but that can be done very well in the pilot hole.

The pilot hole also exonerates the Field Test Borehole, the big hole, from a lot of coring, hydrofrac testing, logging programs. So there are a lot of positive things which argue to do a pilot hole.

So in conclusion, there is drilling experience available for wells in crystalline rocks; however, even if the experience in crystalline rocks for diameters 12-1/4 inch and bigger, 7-1/2-inch, in great depths, of course, is limited. However, in my view, actually drilling in crystalline rocks doesn't differ so much from drilling in sedimentary rocks.

So I would say the drilling expertise which is available in the oil and gas is absolutely sufficient to drill a successful well in a crystalline borehole if you do the things right which we have to do. Also, I've seen in a mined repository you also have to apply proper mining experience. Of course, as we know, the drilling performance, of course, is less borehole instability. That will be a factor in the pilot hole. It's a good thing to do.

Thank you very much.

ZOBACK: Thank you.

VAN OORT: Okay. Good afternoon, everyone. I wanted to start out with a point of criticism. I've seen a lot of what has been done on what you do when you have the borehole, how you're going to evaluate it, how you're going to test it, how you're going to test emplacement, but not on how you're going to drill it. There are bits and pieces there, but there is no comprehensive drilling program. And in Holland where I'm from--which, by the way, is east of Washington--we call that selling the hide before you shot the bear.

So I'm going to give you some tips for the drilling program, some things that I think you need to address. So we're going to talk a little bit about bits, about drill string vibrations, about vertical directional drilling. I'll talk a little bit about the consequences of borehole instability, which is stuck pipe, and talk a little bit about isolation and abandonment.

And first on bits--if you could start the two videos--what you see on top, this is a polycrystalline diamond compact bit, a PDC bit. It fails rocks in shear; it's a shearing force. On the bottom is a tri-cone rock bit that has inserts in there that are made out of tungsten carbide. That's what we call a rock bit or a tungsten carbide insert bit.

And on this graph you see the response of rate of penetration, how fast we make hole, as a function of weight on bit. And you see that PDC bits drill much more efficiently than these rock bits and then another type of bits, which are diamond impact bits.

So the point here is that as long as you can keep PDCs in the hole, as long as you can keep them drilling, you're going to be much more efficient. Typically, we go to a tungsten carbide insert bit if we can’t keep PDCs in the hole, if the rocks simply become too hard. But what we’ve seen over the last decade or so is that PDC technology has become so good that it has started to kind of displace rock bits and tungsten carbide bits, and right now we only go to these for the very hardest stuff of formations.

And so the main lesson is keep a PDC drilling as long as you can and only if you have to make a change, because then you’re down to what Claus already showed you, to these very low penetration rates. I believe that PDCs can drill most shales and most salts, for instance. Only if you go to very hard crystalline rock do we probably have to switch over.

There’s a lot going on in terms of new bit technology. This is what is called a Kymera bit. It was developed by a friend of mine at Baker Hughes called Rolf Pessier. It’s kind of a Frankensteinian clone of a rock bit and a PDC bit. It gives you the high penetration rate of PDCs but with the ability of rock bits and tungsten carbide insert bits to deal with hard stringers. So this stuff can, for instance, drill very hard chert.

A Kymera is a beast from mythology. It had the head of a lion, the head of a goat, and the head of snake. It’s a bit what my mother-in-law looks like, who is a lovely, lovely woman, by the way.

One thing that you will have to contend with if you start to drill a 17- or 17-1/2-inch hole this deep is drill string vibrations. I already want to warn you that that’s going to happen.

And there are three modes in which the drill string can vibrate. It can vibrate in an axial direction, in a lateral direction, which we call whirl, and in a torsional direction, which is called stick-slip. Stick-slip is where the bit actually stops drilling while you’re continuing to wind up the drill string, and then the bit releases violently. And this is a problem drilling hard rocks, and this is actually what destroys most bits. If you 20 years ago would have asked me what destroys bits, I would have said hard rock. Now I say it’s drill string vibrations, because we’ve learned a lot more about these vibrations.

And just to give you a feel for this--if you can start this video--this is a video by Schlumberger. And forget about these nice videos that you see where a drill string nicely rotates concentrically in a borehole. This is more what it looks like, and you can see that the drill string is bouncing off the borehole wall and actually starting to change the conditions a little bit. And you see this become much more violent. These are whirl vibrations, and they shock the borehole, so they can create a lot of borehole damage, in addition to the damage mechanisms that

Steve already indicated. And they can, of course, also damage the drill string and drill string components, including bits, logging tools, and so on.

And this is what might happen if you’re going to be drilling with a relatively slender drill string with a large, beefy bottom-hole assembly at 5 kilometers, so definitely something that you need to be concerned about from a drilling perspective. These are level 3 high-gravity shocks that are happening on the borehole wall and on the assembly.

Vertical directional drilling, Claus already mentioned it. It’s actually not easy to drill a vertical wellbore. That may sound really strange, but it’s actually quite difficult. The bit is a little bit like the undergraduate students that Professor Bommer and I teach at UT. They like to take the path of least resistance. And the bit, for instance, will go into a direction where it encounters the least resistance, and it’s very sensitive to side forces.

Luckily, the technology has been developed to drill perfectly vertical, but you will have to apply those technologies, so you have to use rotary steerables, maybe downhole motors, to keep the well as vertically as possible. And it’s really important for when you get deeper. You could imagine, if I put a big kink in the well shallow, and I try to drill deep, I’m going to encounter friction, I’m going to encounter high torque, I'm going to maybe wear a hole in the casing at surface that compromises my barrier. If you want to drill into the Gulf of Mexico at 35,000 feet, which is what we're doing right now, we keep this dogleg severity, the kinks, that we put in the well less than one degree per hundred foot. But this is an important point also for the emplacement of the canisters at the end of the job.

Well construction and well abandonment, I was really glad when I saw this graph from Sandia. Not only do I see a fairly mature abandonment plan, apparently you are going to negate some of the problems by constructing these wells in Dubai under Burj Khalifa. I'm, of course, speaking in jest. I don't want to create a diplomatic crisis with the United Emirates. The United States doesn't need my help in creating global diplomatic crises.

So stuck pipe, this kind of goes a little bit beyond what Steve said. If the borehole becomes unstable--and you understand the borehole can become immediately unstable, or it could take some time--there are time-delayed mechanisms. And you are looking at fairly high open hole times where the borehole can become unstable over time.

And this can have problems with running casing in the hole, getting casing stuck in the hole, so your slotted line there may become stuck in the hole. If you wanted to place canisters in the open hole, a small caving can already stick a canister, for instance. And normally during drilling we have beefy drill pipe. We can pull on the bottom-hole assembly; we can jar on the pipe. That's also what we do during fishing. Your ability to work these canisters in and out of the hole will be limited when we're compromising the integrity of the canisters themselves. So take a look at that.

Well isolation and abandonment, I would highly encourage you to study the oil field literature, particularly what is written for offshore abandonments. I've lifted a passage out of the Code of Federal Regulations 250, which governs abandonments for deep borehole wells. You can find them in Sections 1712 through 1721. And I really would encourage you to take a close look at that and see how we abandon oil and gas wells and take that as kind of a minimum standard for the abandonment of these wells that you are going to attempt.

One of the things that I want to warn you against is cement. Cement is not a good material. And when I talk about cement, I mean Portland cement. Portland cement, it's sensitive to mud and formation fluid contamination. If you get it to be contaminated with magnesium chloride, for instance, it forms brucite. It doesn't bond particularly well in formations. Clays and shales don't like high-alkaline lime-based chemistry, which is what cement is. It has low tensile strength. If it cracks and it forms these micro-annuli that you already saw Mr. Gibb talk about during the lunch meeting, then these cracks are basically going to stay there.

So you should look at new materials. New materials are becoming available. They are actually quite known within the civil engineering community. This is something from my own lab where we have a self-healing cement based on the alkaline-activated materials that we failed--so we actually failed it in the triaxial tester at 1100 psi at failure. And then we allowed it to re-heal under downhole pressure and temperature in the presence of water, and it re-healed completely and then at 21 days showed original strength again. So take a look at those type of materials as well. Just look beyond the stuff that has been used since the Romans used cement, basically.

So conclusions and recommendations, this project needs a much more detailed drilling program. And the devil is in the details, right? And the big cost overruns in this project are going to be associated with the drilling. So pay attention to this.

The project would technically and economically really benefit from having a good bit expert associated with it to really tell you about the latest in bit developments. Kola and KTB were drilled more than 20 years ago, and lots and lots has happened since on bit technology.

Harmful drill string vibrations, I'm already going to warn you about them. They are going to happen, and you want to monitor them and mitigate them.

I can't stress the importance of this point enough. Borehole quality, tortuosity, and gauge are very, very important, and they will require good vertical directional drilling and also excellent surveying techniques.

Stuck pipe risks of running liners in the hole is an issue if the borehole becomes unstable or is tortuous with a high dogleg severity.

In the panel this afternoon I think we'll hear more about well abandonment and barrier installation.

And then I would encourage you to look at self-healing alternatives to Portland cement.

And the last thing I want to say is Kontinentales Tiefbohrprogramm.

ZOBACK: Well, I want to thank each of the speakers for sticking to the time. And we're going to open the presentations up for discussion, but first I want to give the three presenters a chance to ask questions of each other if they have any. And then I have a few questions set up.

But do you all have any questions of each other? Are you in violent agreement?

CHUR: Not really.

ZOBACK: Okay. I want to then begin--getting back to a point that Claus made, and this is with regard to pilot holes.

And I want to apologize that it seems that we have our backs to you. The tables are taped down. We couldn't move them, okay? I'll just say that.

So with regard to pilot holes, Claus, you outlined all the advantages of having a pilot hole. In looking forward, if this initial test is very successful and we move on, do you all anticipate a pilot hole would always need to be drilled before a disposal hole was drilled?

HICKMAN: Want to start?

ZOBACK: However.

CHUR: I certainly would recommend the pilot hole in conjunction with the Field Test Borehole.

ZOBACK: Right.

CHUR: And so if then that is basically accomplished and you will decide on a real borehole for a real dispository, then certainly I would recommend to do here a pilot hole as well. The question will then be how many wells, let's say, from a site would be drilled for the dispository. But for this specific location, yes, you should drill a pilot hole, because that gives you at least next to other slide like geophysical interpretation. The only chance to understand what is really downhole indicating at least to why catastrophic failures may be in the location selection.

And if I can add one more word here, I understood from discussions outside of this room that the location for the Field Test Borehole and the pilot hole maybe is selected based on availability of proper appropriate ground or so. I would think you should think over that approach, because I think this test site should be selected more or less under the same criteria as the real project, because what will you do if you were to take a wrong location for the test phase and it goes wrong? Then I think that the project is over.

ZOBACK: Good point.

Steve, did you have something to add?

HICKMAN: I'm going to violently agree with that, because I don't think you can predict subsurface stress, structural complexity, heterogeneity, or rock properties from the surface adequately. So any disposal site would have to be preceded by at least one pilot hole if not more. That would also allow surface-based geophysics, for example 2- or 3-D seismics, and shooting into the well to characterize the formation.

And I think that that kind of three-dimensional characterization of the environment before you even think about doing a deep borehole disposal is absolutely essential. The crust is a heterogeneous place. It is hard to really determine where the fractures and faults are from the surface. We know this from studies of induced seismicity and other things happening in crystalline basement rocks. So we need to be very careful and judicious about three-dimensional site characterization. That includes drilling at least one pilot hole to characterize the formation.

I was similarly concerned about the choice of the pilot hole project sites, because it seems to me there is missing an overarching set of criteria for what constitutes a representative disposal site, not going for the places that are convenient or that one PI might propose, but what would constitute the best possible site and then characterize that with the pilot project so there's maximum transfer value to characterizing other potential sites. I worry about transfer value, so each project has to build upon our knowledge and be facing towards a coherent goal.

And, again, I think that you cannot do this project properly without drilling at least one pilot project well at every site and then doing sophisticated state-of-the-art geophysical imaging into and away from that borehole to look for fractures, faults, and heterogeneity that are going to cause people problems.

ZOBACK: Eric, would you like to add anything to that?

VAN OORT: They said it all.

ZOBACK: Okay. One thing I think you just touched on, Steve, that hasn't been discussed much at all, but we know from other scientific borehole drilling projects that they often begin with an extensive phase of site characterization. I believe that was certainly true for the KTB hole. I imagine when you drill a 35,000-foot-deep hole in the Gulf of Mexico, you have done that based on a lot of data collected beforehand, so you hope you have an idea of what--

HICKMAN: Absolutely, that's a $300 million well, so--

ZOBACK: Right, right, exactly. And tying this to the pilot hole and the issues that, whereas logging will give you information about the immediate vicinity of the wellbore, understanding the setting on the scale of meters to tens of meters, you have an opportunity for a crosshole test, which some of you briefly touched on.

But how important do you think that capability is? So I guess there's a two-part question. We will have a test borehole site, which will sample the subsurface at that one point. And if we wanted to then carry that over to a broader program, absent the detailed site characterization, when you go to the next site, how do you know that you're likely to encounter something similar or different? And I'm thinking about surface geophysics; I'm thinking about seismic; I'm thinking about electrical methods, that sort of thing.

So comments? And maybe you'd like to talk about the KTB experience, Claus.

CHUR: I just probably would like to add, with respect to the pilot holes, I think that the setup for the Field Test/Characterization Hole, the two-well approach is the right one. For the real disposal project, probably you might also consider to do a few more wells, but with mining technology. At least I’m aware of 4,000-meter-deep wells and mining technology from South America--I’m sorry--from South Africa, which, of course, are much cheaper and much faster. So for a final project could mention to drill a few of them to be a hundred percent sure that’s the right location.

ZOBACK: Okay. Steve?

HICKMAN: Yeah, I mean, in the San Andreas Fault Observatory at Depth project, we spent years on site characterization, winnowing down from seven to four to one site. And that was absolutely essential. But we are still surprised when we drill. So drilling always teaches you that you’re not as smart as you think you are. And my concern is that we can design the best possible site characterization program in the world and still be surprised by what we drill into. I think you have to do that.

If you’re serious about doing this--and I have some concerns, really serious ones, about the ability to predict what we’re going to find before we drill--you have to have an intensive site characterization program to look for basement faults, for example, that might be offsetting overlying strata. But even then, you know, many faults in crystalline basement are invisible, because they were eroded away, and there were no reflecting horizons to reveal their presence. And sometimes you don’t discover basement faults until you pressurize them and produce earthquakes. So, yes, multiple wells.

Crosshole surveys are better than surface-only. They can see farther away. You might be able to see 10, 15, 20 meters away, maybe 100 meters. But the farther away you see from a well, the less your resolution. So you can see big features at a distance, but those may not be the one- or two-millimeter aperture fractures that carry all the fluid. And we know from geothermal wells, they are often that small.

So you should do all of the above in terms of characterizing a site, but realize that you could still miss what you need to know, and there could still be me fractures away that might cause some problem at some point. If you’re really talking about a hundred thousand years, that’s a much bigger problem than 30,000 or 3,000 years or whatever. So the time duration matters a lot in terms of how much assurance you can have going into a project like this.

But drilling will always teach you that you can’t do it all from the surface, and the world is a heterogeneous place. And especially in crystalline basement, it’s hard to image structures and features in advance. So you will be surprised.

And, last but not least, I would prefer to see in, for example, a string of or a circle or whatever of characterization wells, some kind of a monitoring program early on. If you're going to put something down a hole with a heated radioactive canister, it's going to behave differently than any test borehole would. And you want to make sure that you're not losing materials into the geologic formation. What you're treating as a barrier is really behaving as a barrier.

And, as a geologist, I'm concerned about this, so I would want to, at least for the first few of these things, actually monitor downhole for safety, use those characterization wells to monitor for unintentional release of radionuclides. This is done in CO_2 sequestration projects now, and it should be done in anything like this.

ZOBACK: Okay. Eric, do you have comments?

VAN OORT: A point that I would like to make is that people often ask me if we can't make drilling like car manufacturing. And the thing with car manufacturing is you control all the factors; whereas, Mother Nature brings in an element of irreducible complexity. And that's what Steve already mentioned. You could be drilling close offset wells and see something completely different.

