UNITED STATES

NUCLEAR WASTE TECHNICAL REVIEW BOARD

TRANSCRIPT

FALL 2015 BOARD MEETING

Wednesday

October 21, 2015

Embassy Suites
1250 22nd Street NW
Washington, DC

NWTRB BOARD MEMBERS PRESENT

Rodney C. Ewing, Ph.D., Chairman, NWTRB
Jean Bahr, Ph.D.
Steven Becker, Ph.D.
Susan Brantley, Ph.D.
Allen G. Croff, M.B.A.
Gerald S. Frankel, Ph.D.
Efi Foufoula-Georgiou, Ph.D.
Linda Nozik, Ph.D.
K. L. Peddicord, Ph.D.
Paul J. Turinsky, Ph.D.
Mary Lou Zoback, Ph.D

NWTRB EXECUTIVE STAFF

Nigel Mote, Executive Director
Debra L. Dickson, Director of Administration

NWTRB SENIOR PROFESSIONAL STAFF

Bret W. Leslie
Roberto T. Pabalan
Daniel S. Metlay
Daniel G. Ogg
Karyn D. Severson

NWTRB ADMNISTRATIVE AND SUPPORT STAFF

Davonya Barnes, Information Systems Specialist
Jayson S. Bright, Systems Administrator
Margaret Butzen, Staff Intern
Linda Coultry, Program Management Specialist
Eva Moore, Program Management Specialist

I N D E X

I N D E X
(Continued)

PROCEEDINGS

8:00 a.m.

EWING: If you'll take your seats we'll be starting in just a moment. All right, let's get started with the second day of the Nuclear Waste Technical Review Board's workshop on deep borehole disposal of radioactive waste.

Yesterday to open the meeting I gave kind of an extended version of introductory remarks including a considerable amount of logistical information. This morning I want to make some very brief comments mainly for those who are on the webcast and who have just signed in for today and may have missed some of the points in yesterday's introduction.

So, a few points. 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, the Nuclear Regulatory Commission, or any other federal agency. The Board was created in 1987 by the amendments to the Nuclear Waste Policy Act with the objective of conducting ongoing review of the scientific and validity of DOE activities related to implementing the Nuclear Waste Policy Act.

With this two-day workshop, the Board is looking into proposals and activities by DOE to dispose of some DOE-owned nuclear waste in a deep borehole. The objectives of this workshop are first to identify the technical and scientific issues associated with DOE's research and development program; two, to assess the validity or the viability of deep borehole disposal; and, three to identify technical and scientific issues that might affect DOE's implementation of the disposal of radioactive waste in such a deep borehole.

I'll pass on introducing the individual Board members to those who are on the webcast. You can refer to the NWTRB website and there you'll find photos and bios on all of the Board members, and I'll simply now introduce Mary Lou Zoback of the Board, who is the lead for the organization and conduction of this workshop. Mary Lou is a Consulting Professor in Geophysics at Stanford University.

M. L. ZOBACK: Thanks, Rod. And, again, welcome to everyone. Welcome to those of you on the webcast.

I hope you all enjoyed yesterday. I think we had a fascinating and incredible exchange of information and which I'm sure will continue today. Yesterday in the workshop we focused largely on the engineering aspects of DOE's proposed project to do a test borehole to explore deep borehole disposal of high-level waste.

Today we're going to focus, begin in the morning at least, on looking more at the subsurface environment, what it's likely to be like, how homogeneous, heterogeneous it's likely to be, the properties at depth. And this is critically important, of course, because deep borehole disposal relies primarily on its geologic isolation. So, we'll hear much more about the basis for that.

We'll begin with a panel moderated by Board member Jean Bahr, a geohydrologist, and that will be exploring the geohydrology at depth. And then we'll move onto the geochemistry at depth chaired by Board member Sue Brantley, also a geochemist. From there we are going to move onto the topic of multiple barriers, which has always been an issue with waste disposal. You don't want to rely on any one thing but have multiple barriers, so Board Chair Rod Ewing will chair that panel. And after those three panels in the morning, we are going to have a break for lunch and a chance for public comment. If you'd like to make a public comment there are sign-up sheets outside, and we urge you to do that.