I wanted to go back to something that was said during the Sandia presentation about the use of blowout preventers. The presentation was, do we need them, and, yeah, probably we need them because of regulatory requirements. No, you need them. You absolutely need them. You might be drilling ten wells in the crystalline rock and penetrate no fractures and everything is fine. And then you hit a natural fracture, and you take a big salt kick. And for that one you need the blowout preventer.

So you need to always--with these situations, even for close offset, you need to plan for the worst and plan for the fact that you may not control all the factors.

ZOBACK: It’s probably safe to say that in regard to drilling technologies, using “never” or “impossible” is probably not a good choice of wording in terms of what you potentially could find.

Okay. I’m going to open this up more broadly for questions, but I do want to reserve a little time, because at the very end I’d like to give each of you a chance for any final comment you’d like to make.

I’m going to first ask Board members if they have questions for the panel, and then I’m going to ask the other panelists, because we have an awful lot of expertise sitting here in the first few rows. And if DOE representatives--or Sandia--would like to make any comments, too, just let me know. But first let’s have Board members. Questions? Oh, we’ve got a quiet--okay, Mr. Peddicord.

PEDDICORD: Lee Peddicord from the Board. And this, I think, is primarily to Eric, and it's a little bit beyond the current envisioned program. But we've heard comments today in terms of larger boreholes to accommodate larger packages, spent fuel, and so on. What would be your opinion on the limits of borehole diameter that could serve the purpose of disposal of spent nuclear fuel or radioactive waste?

VAN OORT: Claus and I talked about this briefly, and we don't see any technical hurdles right now why a 17-inch, 17-1/2-inch borehole couldn't be drilled with today's technology. Drill string--

ZOBACK: What about a 60-inch, though, I think is kind of what--

VAN OORT: Well, I think we really need to start talking to some real experts on that, particularly within the service industry. This is where I would sit down with some people from companies like Schlumberger, Halliburton, Baker Hughes, and say, What is technically feasible? What weight on bit can we put on a 60-centimeter bit? What kind of torque can we generate?

ZOBACK: Oh, I was saying 60 inches, not 60--

VAN OORT: 60 inches, right.

CHUR: It's getting bigger and bigger.

ZOBACK: Well, just to get your minds rolling.

VAN OORT: This is already quite exceptional, right?

Typically, at these depths we’re down to 12-1/4, 8-1/2-inch hole, and those have been historically the boreholes that we’ve drilled at this depth. We think the 17 inches is feasible. But, beyond that, you really have to get a final true drill string and bid experts together and say, Can this technically be done?

ZOBACK: Okay, good. Anybody--Claus?

CHUR: Well, I’m aware--I think there is a gas disposal in close by New York where they drilled a 1500-meter-deep well, I think, a diameter of a little bit over a meter. However, it was hammer drilling. That is actually something which, if you do research and you have a recommendation to look at new bit technology, absolutely its important and has been done a lot in the last decade.

That also, I think, applies for getting the status on hammer drilling. That has been done through developmental, of course, hammer drilling would be the fastest drilling option for crystalline rock.

ZOBACK: And that would be dry?

CHUR: Not necessarily dry. It’s a variety between dry, mist, foam, fluids. So that’s an optimization process. And, of course, I think in the ’50s, ’60s, you did bigger holes. I’m not sure about the state, but for military munition tests. I think they would be 1/2 to 2 meters wide. Basically--

ZOBACK: --lower men, people down them.

CHUR: Yeah. We'd be basically, I think, come here to a point where we cross the border from normal rotary drilling--to use the old word--toward shaft sinking. So the diameter is not really, I think, a limitation. In the end it comes down to cost.

ZOBACK: Sure.

VAN OORT: This is the way unconventional wells are being drilled in Pennsylvania, for instance, right, with air hammers, with air going to depths somewhere at 5,000 feet and drilling with an air package with a specialized small truck-mounted rig to do that. As soon as you start getting influxes into the borehole, as soon as water comes into the borehole, as soon as you need to apply overbalance with mud, then you have to switch to more conventional re-drilling techniques.

ZOBACK: Okay, thank you.

Any more questions from the Board?

Okay, let's go to the other panelists, those of you--okay, Narasi, yes. Again, why don't you just come up to the mic and--good.

SRIDHAR: Narasi Sridhar from DNV GL. I think Fergus also referred to it in his lunchtime talk, and I think you mentioned it, Eric, about interfaces between cement and the borehole. But my question really is: Have people looked at interfaces between the casing and the cement? What I worry about is the small corrosion of the casing would hydrolyze and cause local acidification, and that would affect the bonding between the cement and the casing and provide an easy leak-back. And this is something we worried about in CCS operations. And I don't know whether you have encountered things like that.

VAN OORT: No, absolutely, yeah. So both the cement to formation as well as the cement to casing link is a weak link. It's easily broken. In oil and gas wells it's easily broken because of thermal stresses.

So the reason why there are so many cementing issues, for instance, in unconventional wells with gas coming to surface is because the bond between either the cement and the formation or the cement with casing breaks. And that allows methane gas to sometimes come to surface.

It is a continuing challenge with Portland cement. And it goes back to the point that I made. We are still using Portland cement. It's time to really look at different materials, different solutions, out-of-the-box thinking. I was really encouraged by what I saw during the lunchtime presentation about creating seals in a completely different way that might also get rid of the near wellbore damage effect.

So that is absolutely called for. There are significant technical drawbacks to the use of Portland.

ZOBACK: Dick.

GARWIN: Dick Garwin, Panel 7. The discussion at this panel reminded me of a simple technical question, and that is, in the literature you see that a small hole may be stable, but a bigger hole is unstable subject to breakout. I don’t see any reason why that’s so. Why should it be easier to have--except for money--to have a 5-inch-diameter hole to 5 kilometers depth than a 20-inch to 5 kilometers depth?

HICKMAN: So there are two answers to that. There is a weak dependence of compressive rock strength on sample size. It’s not been really well demonstrated, but rocks--when you go from about 7 to 17 inches, in some rock types you’ll drop compressive strength about a factor of 2. And that’s based on some limited laboratory experiments.

There is also the fact you’d be more likely to hit fractures or faults near the wellbore that could cause--because they’re relatively cohesion-free, interfaces cause premature spalling, so you can get spalling, because your probability of intersecting fractures goes up as the hole gets bigger; and then there’s a size effect in compressive strength.

PUSCH: Pusch, Sweden. How do you do--if you get a rockfall in a large-diameter borehole--say around several cubic decimeters--falling out from three intersecting chloride-coated fractures where you get no contact and no effective binding between the concrete and the rock?

HICKMAN: So the question is, how do you deal with that?

PUSCH: Yeah.

HICKMAN: Maybe that's a cementing--well, certainly if it was a chloride-containing fracture, a very weak mineral, it would tend to fall off or shear more readily. So that would create a cave, and then you'd have--with chloride lining. And your question is, how do you bond to that?

PUSCH: Right.

HICKMAN: I think that's a cementing question.

PUSCH: How do you get the cement or the concrete attached to or stay with the rock?

VAN OORT: And the answer is, you don't. When the borehole breaks out and it starts enlarging, first of all, it becomes extremely difficult to evacuate all the debris out of the hole, because your annular velocities will go down. So, actually debris will build up in these basically caves, these enlargements, and it's very difficult to circulate that out.

And then, also, when you start cementing, the cement in those breakouts, you will usually have gelled-up mud that you can't displace, and the cement will just bypass that. So you'll get a very poorly cemented hole.

PUSCH: How about reaming the hole and then casting concrete there and then rebore the hole?

VAN OORT: There’s a comment that I wanted to make already earlier about maybe reusing the pilot hole. Reaming in hard crystalline rock, I don’t know of any field cases, but I would highly recommend against it. Using an underreamer performance in hard rock is not good. You get a very erratic borehole that wouldn’t make for a better solution, I would say.

If your borehole just has a very bad quality, I would just plug it back and redrill it altogether.

HICKMAN: I would say also, in addition to the difficulties of reaming, if you were to cement a hole and just make a bigger hole, the breakouts would form all over again. So you have the same stress concentration acting on the hole. You get a new family of breakouts forming. So it wouldn’t solve the problem. You just make a bigger hole with more breakouts.

And, also, laboratory experiments have shown that when breakouts form, they’re often backed by fractures. So something flakes off into the well, and then behind it is another piece that’s waiting to flake off but hasn’t yet. And so there’d be some fractures behind there. It would be very difficult for the cement to get into those fractures and seal them. And that’s in addition to the interconnected microscopic crack that is created in the damage zone.

So those invisible fractures are sort of hiding back there, and they would be hard to cement off as well.

VAN OORT: But there are also materials, right? You could look at resins, for instance. You can look at resinous materials and polymeric materials that could mix with mud and solidify the mud, for instance. And that has been done. I mean, we've used resin plugs and so on.

PUSCH: It's a problem, I think.

ZOBACK: Okay, Rod, and then Paul. Thanks. He asked first.

EWING: Rod Ewing, Board. So earlier in the morning we were presented with the U.S. program, which is a five-year program. And I'm not a drilling expert at all, but just listening, the recommendation is, we have to pay careful attention to site characterization and site selection, particularly thinking about the transferability of whatever we learn to other sites. We need to consider developing new drilling technologies, new bits and procedures. One recommendation would be to look at new sealing materials that would have to be developed and then, finally, the idea that we need multiple wells for monitoring, particularly for the very first test wells.

So if we did all of that in this program, would you hazard a guess as to what the time period would be, the time required to go through this process? Could it be done in five years? I'm putting you on the spot, but--

HICKMAN: I think it would be very difficult to do it in five years.

EWING: Would you hazard a guess as to--

HICKMAN: I don't know, really, but I just think it needs to be done right. That's the most important thing however long it takes. And I don't think you want to rush this. I think you also need to make sure that whatever you learn in the pilot project phase is of sufficient duration to mean something for long-term disposal.

So if you're worried about hydrologic properties, you need to do the long-term hydrologic tests. If you're worried about seal performance, you need to look at seal performance over long periods of time. And I worry about taking data from a rushed project and extrapolating it over X years where X could be a very large number. So I think the most important thing is to do this right or not do it at all, not whether it'll be five or ten years.

I don't know, I can't tell you an accurate number, but I worry about time scaling, and I worry about space scaling. If you're talking about a hundred thousand years, a five-year project seems very short to me. If you're talking about, you know, something like 30 years half-life, then maybe. But I think we need to decide how long these things need to maintain their integrity--are we talking 30 years, are we talking ten thousand, a hundred thousand--and then design the test project to adequately test the safety of that system, however long it takes, before you put something down a hole, because it’s a one-way trip and we’ll never get it back.

EWING: Thank you.

CHUR: I would like to support that, and also there’s a comment to the cost. Of course, it has been several times addressed how important the cost is, and, actually, it is. However, I think for a project like this where we are talking about a repository for hundreds, thousands of year, a million of years, it can’t be an issue in the up-front if it’s 5 or 10 million or 20 million more costly than--that refers, of course, what we said before.

You should really apply the proper drilling equipment, automatic drilling equipment. You must do very careful--the project must be done with the right personal resources from the beginning. Most of the time it becomes to personal. That’s where failures come. So just spend a couple bucks more.

VAN OORT: Let me add to that. So on the drilling technology, I don’t think new drilling technology needs to be developed. I think on the seal technology some things need to be developed, but on the drilling technology it’s more kind of configuring the right technology, the right existing solutions, for this project. But I feel that that still needs to be done.

And right now I would say, for that rather aggressive timeline that you have right now, you're kind of behind the curve and would encourage you to get the right resources, the right people together, to address these issues.

HICKMAN: And I wanted to add one thing, too. There was a lot of nice work presented earlier about the risk analysis for the engineered system. There needs to be a similar risk analysis for the geologic system. We know how to do seismic hazard assessments; we know how to do other kinds of assessments. It would be pushing the envelope, but this is no less serious a problem than the Yucca Mountain Project was faced with several decades ago.

So the site characterization, the geologic site characterization, the quantification of the geologic risks have to be taken just as seriously as the quantification of the engineering risks, emplacement, transfer, and all that.

So, again, I don't think it matters how long it takes. If you can't do it correctly, don't do it at all. That's my basic feeling.

ZOBACK: Okay. You want to make a response?

GRIFFITH: Andy Griffith, Department of Energy. It's all good, you know, you can relax a little bit. We're not rushing to dispose anything. This is just a field test.

We're going to learn from it. We're going to do it right. No decisions are going to be rushed when we don't have sufficient information.

HICKMAN: Okay, that's reassuring, but I do--the concerns I expressed will guide how the pilot project--

GRIFFITH: And, you know, so far the dialogue has been excellent, I think. We've gotten a lot of excellent questions and good thoughts for consideration, and so I think this is a really healthy dialogue. So I just want to set the right expectation so we're not rushing into anything where there are remaining questions.

HICKMAN: Okay, well, that's good to hear.

ZOBACK: Thank you.

Paul and then--come on up to the microphone, Paul.

TURINSKY: Paul Turinsky, Board. Are there different drilling technologies independent of cost and speed that would leave the adjacent rock in a better shape, or do they all sort of do similar damage to the adjacent rock, to the hole?

VAN OORT: I don't think there is a difference between the different drilling technologies. Now, how you go about delivering those is a big issue. I've warned against drill string vibrations. You can drill a well without drill string vibrations, right? That'll have a huge effect on the new wellbore, taking good care to stabilize the wellbore while you're drilling it, making sure that you have the right wellbore support to dissipate the new wellbore hoop stresses, making sure that borehole instability doesn't happen over time. This was an issue at KTB, for instance. The KTB hole was open for so long, right? Even though you can initially stabilize the wellbore with water-base fluids, they can invade, they can pressurize the new wellbore, your effective stresses go down, and you get time-delayed failure.

All those things is what you need to consider when you are creating a borehole and how you're managing, really, the new wellbore stress state over time, the quality of wellbore that you're going to end up with in the end.

In terms of drilling technologies, it's pretty much similar for different types of bits, different types of technologies.

CHUR: Just to add on that, to at least reduce if not totally avoid the drill string vibration, as we have seen so very impressive on the video, for example, at the KTB well we drilled the whole well with downhole motors. And, of course, that reduces the--and then you turn the drill string only, whatever it was, 10, 15 RPM or so. And then you are rid of these vibrations, which, actually, if you just drill it simply rotary, have a damaging effect on the borehole wall--

VAN OORT: I have to warn you there. If you backream with downhole motors, you shall see the worst kind of drill string vibration that you ever seen, because you have an unbalanced mass in the drill string. Some of the worst drill string vibrations that U.S. operators are seeing in their U.S. land drilling and actually destroys their motors is backreaming with directional assemblies.

CHUR: So you make the point backreaming?

VAN OORT: Yeah.

CHUR: I was at the point drilling. But now we're coming to a university discussion.

ZOBACK: Let's see if we can fit in a few more questions.

PATRICK: Wes Patrick, Southwest Research Institute. First I want to congratulate the panel. You were charged with looking at how to drill, and I'm pleased that through the questions we're hearing quite a bit about where to drill, because I think that is certainly an earlier step in the process.

Several of the comments that have been made, as well as Mr. Griffith's commentary here about what--I guess hinting at what the test is and is not, brings to mind something that I think has to be very clearly in the minds of those who are planning and executing the test; and I'd like to see what your thoughts are on it.

And I see a tension here, because this is going to be a consent-based process for the field test, and it's also going to be a consent-based process for the real disposal. And coupled on top of that is the promise that nothing radioactive will ever go into that test facility.

That brings to mind what seems to me to be a pretty important thing, and that is that the field test be conducted under, as near as one can tell, conditions that are similar to where one would expect or reasonably expect to be able to put the deep borehole disposal site.

Now, granted, granites are complex rocks--or complex--but I would encourage DOE to be thinking about having a field test in an area where it is not unlikely--you know, no promises, but it is not unlikely that they could find a willing party, a willing organization, to accept an actual disposal, because if the tests were to be done, say, in a subduction zone somewhere in the southwest--you know, off the coast of California--and we're really going to anticipate the disposal would need to be done, you know, up against the Canadian craton or something, conditions, stress, uniformity of the materials and so forth could be quite different.

I don't know whether you have any observations on my observation or not.

HICKMAN: I think that's actually a very good suggestion. And I know that the plan is not to put anything radioactive in the first well. You wanted to know how well you are able to predict the long-term performance of the system with the best possible selection of a site, as you pointed out, state-of-the-art characterization of the 3-D volume. You could put either some kind of tracer downhole with an appropriate heater to simulate canister performance or actually some shortened half-life cesium/strontium or something like that that if it leaked out, it wouldn't be as bad as something with a longer half-life.

There are various ways to test this. I would certainly feel more comfortable doing state-of-the-art characterization, then carrying it to the next step either with a tracer that is completely benign or something else to look at the long-term performance of that site once you've done the best you possibly could to select the representative site that's likely to have transfer value to other sites and do the best possible job you can of surface and downhole crosshole characterization, then try something that looks like a tracer test over long periods of time into your monitoring wells and see how the system performs before you go for much longer term or even start talking about longer-term disposal. That would make me feel more comfortable.

ZOBACK: Okay, thank you.

We are seemingly out of questions, but also out of time. Before I close the panel down, Steve, you've had an opportunity just now to express some of your issues and concerns. I'd like to give Claus and Eric 30 seconds or 45 seconds. You don't have to--if you feel you've said what you want to say, is there any final words you'd like to have?

CHUR: First, I think from a drilling standpoint, the program can be done. It's absolutely within the limits of today's capabilities. I would highly recommend to make use of the latest technology regardless if it could give additional--will bring additional cost. However, at the end of the day, you will save much more than you have spent up front. Just a little hint. We can discuss that probably later and separately.

I think your casing scheme is very conventional. If you look at the KTB scheme, it was much lesser clearances, only 15 millimeters, so you even could think of a reduced casing scheme or have an additional reserve you build in, which I think is a good thing.

The thing I cannot personally judge from my experience is the excavation damage zone or near-bore damage to the wellbore zone. If that is the major issue, then I recommend to do additional work on how that can be handled. As I understood, fluid is maybe not such a problem due to the heavier gravity, but then there's still gas migration, just to share that. I know that in Switzerland at the NAGRA they have a lab in Grimsel, which specifically investigates these sealing issues between casing, bentonite, and granite or crystalline rock.

Then I would like to support one comment, Mary Lou, from the morning you made. It’s in reference to public acceptance. I’m coming from a country which had a painful discussion two years now on fracking with the results that fracking for the time being and for the foreseeable future will not be possible anymore in the country--it’s almost impossible--and that is primarily to the video, which was recorded in your country and was not properly handled in our country with a horrible effect.

So even if it’s a clear statement from the government that in these test boreholes there will be no dispository from real nuclear waste, the fact doesn’t matter. I think it was shown in the morning that when I saw the org chart from DOE, there was big box for procurement. I recommend to have the same big box for public relations.

And last but not least, I hope the program will fly, and I would like to enjoy to visit it sometime.

ZOBACK: Thank you.

Eric, final words?

VAN OORT: I’ll take my 30 seconds as well. Just briefly, I agree with Claus that there are no technical hurdles to drilling the well. I want to say that how well you drill, how clever you drill, will have a big effect on the economics of the project. And that will change things by tens of millions of dollars over the lifetime of the program, if not hundreds of millions of dollars. And then the quality of the construction, how much effort you put into constructing a high-quality wellbore, will, of course, have its consequences over the lifetime of the well.

ZOBACK: A good note to close on. And I want to--everybody, let's thank the panelists again for an excellent job.

Okay, we have a 12-minute break scheduled. See you back here at 2:45.

(Whereupon, the meeting was adjourned for a brief recess.)

CROFF: Can we be seated, please?

(Pause.)

Please take your seats so we can get started.

(Pause.)

Welcome back. I'm Allen Croff. I'm the Board member that's going to moderate the second panel session on emplacement modes for deep borehole disposal.

This panel is going to consider deep borehole issues beginning with the receipt of waste for emplacement at a deep borehole that is presumed to exist and be licensed for waste disposal and ending with a deep borehole containing the waste and awaiting closure but not having been closed. And that topic, closure, is the subject of the next panel.

Questions to be considered in this panel are given in the agenda. I’m not going to read them back to you. In summary, we’re going to address issues related to the selection of the waste emplacement modes for deep borehole disposal, normal and off-normal operational safety impacts to workers and the public, and the design of the deep borehole test facility to inform human health and technical risk analyses into the future.

To be clear on this, to take off on what Dr. Gibb said at lunch, in this session we’re talking about operation of a nuclear facility, not drilling or non-radioactive operations and, in particular, sort of the nexus of drilling and how do you handle highly radioactive material safely and reliably.

With that, I’d like to briefly introduce our four distinguished panelists.

First is Wes Patrick, who is Vice President of the Geosciences and Engineering Division of the Southwest Research Institute, where he directs a division engaged in radioactive waste management, groundwater resource analysis, energy exploration and development, planetary sciences, environmental impact assessment, and site characterization--a man for all seasons.

More directly relevant to our task here, before joining the Institute, Wes conducted field test investigations at the Waste Isolation Pilot Plant and the spent fuel test at the Climax Mine site at what is now or was then the Nevada Test Site, which we heard a little bit about this morning. That was an engineering demonstration of emplacing, storing, and retrieving spent fuel assemblies and has some obvious relevance to what we're going to discuss here in terms of emplacement.

Mark MacGlashan joined Schlumberger Oilfield Services in 1979 and worked there as an engineer until 2015. He is responsible for managing field operations engaged in the acquisition of geophysical data collected from boreholes drilled for oil, gas, and geothermal using instrument packages deployed and retrieved with wireline and with drill pipes. He has extensive experience in the use of various types of logging instruments, including sealed radioactive sources and the management of teams in the field to deploy those resources.

Doug Minnema is a nuclear engineer and a health physicist with 36 years of experience in DOE's nuclear complex. He started his career with 16 years at Sandia, where he conducted technical reviews of plans for monitoring airborne radioactive aerosols at the Waste Isolation Pilot Plant. He next became Senior Radiological Protection Advisor at the National Nuclear Security Administration for 11 years; and he is presently a staff member with the U.S. Defense

Nuclear Facilities Safety Board, where he performs oversight of DOE’s defense nuclear facilities in the area of radiation protection, nuclear facility safety, criticality safety, and safety culture.

Finally, Ernie Hardin has nearly 30 years professional experience as a geoscientist and engineer for four private companies and two U.S. nuclear laboratories. He has been involved with underground research at the Stripa granite mine in Sweden, Colorado School of Mines experimental mine, the Lucky Friday Mine in Idaho, G-Tunnel on the Nevada Test Site, Exploratory Studies Facility at Yucca Mountain, and the Waste Isolation Pilot Plant.

Most recently he is the Test Package and Emplacement Engineering Lead for the Deep Borehole Field Test. We heard from him this morning, of course, rather extensively. He is with us here to provide insights on this recent work and the details of their study that are essentially the subject of this panel’s discussion.

At this point, Ernie having given his presentation this morning, as with the previous panel, each of the other three panelists are going to take about ten minutes to give their perspectives on emplacement mode. And after the presentations we’ll again go to the questions and answers.

And, Wes Patrick, if you would be first, please.

PATRICK: Thank you, Allen, for that introduction. And thank you all for coming and spending some time in exploring this very important topic that DOE and the rest of us have before us.

Just to frame my comments today, I am not going to address anything related to policy aspects. The assumption and the comments that I'll be making is that decision has been made, and the Department of Energy has been instructed or made the decision to move forward with conducting a field test to examine aspects of emplacement and other things that will be spoken to by other panelists here today.

So, with that in mind, I have framed my presentation along three lines. First, I want to very quickly give you some background, some lessons learned from the Spent Fuel Test-Climax. That really is the stage-setter, both historically for me, and I was pleased to see that Ernest Hardin and his colleagues have at least looked back at that experiment to see what could be learned from it.

I want to focus then on some specific aspects, some specific observations, about the Deep Borehole Field Test plan and then just wrap up with a couple of summary comments.

We learned a lot at the Spent Fuel Test-Climax, and I've identified several of the items here that are important to that. I'll touch on them very briefly just now, because I want to dig into those a little more deeply in my specific comments about what DOE is currently planning.

It's critically important that the plan, the design, and the execution of the test be consistent both with whatever the current legislative statutory constraints and regulations are or what one could reasonably anticipate to be the case when the actual deployment of the deep borehole disposal mode would be implemented.

The third bullet there ties into those. It's very easy for engineers to "assume away" things. It's harder to assume away them in technical areas, but it is much easier, I've found in experience, to assume away things that deal with the statutory, the regulatory, aspects. So that's one of the lessons that we learned very quickly at Climax and adhered to trying to understand where those assumptions might creep into and avoid doing so.

Very important to integrate fully and hold in an equal standing the engineering and science objectives. All too easy to subordinate one to the other and to the detriment of the program and what is ultimately able to be learned, to be mined out--no pun intended--from the experimental activities.

It's important, we learned, to explicitly account for environmental, safety, and quality aspects that could affect the eventual implementation, even things like radiological safety that are not important to a field test that doesn't involve nuclear materials, radiological materials. There are things that can be done, as I'll speak to later, that can be used to simulate those important aspects.

We learned that it's very important to give preference to engineered controls rather than to administrative controls. Human factors are a ubiquitous problem in just about any operation one can think of.

And the last point that we learned was to employ management principles that allow for flexibility. Call them what you want. Some people like the term "adaptive management". But it's important that those flexibilities be present throughout the design, construction, and operations process.

Let's take some of those lessons learned and move them over into the Deep Borehole Field Test and, by implication, what can be learned there that can be applied to actual deep borehole disposal.

Again, the statutory and regulatory requirements, really need to think through those as fully as possible. Right now the Nuclear Waste Policy Act calls for retrievability, that the option be preserved to do that. It's important, in my view, that DOE think through that and decide whether that's an important part of this. Certainly from everything we know and have heard so far, the Deep Borehole Field Test is going to actually retrieve the simulated packages, so it will be done. But it’s important to do it under conditions that are relevant to what would be anticipated to be done under the deep borehole disposal plan.

I did not identify any areas where statutory and regulatory framing would differentiate between the two techniques that DOE has considered so far, the drill string emplacement and the wireline emplacement. So the analysis results, if only those two are considered, would not be impacted. So nothing, really, that I would recommend be done there.

The field test, as I mentioned earlier, really needs to be framed within the context of what is reasonably anticipated. Why do I say that? It comes down to representativeness of what is done during that field test, and that representativeness, in turn, drives the transferability of the results from the test conditions to any deep borehole disposal that might be adopted as a national policy.

The integration and completeness of the objectives is a very important aspect as well. Operational realism we found to be critically important at the Spent Fuel Test. I believe it is even more so here as we get closer and closer to deciding as a nation of how to dispose of at least some of the types of waste that are out there.

And that drives me to make the second comment in that phrase, is that all possible elements or reasonably possible elements of the deep borehole disposal concept need to be incorporated in the field test. As I look through the current plan, many things are still TBD. And, granted, Mr. Hardin, you know, it may be too early in the program, but I want to highlight that and make sure that that's on the record.

The engineering objectives need to be on par with science. At Climax engineering drove science, and we had to fight tooth and nail to get the right science into that, right, as far as we could take it at that time. Here I see a couple of places in the test plan where it says nothing will be done on the engineering side that'll compromise the science. That swings the pendulum in the other direction. I would call for a balance there, not a subordination of one below the other.

I think there are some interesting things that are said in the test plan about emplacement fluids, including non-mud fluids. It gets onto some of the issues that were raised in the previous panel. Those are some important aspects to speak to. The hydrology, the geochemistry, sealing, long-term performance, all of those come into play when you consider the role of mud. Same is true of the materials that are used to cement in the upper sections of the controls that are in place for the borehole.

There are some things that can be done, I think, to simulate the presence of radiological materials. As a bare minimum, time-and-motion studies can be done there from which one can calculate. I think the last one might also want to give some thought to whether there are ways that the radiation field can be simulated. Those of you who are physicists out here, you can think of RF techniques, EM techniques, things that would allow you to get a simulated effect, detect a simulated effect, without exposing people to ionizing radiation.

Some comments on the completeness of the analyses as they currently stand, I think, are warranted. Consideration, I think, should be given or could be given to a way of taking advantage of our ability to directionally drill--and I'll let some of the drilling experts speak to that a little bit further--but some of the early concepts in deep borehole disposal--actually, at a single borehole--that would then flare out to create four or five or six emplacements there. There may be advantages to using that kind of a technique here. It's worth taking a look at.

I notice also in looking at the test plan that the analyses are not only consistent between the two techniques that were being evaluated, and I think they're important to consider as we think about how transferable might these field test results be over into an actual disposal mode. I mention just a few here that came to my eye as I was looking through things. Maintenance--you may not need to do maintenance in the period involved in this particular study, but to think through that, to plan through that, to look at where the risks are associated with the timing of maintenance. Condition-based maintenance consideration, things of that nature, status monitoring of the various aspects of the emplacement equipment and so forth, status of the emplacement fluid, it seemed to be a very important thing in the drill string operation. Didn’t really pick up on much being thought about or talked about anyway in the wireline emplacement.

So a few of those things. And that’s not intended to be a comprehensive list, but just some things that popped out to me as I was looking at the analyses that have been done to date.

Criticality seemed to have been taken off the table. It might very well be something worth considering. It could be a discriminating factor between the two emplacement modes. Whether it’s a discriminating factor or not, it’s one that you will eventually need to tackle as you look at deep borehole disposal implementation.

I did identify some additional engineering or operational considerations that DOE and Sandia may want to consider in their development contractor. A number of things are listed for further analysis. These analyses really need to be completed.

There are some things, for instance, that we found at Climax that were very important: the gate closure mechanisms, things that would prevent gate closure under load--we saw some of that being simulated in the one video this morning--the need for wireline inspections, again, simulating these sorts of things during the actual field test. Even though they may not be important there, because the duration, the number of trips, etc., are very, very low, they can help in understanding where problems can arise during operation and how controls can be put in place to prevent those kinds of problems or minimize the probability of them occurring.

Based on the high failure probabilities, it may be useful, may be important, to include some of those safety interlocks that you have implicitly included in the deep borehole disposal in the field test as well. The other part of risk, the consequence part of the risk computation, is not going to be very significant for the field test; but, again, it would make the simulation, the field test, much more realistic and consequently may be worth doing.

I think it’s important along those same lines to include in the field test appropriate control systems that will be important in the deep borehole disposal should it be implemented. There are several listed in the tables and the analyses as not being needed for the Deep Borehole Field Test; but, again, my view from the experience at Climax and elsewhere is that even if they're not needed on the test, incorporation of them in that test is very valuable if they are needed in the actual implementation.

The emplacement fluid, very interesting concept there in terms of balancing out the load, slowing the descent rate under normal conditions, but also that would come into play if a cable were to fail or a drill string were to fail. Given the high probability of drop events, I wonder whether some sort of a gravity braking system on the emplacement equipment might also be important. I believe the drill strings, the weights there are so large that that would not be implementable, but wireline single-package emplacements, that should be a readily achievable engineering implementation there. May not be necessary. May not significantly decrease the risk. But that's one that we put on at Climax. Of course, there lowering through air; considerably different situation than what is being proposed here.

Wrap up then just with a few brief concluding remarks. My overall assessment, looking through the information that was available to us, which certainly is not all of it, is that the specifications document does lay out a very sound concept. The preliminary design analyses I found to be very thorough with respect to the emplacement mode considerations and the treatment of risk uncertainty and even taking it a step further into some rather detailed sensitivity analyses. I commend those who are working on the project for those things.

My overall assessment is that the current state of practice and the current state of engineering are included within the proposed approach, and a number of the lessons learned from the Spent Fuel Test-Climax demonstration project have also been incorporated.

And, finally, the specific suggestions I have made, I would just turn to DOE and their contractors and encourage them to take a look at those, give them due consideration as they move forward with the program.

That concludes my remarks.

CROFF: Thank you.

MACGLASHAN: Hi, everyone. My name is Mark MacGlashan. I was an engineer for Schlumberger for about 36 years, and I was in the wireline business, in the wireline segment, that is. So our business was usually running things into the well on wireline, always wanting to get them back out as opposed to leaving them in there. But, still, there’s a lot of technology that transfers over, so I have a few highlights to share with my presentation that would be of interest for planning for operational purposes.