Following lunch there'll be a final panel on the efficacy of deep borehole disposal and risk analysis, and our Board Chair, Rod Ewing, will also moderate that panel. We'll have a short break and then each of the panels, one member from the panel, is going to be reporting back on what they felt the key issues were related to their topic, but not necessarily restricted to their topic as they've listened-- we've got a lot of incredible experts here from around the world, and they've been listening and reflecting on what they've heard both from other panelists as well as from the

DOE plans.

So that's the general agenda for today. We'll end hearing from Tim Gunter from DOE reflecting back on what's been said the past two days. He's been here very attentive and--not Tim Gunter, sorry, Andrew Griffith. I'm looking right at you--reflecting back on what he's heard these past few days and what it might imply for the program.

And I neglected to mention we're going to begin today--but that keeps it a little more efficient--we're going to begin today by hearing from EPA, and specifically EPA's perspective on deep borehole disposal, and we're very fortunate to have Dan Schultheisz from EPA talking today. Dan's the Associate Director for Waste Management and Regulation at EPA, and importantly he's the team leader for EPA's efforts to explore alternative disposal options for low-level radioactive waste plus standards development for spent nuclear fuel and high-level waste disposal facilities, and this specifically would be one such, the deep borehole option would be disposal facility. And from 2011 to 2014 Dan represented the U.S. on the International Atomic Energy Agency's Radwaste Technical Committee, so he may also be able to bring us some international perspective.

And at this time I'd like to welcome Dan up to the podium to get his remarks.

SCHULTHEISZ: Okay. Which one of these am I using?

Either one?

EWING: Either one.

SCHULTHEISZ: Either one. Okay.

All right. Is that okay? Everybody hear me? Okay, thank you.

Good morning. Yesterday was a long day, but I think it was very interesting. And I see most people have come back, so it must have been very interesting.

So, I'd like to thank the Board for this opportunity to talk to you about regulatory issues. The Board, or at least the staff, thought it would be very useful to have that sort of basic understanding of the framework that's in the U.S. and what has been and what may be in the future, so I hope you'll agree with that. Somebody said to me yesterday, "Oh, that's the fun part." I don't know if you'll agree with that, but it's certainly relevant. It came up several times yesterday and there was some discussion about a couple of the aspects that I'll be covering today, and maybe we can have some additional discussion.

So I'll start, and I see immediately my cover slide is violating some of the primary rules by using several abbreviations and acronyms. So, just quickly, EPA is the Environmental Protection Agency. Spent nuclear fuel high-level waste and transuranic waste. And in the subtitle here, CFR is the Code of Federal Regulations. This is a staple of

U.S. government speaking, so we don't try to explain it. It is the compendium of all the regulations that are issued by the different agencies. Title 40 belongs to EPA and other environmental agencies. Title 10 would be Department of Energy and Nuclear Regulatory Commission rules, would appear under 10, the CFR.

So I'll go on from there. So I'm going to start with a little bit of background on the organization in the U.S. and how it's set up legislatively, who's responsible for what, touch on the Blue Ribbon Commission and what they've said about boreholes, look to the Nuclear Waste Policy Act as sort of the framing legislation for the situation in the U.S., and then talk about our standards at 40 CFR Part 191. I'll just say Part 191 for now.

And many of you may be familiar with Part 191 or may have been more familiar with it years ago when it was actively being developed and haven't looked at it very much lately. Others of you may, if you don't deal with this very often, you won't have any idea what it is or what it says, so I'll go through that and then talk about what's in Part 191 and what the requirements are, and then sum up with some questions that we've generated about how we would apply this or develop a future regulation specifically for boreholes.

So, looking at the situation in the U.S., we have three government bodies that are responsible in this area for disposal of nuclear waste. The Department of Energy has been responsible for developing the sites, operating the sites, so this is applying right now at the Waste Isolation Pilot Plant, which is for transuranic defense waste in New Mexico, so DOE is operating that site at the moment. And under the Nuclear Waste Policy Act, or for Yucca Mountain, DOE is the developer, the designated developer and operator of those repositories as well.