First of all, of the four emplacement mode options, the first two that are under the most consideration are drill pipe emplacement and wireline or logging cable emplacement. There are two others that have been--one of them that has been discussed, gravity or free-fall emplacement, and one that has not been discussed yet, and that is what I've termed a conveyance liner. That would consist of an inner concentric casing that is loaded with waste packages at the surface and then conveyed into the emplacement zone on drill pipe.

So back to the drill pipe emplacement option, there are a number of advantages that drill pipe offers. Number one is it's very strong. It's on the order of several hundred thousand pounds, so with a lifting capacity that gives you the--makes it possible to convey multiple waste packages for efficiency. And since we would be conveying multiple waste packages, we would be limiting the number of descents; so with the number of descents, that makes your chance of--reduces your chance of accidents.

The advantage, the greater strength of the drill pipe also is available in the event that the drill pipe or waste packages become stuck in the borehole, something that's a very major possibility. Another advantage is the ability to circulate through the drill pipe. This is a commonly-used technique to free drill pipe and drilling assemblies if they become stuck in the well. Now, this circulation with the current plan, they would be going to the end of the drill pipe, and they would not be able to go past the waste packages.

So some of the disadvantages or drawbacks to the drill pipe emplacement mode. So the fact that the trip with the drill pipe in a well or a borehole of this depth with a drilling rig could be expected to take as much as 24 hours, so to make the most of the efficient use of the drilling rig, you would need to convey multiple waste packages. So that's one disadvantage. It's also a disadvantage in that you would need also complex pipe handling machinery to assemble and hold in place waste packages at the surface.

So one other disadvantage or drawback that might be encountered is, this pipe handling machinery that's proposed, it would be a very complex system. It would have to be capable of supporting the waste packages, also screwing them together or fastening them together. So that could be--with the waste packages in the pipe handling machinery for an extended period of time, that could produce some unforeseen effects, such as deterioration of O-rings and hydraulic hoses and other organic materials such as electrical insulation and things like that.

Some more disadvantages. This will be a complex operation, so there will be more on-site personnel needed. Also, with this arrangement there will be no option to circulate mud or borehole fluid past the waste packages. So with our current, we could have a potential of about 800 feet of waste packages with no way to circulate past them. So if they were to become lodged in the borehole among debris or something, circulation would not be available to assist with that.

Another possibility or potential problem is a failure during assembly of the waste packages in this pipe handling machinery. There is a potential or a possibility that it could leave a connection between two waste packages partially assembled or possibly the pipe handling machinery may fail itself. If this were to occur, it could be a situation that would be difficult to remedy, because you would not be able to approach the machinery because of the presence of the waste packages. And with a partially connected connection, they might not be safe to move. So with this scenario, we could have some waste packages kind of like in place and not safe to move.

Another disadvantage to this--two more disadvantages to the drill pipe emplacement. The waste packages, of course, may be exposed to impact and crushing forces from the heavy weight of the drill pipe. That’s something we’ve been discussing quite a bit.

Another potential drawback as far as testing, the pipe handling machinery is a very complex system. It may be difficult to make a scaled-down working model. Because of its complexity, it may have to be--for testing have a full-scale working model.

Our next emplacement mode is wireline. So due to the strength limits of the wireline--it’s not nearly as strong as drill pipe--it would be planned to convey one package at a time. So in a way that’s an advantage, because you would not need two other things; we would not need to have the pipe handling machinery, and we would have a simpler design for the waste packages themselves since they would have no need for connections between each waste package.

Another advantage of this wireline, the speed of each descent or emplacement would be about six hours, much faster than wireline. The other advantage, because wireline has potential to run instruments, you can convey electrical logging instruments along with the waste package, so this could be a big advantage for monitoring to the surface. The personnel could monitor the depth condition, temperature, radiation level of the waste package.

So one more advantage with the wireline: The waste package is unlikely to be damaged, because the wireline and associated equipment is much, much lighter than drill pipe. Also, again, since the waste packages with wireline would not need to be designed with end-to-end connections, they could incorporate impact-absorbing modules.

Some disadvantages associated with the wireline: Due to the number of descents needed to complete the emplacement project, that’s a large number of descents, about 400. So the possibility of an exposure to getting a waste package stuck in the borehole or some other undesired incident like an accident is quite high since they have to be--there’s a lot of operations involved with 400 descents.

Another disadvantage or drawback: A waste package stuck in casing, if the decision is made to recover it, usually that’s done with drill pipe. So here we would have the drill pipe introduced into the wireline operation, and then you would be bringing in some of the same hazards associated with the drill pipe, which sort of introduces extra hazard with the wireline.

Another disadvantage with wireline is a failure of the wireline instrument assembly or the cable or the release mechanism that’s used to release the waste package in the emplacement zone. If they were to fail during the emplacement, the decision would have to be made to either just leave the wireline and the waste package in the borehole or bring it back to surface to make repairs. So that would bring in a new set of hazards in bringing a waste package back to the surface.

So the waste packages are designed to resist external pressures, but there’s always a chance--as a pressure vessel, there is a chance that these waste packages could develop a leak at depth. And if the pressure were to equalize with the external pressure, you could end up bringing the waste package back to surface with high pressures inside. And with the current design, there is not a good way to know the conditions on the inside of the waste package.

Another item, the last item for the wirelines--so the weight of the waste package, which the buoyant weight is going to be close to 4,000 pounds in the wireline at this depth, would be close to the operational tensile limits of most of the wirelines in use now.

So our gravity or free-fall emplacement advantages, as was mentioned, this is really very, very simple. It’s the least complex by far. So, because of its simplicity, there would be less personnel needed. And because of not having the combined operations with drill pipe or wireline, it may have less chance of becoming stuck in the borehole, because there’s less chance of introducing debris in the borehole with other operations.

Some disadvantages: The free-fall method may need to have a redesigned waste package or a redesigned borehole trajectory to limit descent speed, and it may not be acceptable due to lack of control and monitoring. Once it’s released, there would not be a good way to monitor its descent.

The conveyance liner, this technique would have quite a few advantages, first of all, the ability to convey multiple waste packages at one time to the emplacement zone without having to physically connect them, because they would be stacked inside this inner casing liner.

So another advantage is, along-the-pipe movement of each waste package as it’s placed would be into the conveyance liner, and then that would be only 10 percent of the depth of the well, so there’s less chance of an individual waste package becoming stuck in the borehole.

One more advantage, ability to circulate borehole fluid down into the liner past the waste packages to clear debris or help free the liner if it were to become stuck in the hole.

Another advantage, the liner would serve to protect the waste packages during the emplacement, since they would be resting inside the liner, and they would be protected from impact from the drill pipe.

So another advantage is, just as a general remark, the design and use of casing liners is a really well-developed technology and very commonly used. So there is many designs available, and personnel in the oil technology business usually are very familiar with them.

One more advantage: It's been mentioned that supporting bridge plugs and cementing would be needed to provide support between groups of waste packages. And with this conveyance liner, each liner is suspended separately from the outer casing, so there would not be a need for those unless they wanted to do hydraulic isolation between these groups.

Some disadvantages, there's one principal one. Since the conveyance liner requires an outer casing string for the liner hanger to engage, it might require a major redesign of the disposal borehole; and it's not part of the current planning.

So a few other items that could influence the well design and emplacement modes. Directional drilling. A directionally drilled borehole could offer quite a few advantages. First of all, it could simply limit impacts during accidents if something was dropped. Another thing is, the angle build rate can be very well controlled so that the angle build rate--that's another way of describing the curvature of the borehole--wouldn't stop or impede the passage of the waste packages.

Another large advantage of a directionally drilled borehole is that if the angle from vertical is high enough, then the axial load on the waste packages could be reduced to the point where, again, it would not require bridge plugs and cementing.

And, just as an aside, as a general rule, the angle from vertical, angle of repose, for commonly-used materials in drilling is about 72 degrees.

Another little item of technology, the distributed temperature sensor systems, or DTS, these are fiber optic cable systems that, when they're installed, they're installed during the casing installation along the outside of the casing. They provide real-time temperature monitoring about every three feet from the surface along the casing. They could have an application for monitoring the descent velocity or emplacement of waste packages.

In general, the design of waste packages, they will be exposed to very high temperatures in the emplacement zone. At 16,000 feet they could see 350 degrees Fahrenheit. And depending on the borehole fluid, if it's just water, if it's a vertical well, it's going to be about 7000 psi.

So a failed or damaged waste package could be very hazardous if it's returned to surface, as I said on another slide. It could contain high pressures. In addition to being a waste package, it's also a pressure vessel. So the design of these waste packages should recognize that there may need to be a way to identify pressure trapped inside them or a safe way to release the trapped pressure.

So, in summary, the gravity deployment or free-fall is least hazardous in all respects, but it’s probably not acceptable due to a lack of control and monitoring.

A conveyance liner eliminates a lot of drawbacks associated with both wireline and drill pipe, but it’s not a part of the current planning, and it may require a redesign of the borehole.

The drill pipe emplacement mode is most likely the next most hazardous of these three due to the hazard posed by the weight of the drill pipe possibly impacting the waste packages in the event of an accident; also the associated hazards with the pipe assembly or pipe handling machine or its surface.

Our last emplacement, the wireline, is probably the most hazardous due to the large number of descents needed or operations needed to emplace 400 waste packages at 16,000 feet with a wireline and also with the addition of possible fishing operations that would involve drill pipe.

That concludes my presentation.

MINNEMA: Thank you and good afternoon. I’m Doug Minnema. I do need to note first my disclaimer. As a federal employee who is not a political appointee for my agency, I have to note that these are my opinions, not my agency’s. The second reason I want to point this out is for my DOE friends. They need to know that this is not implying that the Defense Board is going to oversee this project. I am an expert and was asked to talk about a particular area, so that's why I'm here.

I do want to thank Allen Croff and the Board for inviting me. I appreciate the opportunity to speak on this area. It is a little different of an area for me, although I have the technical background for this, but what I've been doing lately is more soft science. So I look forward to it.

I want to touch on four areas real quick. There are some concerns I have about the operational aspects. I am a nuclear safety guy, so I look at it as a nuclear facility from day one. I was also asked to talk a little bit about organizational culture and the impact on safety. That is one of my other areas of expertise, and so I want to spend a couple minutes talking about that, too, and how it may have implications in this project.

You've heard it before; I'm going to say it again. Understanding the requirements within which you have to do this project is vitally important. If you ask me what kind of data you need to collect for assessing human health and safety, I will tell you, "Tell me first what requirements you have to meet." It's not that it can't be done, but your data needs will vary significantly based on what the requirements are.

First I want to touch on radiation safety during routine operations. And where I'm looking at here mostly is before the material--from the time the material comes on-site until it really goes into the hole and is outside of the range of the operators. Certainly it is important after it goes into the hole, if it gets crushed and has to be brought out, that is a problem. But, to me, the biggest risk operationally to the workers involved and, in fact, to the public may be during the time that that material is being handled, shipped on-site, taken out of the cask, put into its fixture or however it will be moved down into the hole. That's where you have the opportunity to have significant exposure levels to the workers.

And I know this is a group from academia and engineers, so I'm going to speak a little heresy. It's a great academic exercise to go through and do all the shielding calculations to do this, but don't rely on engineering and calculations alone.

DOE has a lot of experience handling very hot packages. Some of that experience is good; some of it is bad. But you need to go out and make sure that that experience has been incorporated. It comes down sometimes to simply the types of fixtures that you have on the shielded cask, for opening or closing the lids, a variety of things that come into play that only the person that has done it before can tell you whether or not it will work that way.

Now, going deeper into nuclear safety beyond just the radiological risks, I would actually probably slightly disagree with some of the previous speakers. The Deep Borehole Field Test is one thing, but if you are going to do this for real, you need to think of it as a nuclear facility from day one. It is not a drilling project converting into a nuclear facility. It is a nuclear facility from day one. Safety has to be designed in it from the beginning.

There are basic elements of nuclear safety that we always think about. One is the quality of the knowledge that you know about the material you're working with. In this case it's waste. You don't know exactly what the process history is of the material or what its form is. You know that the packages that you are using, even the cesium packages, may not have good integrity, so you can't rely on them. So you need to independently develop some level of confidence in the integrity of the packaging or the outer packaging you're going to use.

You want to be sure that your safety controls are always effective. Another individual commented--I think it was Wes talked about not relying on administrative controls. He is absolutely right. The administrative controls are probably the weakest part of your whole control set. You have to have some, but you don't want to rely on them as a primary safety function.

And, lastly, especially in a case like this, I did some simple calculations. If I take eight of the cesium capsules and put them in one waste package, I’ve got 5,000 or thereabout rads per hour on the outside of that package. It is not an insignificant dose, though. That means that everything I do around that package either has to be--it either has to be completely shielded, or it has to be reliable such that all the systems are completely fault-tolerant. So if something fails, I don’t want to send in a guy to fix it. I want to be able to recover gracefully. And that has to be designed in and thought through from the beginning, so that is something that the field test aspect is very important to think about.

Another thing that comes into the safety-related systems, we have a couple concepts in nuclear facilities. We talked about material at risk, and we talked about material in process. In this case, the material at risk would be the total amount of material you want to put down in the hole. That's decided by your design, your features.

The material in process in this case, think of it as the material you’re actually handling at any one time. How many of those waste packages am I trying to manipulate at one time? How many do I have on-site? Am I trying to form a drill string of 40 or 50 packages? That material is in process. It’s in a situation where it presents a possible hazard to the workers. And so you really want to try and minimize that.

Now, sometimes you end up in this conflict between, if I only handle one package at a time, I have more wireline operations, but if I do a drill string, I have more material that can get released if I drop it. You have to balance these things. But you really want to think about it in terms of minimizing the possibility of an exposure to an individual. And probabilities don't always get you there, because if it happens once, you're going to fix it so it's probably not going to--hopefully it's not going to happen a second time. But if you think about in probabilistic terms, you're assuming that it's going to happen once every 50 times. There are differences there between a small-consequence accident and a large-consequence accident.

The one thing I want to do here real quick, the risk profiles that you are working with through this operation are going to shift throughout the operation. You're going to be working with different kind of materials, different kind of dose rates. Above ground is going to be different than below ground.

In the nuclear business we have a tendency to try and envelope things, bounding scenarios. You really don't want to do that here. You want to take out as small chunks as possible and analyze each of those chunks separately, because your risk is significant, especially for those workers on-site. Your risk is significant, and it shifts constantly. And if that package is carrying TRU waste or high-level waste or calcine waste, which is very easily dispersible versus a cesium capsule, your risk is completely different. You don’t want to look at it generically and say, well, a waste package is a waste package is a waste package.

On culture I want to look real quick from two aspects of it. There is the organizational culture of the people on the site and their management in that organization. And, in blue, I would ask you the simple question: Would you expect a nuclear operator to operate a drill rig? And if the answer is no, then you probably shouldn’t expect a drill rig operator to operate a nuclear facility. You want to keep the functions separate and make sure that you have the right people doing the right things.

Drill rig operators are very safe doing what they do. Nuclear facility operators are very safe doing what they do. It’s when the mindset gets to the point that, well, this is only a--we’re just putting waste into a borehole, you start relaxing, you start becoming overconfident, you start saying, well, an operator can be an operator, I don’t care if he’s a mining background or a nuclear operator. It affects the way things get done, and it affects the decision making. You need to be very careful about maintaining those two separate.

The other way I look at it--and this is not a criticism of DOE; don’t assume that. DOE is a very dynamic organization. As we all know, their priorities shift regularly; their budget shifts regularly; their leadership shifts regularly. That creates real stress on an organization when you are trying to do a long-term operation. If you try and do a 10- or 20-year waste disposal operation--for example, WIPP--it’s tremendous stress on the culture of the organization. The priorities shift; the people have to shift according to those priorities. In an operation like this when you get to real-time, you really have to take that into account and think about how that will play out and how can I best isolate this operation from the constant change that occurs at the other levels within the organization.

Now, I want to leave you with this. I know we are not flying shuttles, but that’s okay, because this--I think this sentence captured both--I’m sorry, two sentences--captured both the Columbia accident, the Challenger accident. It also captures a lot of my experience over my 36 years with DOE. “Each decision, taken by itself, seemed inconsequential, but in the end they accumulated together.”

You see that I’ve done multiple accident investigations. I’ve done multiple assessments. And where you see accidents occur in this business, it’s where you have multiple breakdowns; and where you have multiple breakdowns, it's due to individual decisions that accumulated that were not recognized--where the accumulated risk was not recognized in the organization.

So I want to leave you with that. Each decision you make on this field test may have significance. You may not know what that significance is now, but it will accumulate. So you need to pay attention to everything until you feel you have an understanding of what's important.

And that's it. Thank you.

CROFF: I'd like to thank all the speakers. We're going on to questions and answers. I'd like to approach this by first offering the current panel a chance to question or comment or offer any thoughts on what they've heard during the last three presentations and maybe a little bit bringing into what you heard from Ernie this morning, too.

And while you're doing that, other panel members, if you are interested and you have a comment or a question, please approach the microphone and queue up, and we'll get to you very shortly here.

First, the sitting panel. Any discussion comments?

HARDIN: I can make a couple.

CROFF: Okay, go ahead.

HARDIN: So Hardin, Sandia. So, Wes, I don't think criticality will be a problem as long as we are not in the business of disposing of spent fuel. I don't see any of the other waste forms being a problem.

Mark, it would be good to talk to you about how to prevent leaking packages from spewing their contents when they get to the surface. I'm sure that problem comes up frequently in the well logging business.

MACGLASHAN: Not frequently, but it's a possibility.

HARDIN: It has happened, yeah.

And I think, Doug, I would agree that radiological worker safety could be a discriminate. I think that might be a direction that we could look into.

MINNEMA: I agree.

HARDIN: In off-normal events.

MINNEMA: Actually, I would say in both normal and off-normal events. We tend to assume that the nuclear industry has a broad range of experience; and, actually, that broad range of experience in in very specific areas. And so when you take us outside of the facility and put us into a field where we are moving material outside of the normal envelope that we operate within, it still is different. And so it's something that you have to think about every day.

CROFF: Wes.

PATRICK: Wes Patrick, Southwest Research Institute. I would add to Doug's comment. There were at least two occasions, one in the shielded high bay area loading packages and one as we were doing the interface, actually getting the spent fuel ready to be lowered underground, where the interface between people who were used to doing, not necessarily non-nuclear, but nuclear weapons things where high-radiation fields were not an issue, came very strongly into play. And, fortunately, we had all the backup systems where we detected in one case a source that was exposed before people got there. But very important.

CROFF: Ernie.

HARDIN: A question for Wes. Hardin, Sandia. The gravity break, was that ever tested?

PATRICK: Patrick, SWRI. Yes. We had a dummy canister that was filled with steel shot, and we did the full test in the lined borehole where the packages would be lowered. We never had an accident condition develop where it tripped, but we did do the full test.

CROFF: I’m not seeing any of the other panelists in the first few rows. Is there anybody on the Board would like to ask a question?

ZOBACK: Mary Lou Zoback, Board. Just a quick question. In Fergus Gibb’s lunchtime talk he suggested an alternative mode of emplacement, coiled tubing. And, Mike MacGlashan--

MACGLASHEN: Mark.

ZOBACK: Mark, yeah, you suggested an alternative. So we heard DOE in the morning present two alternatives, and we’ve since heard two better alternatives. So should the choice of emplacement modes be expanded to explore the better alternatives?

(Pause.)

Well, let’s hear what these guys have to say.

Are you familiar with the coiled--

MACGLASHAN: Yes, it’s definitely a valid suggestion. So the coiled tubing is certainly a valid suggestion--MacGlashan, Panel--but first of all, we might get into the same situation with drill pipe where it’s not as effective to run it singly. Coiled tubing is very expensive, and to use it is quite expensive. But it’s definitely a valid option.

ZOBACK: Do you want to respond?

HARDIN: So Hardin, Sandia. Yeah, we certainly had that conversation. I’ve never really sat down and looked at the conveyance casing idea, but the coiled tubing--I mean, I think Professor Gibb hinted at the problem with it. It’s only good for so many trips. And so--

ZOBACK: It’s only money.

HARDIN: So the philosophy of design here was, do we have this complex machinery subgrade to assemble packages or not? And so with coiled tubing it probably doesn’t make sense to do it unless you do because of the limited lifetime of the tubing.

PATRICK: Patrick, Panel. Just further to that, I think we need to recognize the obvious, that there is a reason why it has a limited lifetime, that it's going through a fatiguing process. That introduces a risk that DOE would need to understand and elucidate very, very carefully.

CROFF: Fergus.

GIBB: Fergus Gibb, Sheffield University. Just a comment on the coiled tubing. We've done some cost calculations for a two-and-a-half-inch coiled tube. It would make between a hundred and two hundred runs, and it works out between one and two thousand dollars a roundtrip. And he's right, there is a fatigue issue with the coil going over a gooseneck every run. But you can monitor that and apply normal standards of safety. You take it out of service before it's done, you know, 70 percent of its life, and that works out. It's surprisingly cheap.

CROFF: Okay. Any other Board members?

Anybody in--I see somebody here in the third row, not a Board member.

NORDSTROM: Kirk Nordstrom, U.S. Geological Survey. I appreciated your presentations, and I had a question for Wesley Patrick. You mentioned that engineering objectives should be on a par with scientific objectives. One should not be subordinate to the other. I'd be very curious to hear how you would achieve that. I've seen that problem in many projects myself, and I wondered, you know, how can you go about and put in appropriate checks so that it did balance out?

PATRICK: Patrick, Panel. I think two things from experience and also they're philosophically pleasing, for what that's worth as well. One is the organizational structure; and as long as the scientists were shown in a staff position to the line organization, the scientists' roles, responsibilities, objectives were subordinate. When it became part of the line organization, organizationally they were on par. So, structurally, you can deal with that in an organizational sense.

At least as important is organizational culture, and that goes directly to, in the vernacular, "Who's running the show, and does that person at the highest level of leadership articulate and move down through the organization?" But it's important that the entire suite of objectives that the project personnel have agreed to and the client has agreed to are indeed implemented with equality.

CROFF: Question in the front row here?

CHUR: Claus Chur with CCConsulting. I have a question to Wesley. I understood from your presentation, you say statutory or regulatory requirements will affect DBD implementation--heat sheet retrieval. Does that mean retrieval will now become a requirement?

PATRICK: Patrick, Panel. In the U.S. right now the

Nuclear Waste Policy Act requires that the Department of Energy, the implementer, must include the potential for retrieval in mined geological disposal. I have no idea whether whatever statutory changes are made would require that or not. I do not know that. I can't speculate on that.

But for some of the waste forms, these unusual waste forms, there is no economic reason for retrieving them and reusing them. Most likely spent nuclear fuel, that's not necessarily the case. The second reason for having retrieval is that if something is detected, untoward, unacceptable in terms of long-term performance, early on in the process, then retrieval might be a necessary option. There's a lot of debate on whether retrieval makes sense or not, but that really becomes a policy matter.

One thing I did try to articulate is that, given the way the Deep Borehole Field Test is going to be executed, they will be demonstrating retrieval with the exception of post-packing materials being placed then so that that part-- they'll be able to do part of that retrieval demonstration.

Does that get at your question?

CHUR: Yeah, I understand exactly what you say. I just think it needs clarification for the DBD project, because if at the end retrieval after sealing would be a requirement, that would change the total picture. So then it would not make sense, in my feeling, to make a field test and--

PATRICK: Well, it could affect it. That would be one of the objectives that would not be met, but it's worth considering.

CROFF: If there's anybody from the DOE community that would like to ask the panel a question, please feel free to come to the microphone.

I'll ask a question maybe of Mark. How much do bridge plugs--or would bridge plugs complicate retrieval?

MACGLASHAN: So there's various types of bridge plugs. There are some that are drillable, and there are some that are retrievable themselves. So they would definitely complicate retrieval. The drillable ones, as the name implies, are drillable, and they fragment when they're drilled, and then they leave debris and the debris falls down. They're usually made of a brittle cast iron that breaks into small fragments.

The retrieval ones are just--they're latched on and just pulled out. So those are the preferred bridge plug to use for something that you want--if you want to retrieve packages below the bridge plugs. Another disadvantage of the retrievable, though, is that the retrieving mechanism can be fouled, and then it can't be removed. So it's a risk every time when it's put in place.

CROFF: And also along--this is a general line of questioning probably to Ernie. In the project, what assumptions is the project making concerning the regulatory framework you're going to--I know you don't actually have one, but what regulatory framework do you have in mind for doing this whole thing?

HARDIN: We don't know. At the present time it's TBD in our document. We said we know there are going to be these types of regulations in effect, but we don't know whether the present ones would be those.

CROFF: I'll open it up to Board staff. Oh, Rod, do you have a question?

EWING: So this is to Ernie, and it goes back to your--Rod Ewing, Board--it goes back to your presentation this morning, but I think of this in the context of emplacement. So if it were just a little shallower and the distance for trips up and down would be less, the possibility of characterizing the rock a little better might improve. So is there any--or what's the reason for 5 kilometers? Why not 4?

HARDIN: Hardin, Sandia. I'll give you my personal understanding of that question. It's related to two things, the quality of the rock that is under sufficient confinement that we're going to have the *in situ* stresses acting to close up the permeability in the rock. And two is the drilling effectiveness, the capacity to drill at a particular depth at a particular diameter.

So you saw the curve today. We're at the margin of what can be done. It produces a waste package of a useful diameter for certain waste streams.

EWING: But the reasoning could go the other way. Rather than be in the margin of what can be done, back off and stay well within the margin and ask yourselves the question whether that's not just as good.

HARDIN: Right, I agree. Hardin, Sandia, again. I mean, we have done studies like what you're talking about or similar to them anyway. And we look at what if we could drill a 24-inch-diameter hole to 4 kilometers, or what if we could drill something even larger to a shallower depth, given the right site, the right waste stream, and this sort of thing. Is that an appealing proposition? I think it could be. My sense is that the thing that would be holding us back is the cost of drilling the hole, which goes up with the volume of the hole. You could think of it that way.

EWING: Okay, thank you.

CROFF: Board staff, any questions?

BAHR: Jean Bahr, Board. Another question for Ernie. This morning you mentioned some sort of crumple impact limiters in the design. And I was wondering what happens to those if they do crumple; do they deform in a way that they end up getting kind of stuck in the liner, and would that affect retrievability?

HARDIN: So Hardin, Sandia. That's a great question. I asked the same question of our engineering team. So when we do get to that point, we need a design that crushes in a nice way, and it needs to be tested. There are lots of different kinds--I've learned that there are lots of different kinds of impact limiters. So I believe that something like that would be possible.

CROFF: Okay, front row.

HICKMAN: Yeah, this is Steve Hickman, USGS. I just want to say, from the drilling perspective, we're over here gossiping a little bit in the front row. But if you try and retrieve something through open hole with all those plugs and seals in place, it'll be extremely difficult. You could sidetrack and all sorts of things. So we need to clarify this issue of whether or not retrieval is going to be expected through a one-kilometer-thick sealed-and-packed-off zone or whether we're talking about retrieval inside a cased hole, because those are very different challenges.

So that's something that needs to be resolved early on, getting back to Claus's question.

CROFF: Anybody else? Going once. Okay, I think we've exhausted ourselves here. I'd like to thank the panel very much. Let's give them another round.

And to the next panel without a break. We're going to change the tires with the engine running. So I'd like to thank the panel. Don't forget to give up your microphones and bring up the new one.

(Pause.)

FRANKEL: My name is Jerry Frankel, and it’s my honor and privilege to moderate the third and final panel of today’s activities.

We are going to discuss boreholes. We’ve heard a lot already. We’ve heard, in fact, that we are relying on the natural barrier of a very deep rock formation to protect this radioactive waste and delay its release. But, on the other hand, we have this straight path back up to the world, and we have to make sure that that highway isn’t open and is blocked off. So we have a panel of three experts, all from academia, to help us go into some more detail about borehole seals. And I would like to introduce them now.

Our first panelist is Paul Bommer. He is in the Petroleum Engineering Department at the University of Texas, like his colleague, Eric van Oort, who we’ve heard of before. I guess it makes sense that University of Texas has a strong program in petroleum engineering. Paul has 25 years’ experience in oil and gas operations. He is now torturing undergraduates on topics like drilling and completion. And we have asked him to participate in this discussion by bringing his experience from the oil field operations in the area of borehole sealing.

The second panelist is Nick Collier, who is in the deep borehole disposal research group at the University of Sheffield, a group that was started by Fergus Gibb, whom we've heard from. So Nick has a Ph.D. in cement science. I think the gauntlet has been thrown down on cements already, so he'll have a chance to address that. But Nick is involved in these other topics that Professor Gibb described in terms of new ways for waste form support matrices and barriers against release, and we'll be hearing more about that.

Our third panelist is Roland Pusch, who is from the--he's a Professor Emeritus at the Technical University in Luleǻ. I probably didn't say that right. He has a Ph.D. in soil mechanics and geology and, by his own account, has a hundred years' experience in the field; and I have no reason to doubt him on that. He has been involved in many aspects of the topics that we're discussing and has written a book on rock mechanics and recently published a book entitled "Bentonite", simply "Bentonite". You can get it on Amazon. So we've asked him to discuss bentonite as a borehole sealant.

So what we're going to do is follow the same MO as the previous panels. We'll ask the panelists to try and limit their presentation to ten minutes or so, and then we'll have a little discussion amongst ourselves and open it up. I think there's probably more questions and comments on this area.

So, first, Paul will come up and have some introductory comments as well into borehole seals.

BOMMER: Thank you. I get fifteen minutes, because I get to do this. So I have the classic Andy Warhol fifteen minutes of fame, and it's counting right now.

Since Jerry brought it up and Professor van Oort brought it up, I get to pile on a little bit more about the undergraduates. An undergraduate is the only consumer in the world who pays good money for a product and then hopes like hell he doesn't get it. It's a joke, okay? Come on. It's 4:00 o'clock. Come on. All right, so we'll get serious if that's the way you want to be.

Borehole seals. All right, so our overarching questions--and I'm not sure we're going to answer these completely--what materials and process have been developed for sealing and used to seal boreholes under representative conditions? What evidence is there for long-term effectiveness of borehole seals? How can we predict the long-term performance of seals? And what level of performance of a borehole seal is critical to the safety of deep borehole disposal?

All right, now, this slide--I want to spend a couple of minutes on this, because this really, I think, is an important slide even though the cartoon is poor. This is supposed to be somewhat similar to the cartoon you've seen already about the proposed plugging of the deep borehole well for radioactive waste. And I want to draw your attention that this thing has been filled top to bottom with solid material.

Now, the solid material, we can argue about that. Some of it may be cement; some of it may be asphalt; some of it may be clay; some of it may be gravel; some of it may be sand; but it’s all solid. And this, in my mind, helps to replicate the overburden that we have gleefully removed with a drill bit. So as the lady from Pennsylvania pointed out already, the borehole is the way out. I mean, we can argue about cracks in the rock and, you know, all this other stuff; but if the borehole is not sealed, that’s the way out. This is the most important activity that we will do on this well, and that’s called sealing it up.

So I think filling this up with some kind of solid material is very important. And there are a couple of analogs for that. Back in the ’60s/’70s there were two nuclear bombs set off in low-permeability gas reservoirs to see if it stimulated gas production. One of them was called the Gasbuggy Project. The other one was called the Rulison Project, both of them in Colorado.

The second one, the deeper of the two, the Rulison Project, was 8,200 feet deep, and they set off a 40-kiloton device in that well. And that 40-kiloton device made a gigantic cavern. And the wells that were drilled, one was drilled to emplace the device. Another one was drilled as a monitoring device. The monitor well was filled up top to bottom with cement. The emplacement well was filled up top to bottom with alternating layers of nothing more than gravel and sand. Now, when that thing went off, it actually had surface manifestations. The wells did not fail. So those wells proved to my mind that even in the presence of setting off a nuclear device, we ought to be able to plug them.

So that is why I think the cartoon showing this completely full of solid material is very important. And you'll see the difference between this idea and what the oil and gas business routinely gets away with a little later.