EPA has responsibility to develop the general environmental standards. What are the criteria for protection of human health and the environment outside the site where the waste is being managed, so that's that we do. And then more specific criteria for compliance, for licensing, would be then be developed for any specific site that is chosen to host a repository. And for the WIPP, under specific legislation EPA is doing that now. For the Nuclear Waste Policy Act sites or Yucca Mountain the Nuclear Regulatory Commission is responsible for that. So I hope that sort of clarifies what we do versus NRC does and what DOE does.

So, any performance assessments that would be performed for this borehole would be judged by the Nuclear Regulatory Commission for compliance with their requirements as well as our standards.

So, touching on the Blue Ribbon Commission, we talked a bit about yesterday, but specifically for boreholes, of interest to us, the Blue Ribbon Commission recommended that EPA and NRC develop a new safety standard and regulatory framework for boreholes informed by the efforts such as what DOE is contemplating now, R & D efforts.

It's no secret, I'm not telling anybody anything they don't already know, that neither we nor NRC are actively doing this at the moment. There are some other things that we feel need to be in place before we can embark on something like this, so in the absence of specific standards and requirements, what can we say about the existing regulatory framework and how it might apply to boreholes?

Well, as regulators, the first thing we want to know is what jurisdiction do we have? What legal authority do we have to do something? So, we look at the Nuclear Waste Policy Act, which directed EPA to promulgate generally applicable standards for protection of the general environment from offsite releases from radioactive material and repositories. So, we issued our Part 191 standards finally in 1993. Those standards are being used now to regulate the Waste Isolation Pilot Plant.

So for our purposes, we would want to know if this is a borehole thing or not; can we deal with this? And of course we have lawyers who look carefully at this and want to make sure that we don't go beyond what we're allowed to do, not that we would ever do anything like that.

So there's also a definition of "repository" in the Nuclear Waste Policy Act, so we're developing standards for repositories, and the Act defines repositories as system licensed by the Nuclear Regulatory Commission, permanent deep geologic disposal, high-level waste and spent nuclear fuel, whether designed to allow recovery of waste or not. This point will come up again, and it includes both the surface and the subsurface facilities parts of that.

So, looking at that definition we would conclude that a borehole that meets those conditions are repositories for purposes of the Nuclear Waste Policy Act. So, this falls within our authority to regulate under the NWPA.

So, looking at Part 191, what does it say about boreholes? Does it say anything about boreholes? Well, we did talk about how we viewed the applicability of these standards when we proposed them in 1982 originally, and what we said was--we were talking mostly about mined geologic repositories, but what we said was we concentrated on geologic repositories because that is what DOE is planning to do and there's a lot more information on that, but we would see them as applying to any form of land disposal, and any other method of disposal would need to be as protective as a mined repository. So we would state that, yes, we contemplated that these standards could apply to boreholes, so we would say that Part 191 does apply to any boreholes used for disposal of transuranic waste or spent nuclear fuel or high-level waste. So, we are in a comfort zone here; we feel like we have something that does apply.

So now I'll talk generally about what's in Part 191 and go through the different provisions of it and talk a bit about maybe how they might or might not apply to boreholes. So, there are three subparts, two basic topics that are discussed. Subpart A is the pre-closure standards. It's operational and includes--definition is dose limits for the public for management and storage of these materials. And then we have the disposal, the post-closure issues, which includes three basic compliance criteria. Containment requirements, those are generally releases to the environment, how much can be released to the environment over time. We have an individual protection requirement, a dose limit to a member of the public, and we have the groundwater protection requirements that have to be met as well. And we also include some assurance requirements, one of which was very important for the discussion we had yesterday and I'll talk about here, and then sort of what is involved in the safety assessment. So I'll go through each of these some more additional detail.

So, Subpart A covers management and storage, so it limits radiation doses to members of the public outside the site from management and storage, and in this case management includes emplacement. So, the discussion we had yesterday about emplacement, this would fall under the management and storage portions, so at any facility regulated by NRC or by its agreement states or at any disposal facility regulated by DOE but not regulated by the Commission or agreement states. So, this borehole would be, if it's a Nuclear Waste Policy Act facility, it would certainly fall within this applicability.

So, Subpart B, the disposal, applies to radioactive materials released in the accessible environment from disposal, doses to the public from disposal, and groundwater contamination resulting from disposal. So, some of the relevant definitions we have: Disposal, obviously, is an important thing to define. Permanent isolation of waste from the accessible environment with no intent of recovery. This is very similar to the definition in the Nuclear Waste Policy Act itself. So, again, whether or not such isolation permits recovery. And we gave an example in our regulation disposal in a mined geologic repository occurs when all of the shafts of the repository are backfilled and sealed, so this would be the point where you've applied to seals to the borehole and you don't anticipate doing any more. You have nothing else planned for that facility.

Disposal system is a combination of engineered and natural barriers. We have a panel on barriers I think this afternoon or later this morning, so a combination of engineered and natural barriers. We also defined a concept called the "controlled area." It's the surface locations and area around the repository itself. We defined certain distance parameters, and it includes the subsurface as well as the surface. And this is what defines the accessible environment. The accessible environment is what happens outside the controlled area. The controlled area is considered part of the disposal system, so it is not subject to the compliance demonstration.

We've mentioned a couple times permitting recovery or designed for recovery. We also talk about retrieval, removal of waste, and the question is if you put in can you get it out, and so we had this discussion yesterday. The Nuclear Waste Policy Act was mentioned. It says, "Any repository shall be designed and constructed to permit the retrieval of any spent nuclear fuel placed in such repository during an appropriate period of operation of the facility. And these reasons could include public health and safety or the environment, for economic recovery reasons, and it also specifies that DOE would determine what the appropriate period of operation would be and NRC would then give their approval or disapproval as part of the license process.

It doesn't mention just spent fuel here and not high-level waste, so there's possibly some wiggle room there if you're just disposing of high-level waste.

What we said in CFR Part 191--let's say the whole thing. This is one of our assurance requirements. Disposal systems shall be selected so that removal of most of the waste is not precluded for a reasonable period of time after disposal. So after the seals have been in place we are still saying you need to consider how you would get that waste out for a reasonable period of time, which we have not defined in a generic way. We said when we issued this requirement that we did not expect such retrieval or removal to be easy, we didn't expect it to be cheap, but we did expect it to be not precluded. So this would be one area where we would need to think about application for a borehole based on the discussion we had yesterday, and we'd be very interested in seeing how DOE's going to demonstrate retrievability in a general way during the operational period.

So moving on, Subpart B then contains containment requirements. This is a limit on cumulative releases of radionuclides to the accessible environment, again, outside the controlled area, for 10,000 years after disposal, so after you've closed it up and you're not anticipating any further activity. So we require that it's based upon performance assessments that incorporate all significant processes and events that may affect the disposal system. So this could include an intrusion event if one was contemplated. We talked yesterday about sites with mineral resources, those sorts of things. If there is an intrusion event that can be contemplated and reasonably looked at, that would be addressed here. So the release limits are calculated for each individual radionuclide per metric ton of heavy metal in the repository. So, they are scaled to the inventory, and one of the reasons for this was that it would address situations like a borehole where you may have multiple places where you have one or two boreholes with not a lot of inventory, so it's based on what's in there not sort of a total amount that applies to any repository no matter how large it is and how large the inventory is. And we specify probabilistic criteria for determining a reasonable expectation of compliance with the release limits.

Subpart B also includes individual protection standards, so it is a dose limit to any member of the public in the accessible environment for 10,000 years after disposal through all pathways of exposure, but this only applies to the undisturbed performance of the repository so it would not include an intrusion type of event and, again, a reasonable expectation of compliance.

Subpart C, the groundwater protection standards, limits releases to groundwater, not cause concentrations in groundwater in the accessible environment to exceed the maximum contaminant levels, which are our drinking water standards, for 10,000 years after disposal, so that's a specific regulatory limit. It applies to underground sources of drinking water, which has a very specific regulatory definition and might not apply to some of these groundwater sources that are at depth where they're very heavily saline, high levels of dissolved solids. Again, undisturbed performance of the repository and a reasonable expectation of compliance.