Okay, let's see, we've had lots of people who studied this, are studying it. We've heard of one innovation from Professor van Oort already today. I'm sure there are many others. Modeling of the seals has been done. It suggests long-term stability. I don't know what--I don't know how to feel about models. I had an aerospace engineer one time tell me, "Look, if you've got somebody who's got a competing model, you can make theirs eat dirt." So, I don't know, you know, models are only as good as the mathematics and the assumptions behind them. I don't know how good we feel about that for thousands of years. Now, the life of the material, there may be a few analogs for this, not many.

Okay, so here's my part.

In oil and gas wells, we've already discussed that we need to have seals on the outside if we're going to stabilize the wellbore with casing. That's shown by the curved arrow, showing an annulus that's been successfully filled with cement. And whenever it's time to get rid of this thing, plug and abandon it, which nobody in the oil and gas business likes to spend a darn dime to do, you're supposed to fill it up with a sealant on the inside, and normally that's cement.

And I must say that the seals--you really can't do this divorced from the architecture of the wellbore. So all of this has got to be a unified plan. You better think about the end of the day when you're designing the wellbore.

Okay, so traditional seals are Portland cement. Now, I have to confess, I don't hate Portland cement with quite the same vigor as Dr. van Oort; but I may come around to it before he's completely finished with me. He is a very persuasive man.

Portland cement is still widely in use; and when it works, it forms a low-permeability solid that establishes strength. If it's correctly formulated, it resists corrosive attack; and if it's properly used, it forms adequate bonds with the casing and the rock. Lots of "ifs" in there.

Now, here are some mechanical devices. Some people use external, swellable packers--that would be that guy--on the casing. This is a picture of a bridge plug that could be set inside the casing. And this guy over here is expandable casing. Right there is the part that's being expanded. You know, all of these could be counted on maybe to seal, maybe not. They're just a mechanical device after all, but sometimes people use them.

All right, so seals certainly can fail; and if they do, we have a channel. The channel is the flow path. The flow path could happen because I did poor practice. You know, lots of oil and gas companies get away with poor practice, and a bad cement job is their reward for this. If I exceed the mechanical strengths of the seal--Dr. van Oort has alluded to that already--I'm going to crack it; it'll fall apart. Cement exposed to fluids that degrade it will, of course, affect quality of the solid.

And back to the mechanical devices, external casing packers can fail; they may not set. Who knows what kind of seal you really got when you expand the expandable casing. And bridge plugs, even though commonly used as part of the plugging process, in my opinion, should not be counted on as part of the long-term plug. So failure of any of these just give us a flow channel.

All right, so now let's talk about the plug and abandonment of oil and gas wells anyway. That's really my charter. I'm supposed to talk about oil and gas wells.

Clearly there are regulations for this. There's a governing body out there. Dr. van Oort has already showed a detail of offshore regulations for plug and abandonment. So let's take a look at a couple of more cartoons. This guy over here might be a cartoon for a simple well that turned out to be an ouchy. That's just a good old-fashioned dry hole. There's nothing in here but maybe saltwater.

So if that's what we find, the regulatory body might require us to set a plug at the bottom of the well. A hundred-foot cement plug is typically all you have to do. And then up at the top I've got a hundred-foot plug that's going across the shoe of the surface casing, another hundred-foot plug across the base of the usable quality water, a ten-foot plug in the top, and I whack the wellhead off and weld a cap on top, bury it, and hope I never see it again.

Now, everything else between these cement plugs is the drilling mud that was there. There is a statutory weight for the drilling mud. But, you know, drilling mud left in here in perpetuity kind of falls apart. The solids begin to fall out of it, they go to the bottom, and what you have left in here is mostly water if it's water-base. Or if you went to the trouble and expense to leave synthetic oil-base or oil-base mud in here, it's probably just going to be mostly oil. So it's debatable how much good that mud does in actually preventing the cross-flow of fluids.

Now, the second cartoon over here might be an old producing well where part of the production casing has been cut and pulled. Down here at the bottom, that cement plug, you might actually be able to just spot that inside the production casing. But I would propose a better way would be to do what they call a “squeeze job” where I’m going to force this cement under pressure to go out through the perforations and enter--in whatever fashion I can force it--enter into the matrix, enter into the permeability, plus leave the cement inside the wellbore so I’ve got a plug inside and out.

And that might be something to consider here. If we’re going to use cement, maybe figuring out ways to do squeeze jobs for the emplacement of some of the cement plugs might help force some of the cement outside the borehole itself. But then, beyond that, the well is left full of mud, and I’ve got a hundred-foot plug here and a hundred-foot plug there, ten-foot plug at the top, and I think I’m done.

Okay, now, there are a few alternatives out there, and not listed is some of the newest stuff. This is out of the literature. Portland cement with blast furnace slag might produce a stronger, more resistant cement. Blast furnace slag has been reported to convert clay-based drilling muds to a cementitious material. Modified, chemically-bonded phosphate ceramics, Halliburton and others got on board with one of the national labs and created some cements that, to my knowledge, are working okay out in a couple of geothermal wells in Indonesia.

You can even make temporary plugs of barite. Barite, of course, is a high-specific-gravity solid. Or I could put in here some bentonite. I think my colleague, Roland, will speak eloquently about that, so I need to say no more about bentonite. It is a low-specific-gravity solid. But both of these could be solids that we might choose to help fill up part of the wellbore.

All right, now, testing of this, getting back to the lady from Pennsylvania who was worried about the conventional design of the well--and certainly there are parts of our well that will be conventional designs--I'm going to cement casing in the ground, and, by golly, I hope it stays there forever.

One thing we might choose to do before we say that was acceptable, we can run cement bond logs. A cement bond log is a wireline tool that I'm sure our friend from Schlumberger could speak at great lengths about. Cement bond logs will tell us whether or not the cement quality outside that casing looks acceptable or not, so we probably ought to think about doing that before we accept that cement job.

A negative test, a positive test, these are just pressure tests placed across the solid to see if it'll hold.

And, you know, you could even go down and tag it. I can tag the wellbore to make sure if I really intend to fill it all the way up with solid material, I can tag it with a wireline, make sure the fill-up is occurring correctly.

And then general guidelines: Use enough sealant--more is better--use cement that we believe will give us the strength we want; and, by all means, using the right stuff with poor practice never works. So there are some poor practice/good practice issues we should always keep in mind.

And, in addition to the two wells out in Colorado that didn't leak when the thermonuclear devices were set off in the hole, as Dr. van Oort already pointed out, the Romans invented this stuff. And the last time I checked, the Colosseum and at least part of the aqueduct are still standing, and they've been there over 2,000 years. So sometimes the magic works.

All right, thank you.

COLLIER: Thank you very much. Thank you to the Board for the invitation to contribute to this workshop, and I'm just going to bend down and I'm just going to retrieve the glove that was just dropped earlier for me.

So I'm just going to talk about sealing and support matrices. The University of Sheffield deep borehole disposal concept uses various matrices to fill annular space within the disposal zone. First of all, that's the annulus between the waste package and the borehole casing and then between the borehole casing and the rock wall itself, and we call these sealing and support matrices. Apologies for the acronym, but we refer to them as SSMs. And as the name suggests, they, first of all, seal the individual waste packages within the disposal zone and also support individual packages during deployments.

In terms of individually sealing the packages within the disposal zone, the low-permeability matrices restrict access of the borehole fluids to the casing and the canisters and delay any corrosion processes and also restrict the flow path of any gas generated from corrosion.

So this is just a quick schematic of the various options that we work on. On the left-hand side is the HDSM option--again, apologies for the acronym--the high-density support matrix--and I'll explain that shortly--on the right-hand side cement grouts option. And these are the waste containers within each disposal zone. But I'll explain that more shortly. But, essentially, these matrices are there to maximize the near-field safety case, so please keep that in mind at all times.

Okay, so we've got two main SSM variants. The preferred option is this high-density support matrix, which is essentially a lead-based low melting temperature alloy with a eutectic solidus around 185°C. So when the temperatures in any of the annuli exceed that, the HDSM melts, flows around the waste packages, and we find it solidifies. If the temperatures within the annuli do not exceed this, then you can't use the high-density support matrix, because it would not melt; and in that case we use cement grout, which is what I'm working on, and in this instance we are developing an API Class G oilwell cement.

So just to explain a bit more of the high-density support matrix operation, there's a quick animation here. So here is the bottom of the disposal zone lined with a perforated casing. You then emplace your first waste container using either coiled tubing or a drill pipe, whichever option you go for. That's immediately followed by a release of the high-density support matrix to fill both the annuli, because the material will flow through to the outside annulus. You then insert the rest of the containers at intervals, each with a quota of high-density support matrix, and then add an extra head, like so. And the waste package heat will melt the matrix; it'll flow and settle into the annuli and eventually solidify, therefore sealing your individual containers within the disposal zone.

So that's a little bit about the HDSM--sorry--the high-density support matrix.

Moving on to the cement grout, so the grout that we've developed has to have various physical and chemical properties. And so the physical properties we need to consider workplace properties such as thickening and setting time to ensure correct deployment; viscosity and flow characteristics to allow it to flow around the waste packages; properties such as density, permeability, and porosity to ensure we provide the best seal around the waste packages, and also other properties such as strength so that the grout is strong enough to withstand the overlying force from the containers--sorry--the force from the overlying containers.

In terms of chemical properties that are important, so it’s just like we’ve heard this afternoon: reactions between the grouts and the borehole fluids, the waste containers, the casing, and the near-field rock. Similarly, we need to also ensure that the grout produced is durable in terms of composition and microstructure, and we can control that by the cement precursor powders.

We look at three critical times in terms of grout deployment. That’s the time to get the grout package down to the disposal zone, the time to float around the waste package, and then the time to set. So we are developing two options, the first one being called Option 1--now, there’s a surprise--where you put the waste package in first and then followed by the grout, and the grout flows around the waste package, thereby sealing it in.

Option 2 is a converse of this where you put the grout in first and second the waste package, and the waste package sinks down through the grout.

We look at various delivery methods such as pumping, using coiled tubing as in remedial cementing. We're considering looking at dump bailer equipment to locate a volume of grout within the disposal zone and also to design a bespoke delivery solution.

We also need to consider the influence of the borehole environment on the cement grout. For those cement chemists out there, you will know that the elevated temperature and pressure causes acceleration of the grout thickening and setting, so we need to retard that so that we get the paste down to the deployment zone as a wet paste. So we're looking at using organic and inorganic materials there. Also, the elevated temperature and pressure will also affect the hardened paste composition, which is important, because we want the most durable and strongest cement hydrate phase to form.

In terms of the grout, the groundwater composition of this may influence workplace properties, so the most important there is the amount of chloride present in the groundwater, because that may affect setting again. So we need to assess that.

In terms of the effects of the irradiation, we will look at this in terms of experimental work in the future. But we take confidence from the fact that the likely dose from a container of spent fuel or vitrified HLW is likely to be at least on order of magnitude less than that experienced by grouts during the developmental work that was performed in the 1980s in the occasions where we cemented waste.

So that’s about the SSM, the sealing and support matrices, what we do to select which ones in use. So we perform heat plug modeling at Sheffield, so this is just an example of that work, so these are time and temperature plots for a thousand pins of 15-year-old spent UO_2. These are the isotherms in the middle, bottom, and top of the containers at 185°C eutectic solidus of the HDSM. So the temperature in this portion of the graph, you use HDSM. At the temperatures down here you use the cement grouts. And the assessments of these heat flow results will decide which matrix you select for which disposal scenario.

Okay, so just a final slide now on the rockwelding. Fergus Gibb explained it briefly this morning, but I was also asked to put a slide in about this. So it’s a process that’s being developed at the University of Sheffield, and its purpose is to cause isolation of the disposal zone, so effectively to seal off the borehole after the disposal zone has been filled up. And, essentially, it’s the only method capable of eliminating the disturbed rock zone, which is produced during the drilling process.

It uses a sacrificial electrical heater to melt and fuse both crushed granite backfill, which you add, and also the host rock as well. And that’s just what’s shown in this. This is the top waste package. There is some crushed granite backfill that has been added; a cement plug; you then cut away and remove the borehole casing. You locate a volume of crushed granite backfill followed by your electrical heater on an umbilical, further volume of crushed granite backfill, followed by a pressure seal, and you then just switch on your electrical heater, and it melts both the crushed granite backfill and also the host rock around it. So it fuses the crushed granite backfill within the host rock. You can do multiple welds above the disposal zone.

So, like I said, it’s under development at the University of Sheffield, so the R&D activities that we are performing are based on heat flow modeling; experimental melting and recrystallization of the granitic rock and then refined for the host rock; design of downhole heater packages; deployment engineering; and then, finally, larger-scale trials.

So I hope that that explains what we’re doing and the options that are there in terms of the sealing and support matrices and also the rockwelding. Thanks for your attention.

PUSCH: Firstly, I'd like to express my gratitude for having been invited to this meeting. And I've learned a lot from this, but don't change my mind, of course.

So the next one here, this is me here, and then we see that one. Well, this is something that has been expressed in various ways by people giving lectures here; that is, how the rock structure really is. And what I wanted to show is that if we--oh, good heavens, that was too much-- Okay, so that one.

This is a schematic, a picture four big rock elements, each with, say, 500- to 1-kilometer edge length. And what it is meant to show is that up here in the first 500 meters down to a 1,000 meters we have frequent fracture zones, big ones, smaller ones, and they are all interacting. If we take out the elements and look at the elements, it looks like that. So these continuities are on different orders.

Now, if we move from this area, this is the 400-meter area. Here is where SKB's mined repositories are and four other major--these large amount of fracture zones that are hydrologically active and interactive. If you move down we see that fewer and fewer of these fractures zones, so what remains to see here is the major fracture zones. These are the ones that carry water. These are the ones along which displacements, tectonic and seismic events take place.

So one can say we understand all that if we should find the proper place for a VDH hole--for a deep hole. It should be that interactive(inaudible) minimum number of major fracture zones that we have identified by all these geophysical measurements we know that we need to have for characterizing the rock volume.

So the next one would be--this is also something that has been mentioned that is of absolutely greatest importance; that is, the density of the groundwater. This is the essence of the VDH concept.

This is a Swedish example; it’s made by SKB. It’s a number of boreholes south of Stockholm, and here we can how the different salt contents are distributed. So down here the brownish thing is old, heavy, and stationary salt water. The higher up we become here, we see that we have less salt water, and this is movable. So it’s very important, I think, to realize that if we can come down below 2, 3 kilometers depth, we are in an area where groundwater is practically immovable and will not bring up any radionuclides that may be released from the waste.

Now we come to bentonite. I hate bentonite, because that is the geological name. What it is is a clay that is rich in smectite, expandable mineral. This is to be remembered. I would say that to my students—the test they will never pass if they say bentonite instead of smectite.

The constitution of the clay here. The dominant clay mineral belongs to the smectite family. There's a lot of them, nontronite, beidelite, and God knows what. And they form a continuous system with very small voids, and that is the reason why the permeability is a hundred to ten thousand times lower than ordinary clays like illite and kaolinite.

So if we make a schematic section on this small scale, say a tenth or a hundredth of a millimeter, we have these systems called stacks of lamellae. Water in here is not movable. It's actually locked and fixed, attached to the clay mineral surface. But we have channels that we have open voids, and these are the ones indicated here. There is where the water moves.

My throat was okay this morning, but not anymore. What happened?

We have a bulk density of smectite-rich clay that we may call bentonite, but remember the incorrectness. That is on the order of 1800 to 2000 kg/m^3. Then the hydraulic conductivity and the swelling pressure are fabulous. So, again, they say the bentonite. I hate it. I hate it because you use it.

This is dispersed clay, so all these little flakes here, they represent groups of parallel lamellae sticking together. Between them we have voids of different size here.

Now, if we consider a little unit here, it looks like this. If we have, in the case of sodium saturated montmorillonite in a salt. This is very low density. Those who can read it, this is below 1600 kilometers—kg per cubic meters for each individual diagram.

So here is water that is organized between the lamellae here. It’s impermeable. This water is not movable. If we apply a very high hydraulic gradient, we can have water flowing here. But on the normal condition it doesn’t--

FRANKEL: Water--

PUSCH: Thank you. What they say here is that when the density increases of the clay, the swelling pressure, called the PS, increases. So we go from a very low value--from a density that’s typical of borehole muds of 1100 kg/m^3 whereas swelling pressure is none and increase that to about 1600, 1800 kg/m^3, the swelling pressure increases to about one megapascal; that is 1000 kg/cm^2. You know what that pressure is? It’s a rather heavy lady dancing step dance, having high heels and standing on one of them. That’s 1000 kg/cm^2, if she is jumping--

The difference between the diagrams here--I’m too old for that.

(Pause.)

That will be much better. Can I give you a sign like that? Next, please.

Well, this is what bentonite is like. You have that in Wyoming and South Dakota and various other places, in Europe, and it’s all over the world. To the left you see that there is an excavational exploitation of such clay in Northern Germany. And if you take a piece of that and core it on the table here, it looks like that. If you take that and put it in a little hole and let the clay take up water while keeping it in that little hole, you get this.

So every little grain here expands and swells out, and it ends up as a cubic element that is rich in water and is soft. But if you have it prepared by putting this material in a form and apply a pressure, then you come up to--you get this type of block. So this one has been compacted under 100 megapascal, and I would say the diameter here is about 30-centimeter thickness, about 15-centimer, and the density--the dry density, that we call it, without considering water is on the order of 1600 or 1700. You would never forget this speech, nor would I. We have prepared blocks like that with a diameter of 2 meters. But as for plugging big boreholes that can put in canisters with highly radioactive material.

You’ll recognize this picture also from the previous presentation. This is, in principle, how I think one can do. We put in here clay plugs. These are the clay plugs. And here below, in our case, there is no waste until down to 1,500 meters; in your case it’s 2,000 meters or 3,000 meters. Yeah. And down here we have the same principle as you propose here, and that is to have the supercontainers separated by clay. This is what it looks like.

So these are the boreholes. And in the upper part where we do not have any waste, we just put in these supercontainers. This is a supercontainer. And you'll see the perforated liner tube here. And in that is the canister with highly-radioactive waste.

And between is clay, highly-compacted clay. And this clay, when you put it in here, it takes up water from the rock, it expands, and since we assume that we start with a bore mud in the hole--so if one starts here with a highly-compacted clay with a dry density of, say, 1600 to 1700 kg/m^3, it would take up water through the perforation. And the clay expands through the perforation and consolidates the clay mud that is outside here.

That means that in a few days, I would say in 24 hours, the mud is being consolidated to a thicker state. After a long week, the difference is much less. Mud has been stiff clay and this clay here has been a little thinner, a little softer, because it's given off the clay.

So you end up in a system that is a fairly homogeneous clay mass that has a density of about 1900 to 2000 kg/m^3. That clay is impermeable. We don't have—am I to stop now--all this trouble I've caused--I would say that it's impermeable since we do not have any hydraulic gradients in the VDH, no horizontal, no vertical, and with this extremely dense clay, we have no percolation of water. Diffusion takes place. So if we have concentration differences in units, in ions, then diffusion can take place.

Next please. Try to read the end of it here.

So if we look at the upper one that the function of the bentonite seals in the upper part and down here is--well, that's also the upper part--but where temperature starts to be a little higher. So we see that we have here--when this clay with 1900 k/m^3 finally gets calcium-saturated, because the groundwater has calcium as dominant cation, then the hydraulic conductivity can be up to 10^{-11} meter per second, but in practice it would be lower than that.

And if you see down here--what happened with the metallic ions--that is the canister and this perforated tube--what happens with that? They be converted to magnetite, hematite also under both aerobic and anaerobic corrosion. And this gives of free ions. And what happens is that these ions exchange some of the ions in the clay like this; aluminum will be released from the clay like this or move over to the tetrahedral sheet in the clay so that an internal exchange of cations in the crystal.

But we also get release of silica. So silica in the case, we have a quick reaction; and when the temperature is hot, we get silica to become oversaturated. It’s oversaturated with respect to silica. Then silica is precipitated, and we get cementation.

Next please—soon going to stop. So there is where we have up to 150 centigrade, and since we have a high density, there is no risk of erosion. It would not be affected by water flowing there, and there’s a long-term function of them. We see that when temperature again is going down to less than 100 centigrade, we would still have the phenomenon with silica precipitation. But the clay minerals are intact. So, in principle we have montmorillonite, which is the major clay mineral here, is preserved over--I would say over practically any period of time.

I wouldn’t believe this myself if I didn’t have validation from the nature itself. There are a number of practical examples, like in Sweden, we have bentonite layers where we have temperature impulse from diabase being spread over the--or pressed into a series of sediments, giving approximately the same temperature history as we have in the VDH here.

And there is Ordovician time. It’s 450 million years ago. And if we go there and take samples, we see that there is still 25 percent montmorillonite like this. It’s ductile. It’s expandable. So the mechanism is clear. We have it demonstrated and validated by nature.

So, at last. Thank you.

FRANKEL: Okay, well, we won’t forget that. Smectite, right? Not bentonite.

So I’d like to give any of the panelists an opportunity to add anything to this or--

BOMMER: Roland, I have a question.

FRANKEL: Can you give your name?

BOMMER: Bommer, panel member. Roland, it’s possible that the wellbore will be drilled with an oil-base drilling fluid. If your supercontainers are put down at the bottom of the well with oil-base drilling fluid, does that change the dynamic of the way they react?

PUSCH: I don’t think there would be very much change. But organics are not allowed in repositories like that. So the oil left in the system, the problem is that all organic materials that we have in the repository can create organic colloids, and organic colloids are radionuclide-bearing, so that was absolutely forbidden to have--we can’t even in the concrete have fluidizer, you know, the ordinary fluidizer of concrete. We can’t have that. Instead, we can have minerals like talc, which is a new type of concrete that we’ve developed.

FRANKEL: Go ahead, Nick.

COLLIER: Is it okay if I just say something on that point—in terms of organics? Nick Collier, University of Sheffield. You’re right. In the GDF environment, yes, organics are not allowed. I think what should be considered is that this is a different environment, okay? So you’re at high pressure and high temperature, and that environment is going to break down any sort of organics that you use.

So, for instance, you use organic materials as very efficient retarders and also semi-plasticizers and we are looking at those for our grouts. We are also looking at inorganic materials as well, of course. But the temperature and pressure will break down the organics that are used. And I think we should also bear in mind that once the borehole has sealed itself above the disposal zone, just like somebody was saying this morning, it doesn’t matter.

PUSCH: I have a short comment on that. I have not investigated that, so I cannot say whether it’s reasonable or not. What I can say is that the authorities would never accept it in Finland and Sweden.

COLLIER: Yes, it would need to be assessed for the safety case. But I think it’s different for the deep borehole disposal environmental--GDF environment.

FRANKEL: I think that gets to one of the points that was a question here that maybe no one really addressed, but how best to test these seals? So what we can we do? I think Steve Hickman said that they need to perform over a long time. And so do we need to test over a long time? Can we do meaningful accelerated tests? Yeah, Paul.

BOMMER: Bommer, panel member. I think when the seals are being installed, they're certainly possible to test. You can see if they're there; you can tag them; you can pressure test them; you can do whatever you want to do to them. But after it's done, the only way to figure out if anything is migrating towards the surface would be to have some monitor wells. And the monitor wells would have to be drilled to, I don't know, whatever depth we're interested in protecting, certainly the base of the usable-quality water, and then how long do you do it? Who's going to mind the store over--if it's 30 years, I could see it. If it's a thousand years, ah.

FRANKEL: Well, I'm thinking of coming up with a safety case, right? So they're doing a field test and not putting seals down in there, doing laboratory tests. So can we use laboratory tests to predict the long-term behavior, or does it matter?

COLLIER: Nick Collier, University of Sheffield. I don't know. There is no evidence for long-term testing. And because it's such a long-term process, it's extremely hard.

Somebody was saying this morning, "Well, why don't we use analogs to do some testing?" But in the Characterization Hole, before we then start to move on to the Field Test Hole, you need to test that for thousands of years, don’t you? So it’s extremely hard. And as far as I know, there aren’t any methods to accelerate that either. So it does need to be assessed.

In terms of the cement durability--and, by the way, I could give a whole lecture on the reasons for using cements and how they would operate, but I’m not going to.

We can take a bit of encouragement from the natural analogs, for instance the site out in Jordan where they had rock strengths that are similar to cement composition. And they’ve been out there for millions of years with groundwater flowing through, and they have been extremely stable, very durable, for millions of years. But it’s hard to then convert that from that natural analog into something that we could use in this case.

FRANKEL: Roland.

PUSCH: I would like to add one thing, and that is that according to the program that we have got for the test hole that DOE is planning, there was a question how can you test those? Can you test the clay, the tightness or the units? Can you test that on site? And for clay, you cannot, because you would not be able to get the clay fully saturated in less than 200 years. Then to make a percolation test would take another 500 years.

And so in the future, my grand grand grandson, he could perhaps engage for that.

But the clay is so fantastically tight, so the only way of getting information on the performance is to run accelerated laboratory tests and understand the mechanism. As long as you understand the mechanism, you can be accepted in a relatively short--

FRANKEL: As long as the mechanism doesn't change in the accelerated tests.

COLLIER: So you can--sorry, can I say something?

FRANKEL: Please.

COLLIER: You can do leaching investigations, of course, but that's not the same as sealing investigations, you know, because that's what we're talking about here, isn't it sir--

FRANKEL: Yeah.

COLLIER: --the sealing performance. And, of course, I'm sure that we are all aware of leaching tests that are done for materials that are used in the geological disposal facilities, but it's a different environment here, a different application, I think.

FRANKEL: Okay, I'd like to ask the Board to bring up any questions or comments they might have.

EWING: So Rod Ewing, Board. Just to continue the discussion of testing procedures, given the apparent importance of the seal for this type of strategy, because that's the difference between it working and not working in terms of communication with the surface, wouldn't it make sense to do the work on seals early and more diligently rather than waiting?

As an example, I can imagine experiments where you would have relatively shallow holes. You would try the different seals--concrete, bentonite, and so on--and then after five or ten years take core and see what had happened. Now, in the case of bentonite, the expectation would be that not much, because you need longer, but it would still be important to confirm that not much has happened.

So I think--I can imagine field tests and laboratory tests that would be relevant to this strategy, but there is some urgency about doing this early in the program, not at the end.

PUSCH: Absolutely. If I can answer that, this is exactly what we've been doing. So we have been running an underground factory for our major depths under repository condition tests similar to that, so with clay and cement, and extracted that after four years, I think it was, finding then how the process is going on. And it's exactly what I could expect. The predictions said that, and it was demonstrated. But it was not complete, because it would take 300 hundred before it did that. But you could see--as you say, we could find out whether the predictions are correct, if the model is right.

COLLIER: Collier, University of Sheffield. I agree, as long as we test at the same temperature and pressure as will be down the borehole. And that's what's tricky. I mean, we can probably get access to the boreholes in the U.K. that are a thousand meters deep, but that's no good because it's not hot enough or has the kind of pressure without, you know, designing and building kits to mimic that. But, again, you can't accelerate the testing. That's what's hard, isn't it, because you can't wait a few thousand years to see if the seals work. You can develop theories from studying them in the short-term, but then doing long-term testing is extremely difficult.

FRANKEL: Mary Lou.

ZOBACK: Okay, this may sound tongue-in-cheek, but this morning Sue Brantley asked if there were any microbial studies planned for the test borehole, and I think the answer was no. And just for a lark, I Googled microbes that eat cement and found 330,000 references. And if it's going to be down there for a hundred thousand years and starts out nice and warm and all this additional energy that hadn't been underground since the Precambrian, might we create a factory that would have these lovely things growing and just munching down the cement plugs?

COLLIER: Okay, can I pick up my gauntlet once again, please? Nick Collier, University of Sheffield. What I didn't say here and what I wanted to say right from the start was that the work that we're doing is not advocating the use of cement as the final borehole seal, so it's to provide additional sealing within the annuli. So you haven't just got water in there that's causing corrosion of the canister or the casing. You provide an additional barrier. I'm sure you understand that. So that's being used effectively in the short-term until the borehole is sealed and then provide additional sealing to enhance the safety case.

So I just want to make that point.

ZOBACK: I don't know if microbes like smectite, but do you have anything to say about--

BOMMER: Well, the only thing I was going to say--this is Paul Bommer on the panel--is that, as Nick already pointed out, the cement really isn't the full seal. There are other materials in here. And I think it's very important to try to fill the borehole up completely with solids; don't leave any fluids in it.

FRANKEL: Sue, lady from Pennsylvania.

BRANTLEY: Sue Brantley from the Board. I've been debating whether to say anything, because I'm basically confused. And, as the lady from Pennsylvania, I just thought I'd express, you know, this morning with Lynn Orr I kind of see an image where we're going to do some tests for five years, and then we are going to have the possibility of actually putting some waste down in five years. And so I've been trying to understand this plan and where we are. And I’m just going to express the confusion I feel at this point in the afternoon.

So one of my other questions was about, aren’t you cementing the borehole, because in Pennsylvania we often have to cement our boreholes? Well, I was told the crystalline part of the borehole didn’t need to have cement, and then I listen to a panel, hear all about how the borehole should be filled. So I’m confused.

And then we’ve also talked about wireline emplacement versus the drill emplacement and the coiled tube emplacement. And I’m not really understanding why we chose wireline, probably because I didn’t understand those trees and the risk analysis, which, you know, I can work to understand. But, nonetheless, what I don’t quite see here is how in five years we’re going to have answered these questions. So I’m sort of confused.

BOMMER: Is there someone from DOE that wants to respond? Andy?

GRIFFITH: Sure. Andy Griffith, Department of Energy. Yeah, as far as the field test is concerned, right now it’s planned for five years. Clearly, I think, based on this discussion, we’ve learned a lot, and we’ll learn more tomorrow. Whether it stays five years or not in order to answer the important questions on whether we go forward or not, that’s yet to be determined. We’ve got a long way to go. We’re just starting.

As far as plans for the concept of five-year placement, probably very optimistically at the soonest if everything went perfectly, and all the concerns were addressed over the next five years, that’s very optimistic; in DOE environment, I’d say highly unlikely.

But, still, you know, we have to plan, we have to consider, okay, if we go fast, how fast can we go? If we have to slow down, how much do we slow down? You know, all these things really have to unfold. And we’re providing options for the policy and the decision makers, and that’s really the focus. And the next five years is what’s really important, I think.

FRANKEL: Go ahead, Pat.

BRADY: Yeah, this is Pat Brady from Sandia. I would like people to come back to what Fergus Gibb said early on about the required longevity of the seals. Specifically, the seals have to perform long enough so that time elapses for the hypersaline waters to seep back and the thermal pulse to go away. Now, for spent fuel that thermal pulse is ten times the half-life of the strontium and the cesium, so that’s 300 years. So when we look at the long-term performance requirements of the seals, we’re not looking at ten times the half-life of the plutonium and the americium. We’re looking at it for the heat-generating isotopes. So it's not tens of thousands of years; it's hundreds of years.

And, again, once the reducing conditions and the high salinity comes back in, the seals somewhat become superfluous, because there is no driving force.

FRANKEL: Go ahead, Nick.

COLLIER: Yes, can I say something else? Nick from the University of Sheffield. I think that was a very good point raised, so I'm not going to call you the lady from--Susan.

BOMMER: Why not?

COLLIER: Because there are different concepts out there, aren't there? There are different groups and people have different ideas as to the best deep borehole or most appropriate deep borehole disposal concept, so maybe that's the reason for some of the confusion.

BRANTLEY: Well, I guess I was getting--this is Sue Brantley again--I was getting at, what is the plan for figuring out, of these various ideas that are out there, which one would work best in the sites that we might choose? So how are we going to choose? How are we going to learn what we need to know to choose? I haven't really heard that plan.

GARWIN: Richard Garwin, Panel 7. Regarding the rock melting concept, I think it's only a concept. And I hear that there's going to be loose granular fill, which will be melted, but then there will be a void, you know, a frank void where the void’s base of the granules is now consolidated in the rock melting. And I worry about the massive plug--molten rock--which has then had a boundary with the solid rock and now shrinks. So what do we know about a path around the formerly melted rock at the place or in fissures then in the unmelted rock around it?

COLLIER: Nick from the University of Sheffield. This is where I don’t make myself look stupid by making myself look stupid and ask Fergus Gibb to answer that question, because he is leading that work at the University of Sheffield.

FRANKEL: Please, yes.

GIBB: Yeah, that’s a pretty good question. What happens in the rock melting scenario is that the backfill and the host rock melt; and, of course, it’s down the borehole, which is full of water, so you have supercritical fluid, aqueous fluid. And as you see in normal experiments, this rises above the melt. So you would end up with a melt zone which recrystallizes. And between that melt zone and the pressure seal at the top, you have effectively a void in which there’s supercritical water. It doesn’t matter, because you’re going to seal the thing at the bottom, not at the top.

And as for the question about the contraction, I mean, I don’t believe that that’s a problem. This is an issue which we’ve looked at already. If when you put the heat source down you raise the temperature, most people would think that what will happen is that as it heats up it will cause fracturing and cracking, and as it contracts it’ll be worse. But that’s not the case, because if you take the analog of natural rock, natural magmatic rocks, any of you geologists will know that if you look at something like a basaltic dike, if you look at the edge of the dike, you’ve got a lot of cooling cracks, fractures. That’s because the cooling--the cracking--sorry--is contractional, but it’s dependent on the thermal gradient and the cooling rate. If you look in the center of the same dike, you’ve got massive rock without any cooling joints.

And if we control the cooling rate of the partial melt--and, of course, you have this thermal gradient that goes from ambient temperature into the heated zone--if we control the cooling rate properly, we can recrystallize the rock without causing any cracking.

That’s what I believe. We’ve seen that in small-scale experiments. But until we do a large-scale trial, we don’t know for sure, but I believe it will work okay.

FRANKEL: Okay, thank you.

Are you responding to this?

VAN OORT: I have a follow-up question.

FRANKEL: A follow-up. Go ahead.

VAN OORT: Eric van Oort with UT-Austin. So my follow-up question is this: With the metamorphosizing of the rock, we have the heater and its umbilical permanently embedded in the rock. What are the chances of those becoming part of the leak-back?

GIBB: Fergus Gibb again. Yes, that's absolutely right. We rescue the umbilical, because it's expensive by cutting it off above the welded zone, but the rest of it's still stuck in there. But it could form a path for escaping fluids. But then it's above a welded seal, so anything has got to get past the weld to get into the part of the zone where the umbilical is. It's sealed solidly across the bottom.

FRANKEL: Okay, Mark first and--yeah. This is all on the same topic here, so--

M. ZOBACK: Oh, it's not about the melting.

FRANKEL: Okay, go ahead.

HICKMAN: Sorry, Mark. So I didn't have time to talk about my presentation.

FRANKEL: Identify yourself.

HICKMAN: Oh, sorry. Steve Hickman, U.S. Geological Survey. There have been laboratory experiments in the '70s and '80s that show when you heat up quartzofeldspathic rocks, the different thermal expansion between quartz and feldspar causes incredibly intense fracturing up through the alpha-beta transition in quartz, which is 570°C. So when you melt a rock, the melt may crystallize as some kind of a crystalline solid, but everything around it, especially if it goes through the alpha-beta transition, will have an incredibly dense network of grain-scale microfractures, and permeability measurements by Barrow and Hansen (phonetic)--I was going to bring a paper down later for them; I brought it with me just in case--shows that you get a 3-order-of-magnitude increase in permeability in the thermally-shocked rock even under uniform heating, so no thermal gradients, just everything warms up and cools down uniformly. And it takes a lot of confining pressure to suppress that. You never get rid of it. So it’s permanent thermal cracking damage that will surround the melt.

So I was suggesting that part of the experiment should be to actually see what you have around such a melt. Do you get contractional strain such as Dick Garwin suggested and also grain-scale microfracturing, which is suggested by all the laboratory and theoretical models I know of for thermal fracturing in quartzofeldspathic rock? So it’s a concern that I have about the model.

FRANKEL: It seems to need some more work.

Mark, go ahead, please.

M. ZOBACK: Mark Zoback, Stanford. I actually have a question about perhaps this simplest cartoon we’ve seen all day, and that is a canister or multiple canisters with cement or perhaps a low-temperature melting material in a uniform annulus around them. We know from trying to cement strainmeters, which are maybe about the same size as one of these canisters, in shallow holes how extraordinarily difficult it is to actually get one of these things cemented into place with a uniform seal all the way around it. Doing that at 5 kilometers is almost unimaginable.

We've seen the cement just sort of sitting there waiting for these things to be dropped into them. That's kind of hard to do. We've seen things coming in from the top after all the canisters are in place. That's impossible to do, because you've got mud in there and it needs to go somewhere.

So could someone just explain how we get an annulus of anything, whether it's cement, low-temperature melting, lead-something-or-other, bentonite, or whatever? I haven't heard that yet. And we can pull the casing out--we have to pull the casing out in order to do that. That could be problematic. If you can't pull the casing out, you're really cooked. If you cut the casing off at the top of the canisters, you can fill the hole, like Paul suggested, but it's that section of the hole with the canisters that really confuses me.

BOMMER: I think he's right.

FRANKEL: Nick, that was your cartoon, I think.

BOMMER: Yeah, he’s jumping on you, Nick.

COLLIER: Sorry, that was my cartoon, yeah.

FRANKEL: I’m sorry.

COLLIER: So the canisters--Nick from the University of Sheffield. The canisters will, as a concept, be equally spaced within the central casing. We have simulated a canister grout flow, so both Option 1 and Option 2, which would be drawings that you were referring to then, I think. We have simulated that in the labs; it was at atmospheric pressure and at temperature and also at a small scale. But we have simulated that in our labs.

But yes, it’s going to be hard. But it’ll be within a--it will not be in drilling mud environment. The borehole will be washed with fresh water before any sort of operation. So that’s it and that’s that.

FRANKEL: I want to have some more conversation, but I do want to say that we will leave time for the public comments. I think only one person has signed up. If you’re a member of the public that wants to make a comment or ask a question, please still sign up. But we’ll take a few more minutes, if that’s okay, on this discussion and--

ZOBACK: Can we check and see--is Kevin Kamps still here?

LESLIE: He’s here, he’s here.

FRANKEL: Okay. So let’s have a little more discussion here, and then we’ll make sure to leave time for that point.

Please.

HARDIN: Ernie Hardin with Sandia. I’m going to respond to what Mark Zoback said. The base case for this is not necessarily to encapsulate emplaced waste packages in a time-sensitive, rigid curing material. The base case is to fill that interval with an emplacement fluid and emplace in the fluid, okay? So this does not become a question critical to the success of borehole disposal. It’s an enhancement.

So that base case we’re talking about would involve fixing the guidance casing to the rock wall, using some degree of cement. Why? Because you have to provide mechanical support to that casing. So envision then some cementing going on in the annulus. And then you emplace a number of packages into the fluid, and then you set a cement plug. So that really is the base case. We’re not counting on the impossible.

FRANKEL: Okay. Bret.

LESLIE: Bret Leslie, Board staff. I’m going to try to tie a few things together. And it’s a question for DOE, and they don’t need to answer it right now. But one of the things that Wes said was you have to think about both the engineering and the science. And they have to be thought of in the same way.

Well, one of the objectives is adequately low permeability. That term has not been defined both for the natural setting or for the seals. And if you’re trying to test the feasibility, unless you know what you’re measuring to, how do you determine whether you’re adequately low permeability?

FRANKEL: Anybody want to respond from DOE? That’s a good question. Yeah, go ahead.

BOMMER: This is Bommer with the panel. I thought there was a standard published for the permeability of the seals, anyway, and it’s pretty low. Cement, on its best day, might achieve that. And I suspect Roland would defend bentonite under the correct conditions.

COLLIER: Nick from the University of Sheffield. I’ve got data in front of me here, which demonstrates that the hydraulic conductivity of a likely host rock and hardened paste and bentonite--sorry, I shouldn’t say bentonite, should I--smectite and clay are all of the same order of magnitude.

FRANKEL: Okay, we’ll take one last comment or question.

NOVAKOWSKI: My name is Kent Novakowski. I’m from Queens University in Canada. So we talked a lot about permeability, hydraulic conductivity, in the last few minutes. And one of the other parameters that is going to be a governing--or lead to a governing process is porosity, because this environment is likely to be diffusion-dominated once the well wets up again. For example, if we have hydrostatic pressures, the dominant transport mechanism will be diffusion.

So I might ask this question then; in fact, Dr. Pusch mentioned this. Bentonite will--or smectite rather--will behave differently than cementitious grout seal will, which will also behave differently than fused rock seal will, and all because of the difference in porosity.

So any comment or thoughts on that?

FRANKEL: Go ahead.

BOMMER: Bommer with the panel. It might be a good thing. Vive la différence might help us. You know, we haven’t even discussed the application of asphalts, asphaltenes, other plugging mechanisms. So I think all of these things have got, to a certain extent, work together.

NOVAKOWSKI: So we might have orders of magnitude difference in porosity values between materials. And I think that is extremely important if we’re looking at transport times around, let’s say, a 10- to 15-foot-thick section of sealed borehole.

COLLIER: Can I comment on that just quickly? Sorry. Nick from the University of Sheffield again. Yes, I mean, I’m certain that you know a lot more about it than me, but in terms of the--I think the important factor might be the hydraulic conductivity rather than the porosity, because porosity might be closed off. And, of course, it's the interconnection of the porosity surely which allows the pathways.

FRANKEL: This has been a really great discussion, really what we envisioned when we thought up this workshop. So I'm going to call it to a close, and let's thank the panel one more time.

ZOBACK: Thanks. And as I indicated beginning, we always have time for public comment. And I'd like to call Kevin Kamps up. He signed up for the public comment.

KAMPS: Thank you, Dr. Zoback and Chairman Ewing. Thank you, Board members, for a great session. The hour is late--

ZOBACK: Can you identify your affiliation as well?

KAMPS: Yeah. My name is Kevin Kamps with Beyond Nuclear, where I serve as Radioactive Waste Specialist; and I also serve on the Board of Directors of Don't Waste Michigan, which is the statewide watchdog on nuclear power and radioactive waste. And I'll try to keep it brief. The hour is late. Just a few thoughts.

I hope folks can understand public skepticism about a proposal like this. I mean, name the technological disaster or catastrophe, and some of the thoughts that came to my mind today listening to the presentations were books like Charles Perrow's Normal Accidents--from 1999--Living with High-Risk Technologies. Three Mile Island and Chernobyl were case studies in that book.

Another book that came to mind--someone mentioned off-normal today--was Nassim Taleb’s The Black Swan: The Impact of the Highly Improbable.

Speaking on behalf of Don’t Waste Michigan, someone mentioned today the potential of on-site disposal. Someone else, another presenter, mentioned remote locations for deep borehole disposal. And I would just point out that in a place like Michigan it’s against the law. So it’s against the law to dispose of radioactive waste within ten miles of the shores of the Great Lakes. So doing the geometry, I guess, 5 kilometers deep, how close to the shore, there are issues like that. And I think the public aspect of this is very significant.

So, for example, in Michigan there is a proposal in Ontario by Ontario Power Generation to create a deep geologic repository only 2,000 feet deep right on the shore of Lake Huron for low- and intermediate-level radioactive waste, but there is also a simultaneous parallel process for high-level radioactive waste disposal in the same vicinity of Ontario right on the lakeshore.

And so the response, it’s taken some time to evolve, but you now have, long story short, in pretty much the entire congressional delegation of Michigan, bipartisan, opposed to the idea, calls for international joint commission, comprehensive review to take place, so the public aspect.

Some other things I just wanted to touch on. Quality assurance was mentioned today, I believe, and it's certainly very significant. So, for example, the containers, we have information from whistleblowers, just to name one example--there are many--the Holtec container used for high-level radioactive waste storage at a third of the reactors in the United States at this point, also certified for transport.

So an industry whistleblower, Oscar Shirani of Commonwealth Edison/Exelon, an NRC whistleblower, Dr. Ross Landsman of Region 3 in the Midwest, with very serious questions about the quality assurance or lack thereof on the Holtec containers, to the best of my knowledge, never adequately addressed to this point. And that was some 15 years ago, and so many of them loaded since that time. So, of course, QA is a huge issue in here.

Another thought that I had about today, it's hard for me and, I think, a lot of people to wrap their head around the Blue Ribbon Commission's finding/recommendation that an independent agency, not the DOE, would be in charge of radioactive waste management in this country. And yet the Department of Energy is still playing a huge role in these discussions. And so that's kind of a hard one for me to figure out today.

Another aspect, a remote location versus on-site disposal--and it was mentioned today--consent-based siting. And so when I hear remote location, I mean, it certainly evokes Yucca Mountain, Nevada. The problem is--and I remembered back to the first meeting of the Blue Ribbon Commission in March of 2010, I think it was, where I pointed out to them that day that President Obama, a year earlier in his Women's History Month proclamation, March 2009, named Grace Thorpe as a woman defender of the environment, women leading the way to save planet earth. She was a Sac and Fox Indian on the board of directors of Nuclear Information and Resource Service, who one of her claims to fame was that she defended her community against a centralized interim storage site and then helped 60 others across the country, Native American reservations, to organize against being targeted for these facilities. President Obama honored her for that.

And then, ironically enough, Native American reservations were part and parcel a part of the Blue Ribbon Commission final report as still on the target list potentially, so real issues of environmental justice that was just raised by the Western Shoshone Indian Nation at the NRC's Yucca Mountain latest EIS iteration out in Nevada. So that's another problem. On-site problems in a place like Michigan, remote problems when it comes to environmental justice.

And I guess the last issue I'll touch on for today--I may have more to say tomorrow--someone, one of the presenters today, mentioned cement being solid and good to go for thousands of years, and I know there's been some back-and-forth about it.

But I guess another book that came to mind is a really fascinating one called Concrete Planet: The Strange and Fascinating Story of the World's Most Common Man-Made Material by Robert Courland, just out a few years ago. And he points out--I mean, the Roman concrete was mentioned in one of the presentations--that the magic of concrete was lost for a thousand years during the Dark Ages. And it wasn't until the middle 1700s or late 1700s that it came back to western culture. And one of the problems--it's one of the issues in the book--is the rebar reinforcement in concrete means that these days concrete structures will last for maybe 200 years, maybe 50 years, and the Romans would have been horrified. So Hadrian's dome in the Pantheon has lasted 2,000 years pretty well. But these days, when you make mistakes in fabrication or a lot of issues that have been brought up today, that's the challenge.

And I'm glad that someone mentioned the space shuttle disasters. That's another book that came to mind today was Dr. Ron Kramer at Western Michigan University, The

Space Shuttle Challenger Launch Decision. You know, the science has dominated today, which is appropriate, but, unfortunately, just up there in Capitol Hill science often takes a back seat. I think that's what happened at Yucca Mountain, has happened so many times.

So, yeah, I'll probably have more to say tomorrow. Thank you.

ZOBACK: Thank you very much.

Okay, seeing no more requests for public comment, I want to thank Kevin for that input. We appreciate hearing from the public.

And I want to thank all of you for sitting here and being so attentive all day long. Your reward now is poster sessions. If you're staying here at the hotel, on your way to the poster sessions, which are across the lobby, you may stop and pick up happy hour free beverages. But please go on over to the poster session.

And those of you that really love this room, we're going to have two of the posters in this room to relieve some of the pressure. The posters, I will say, are presentations by DOE, one for each of the panels, presumably addressing the questions that were asked. So in this room will be posters for panels tomorrow, 6 and 7, the final two panels. One is on the efficacy of--

SPEAKER: Multi-barriers.

ZOBACK: One is on multi-barriers and--what’s the other one?--and risk management, risk control.

Anyway, you have your choice. If you’re staying at the hotel, show your key and you get a free drink.

And thank you, and we’ll see you again bright and early tomorrow morning. Thanks a lot.

(Whereupon, the meeting was adjourned.)

C E R T I F I C A T E

I certify that the foregoing is a correct transcript of the NWTRB International Workshop on Deep Borehole Disposal of Radioactive Waste held on October 20 and 21, 2015, in Washington, DC, taken from the electronic recording of proceedings in the above-entitled matter.

November 4, 2015 s//Scott Ford___________________

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