Now I'll cover a little bit of history around this issue, because some of you may have sort of looked at it when it was happening 25 years ago or so. The original standards that we issued in 1985 had a groundwater standard in it, but it was not formulated in this way. It was challenged in court as allowing endangerment of groundwater contrary to the Safe Drinking Water Act requirements for underground injection. The court ruled that, We conclude that the primary disposal method being considered underground repositories would likely constitute an underground injection under the Safe Drinking Water Act. Likely constitute an underground injection under the Safe Drinking Water Act. This might strike you as not a reasonable conclusion, but nevertheless it is there. But we addressed this issue by putting these groundwater standards in place which are consistent with the Safe Drinking Water Act. There is no final court ruling on this point, but as we look at boreholes, which look a lot more like injection wells than a Yucca Mountain or a WIPP, we may need to think about how this issue would need to be addressed, if it does.

Alternate provisions: The two areas for disposal and for groundwater also include general requirements or provisions that allow EPA to develop alternate provisions for Subparts B and C, and essentially what we have to do is go through a public rulemaking process to establish those. Anything we would do for new standards we could do under these provisions. We have to do a proposed rule and allow public comments and then do a final rule and consider the public comments. So, this does provide us with some flexibility. We have never invoked it, never tried to use it, but it is there.

So I'll finish by going through some questions that we have in relation to this topic and our standards and future standards that may exist. Is a borehole used for disposal or a repository? As I said, we certainly think it would be. A new legislation may define repositories differently and may define boreholes as completely separate things and give us different authorities, but that's speculative at this point.

How would you define the controlled area for a borehole or a couple of boreholes that are in a very small area, maybe the size of this room? Does it make sense to have a controlled area in that case?

What is the accessible environment, which is, of course, defined based on what the controlled area is for determining compliance?

What constitutes a disposal system? Engineered barriers, natural barriers, what is the disposal system?

One borehole versus multiple boreholes: If there are several boreholes in an area, do you treat each one individually? Do you treat them all together? How do you do that?

Intrusion: Is intrusion an issue? How would you define that? What would be the probability of an intrusion if you could come up with a credible scenario?

Adequate characterization: We heard quite a bit of discussion yesterday; we'll probably hear some more today. What's going on down there; can we really ever know?

What would be the engineered barriers? Would we have special containers defined as engineered barriers? Special casings? Chemical barriers? There was some suggestion yesterday maybe the seals would be engineered barriers.

Retrieval: How can DOE ensure that the waste could be retrieved? How would they do that for any particular borehole system or waste type or waste container? How would you actually demonstrate that satisfactorily for regulatory purposes?

Again, this underground injection control issue. Are there things that we would look at from that program that might actually be useful to think about for boreholes and if whether we did them or DOE incorporated them into its technical criteria, integrity testing, those sorts of things, or NRC? Are there things that we would think would be appropriate to look at for boreholes in particular?

Alternative standard provisions: Is that a way to go for us to develop new provisions specifically for boreholes or would we need to do a whole new rulemaking?

And here's something that has not been discussed but has been in the past an issue. If there are some wastes contemplated for boreholes in the future that contain hazardous or mixed waste, what do we do about that? They are regulated under a completely different authority under a different act. Here's an acronym that has not been defined. RCRA is the Resource Conservation and Recovery Act. It is the statute that governs management of hazardous waste, and no migration variance is one way to address that. One was contemplated at WIPP until the legislation was amended to remove that requirement for compliance. It was very difficult to demonstrate that, so that's just an issue that we thought of because we also deal with the hazardous waste.

So in summary, we would believe that deep boreholes used for disposal of nuclear waste are repositories as defined in the NWPA, Nuclear Waste Policy Act. Our standards in Part 191 would apply to deep boreholes as currently written. We would need to think about how they would be applied, but we would also want to consider whether we would need to put some things in using these alternative provisions or a separate rule to better address or specifically address some of the issues surrounding deep boreholes. And if the borehole concept does move to implementation, then there are a number of regulatory issues that we certainly would be in discussion with NRC and DOE about about how to do the analyses and what would be acceptable and what might need to be otherwise addressed.

So that is my last slide, so I'll be glad to take any questions.

M. L. ZOBACK: Okay, thank you. Thank you, Dan. We have lots of time for questions, and I failed to mention earlier the procedure generally with questions is that we're going to begin with Board members to see if they have questions then we move to Board staff, then we'd like to open it to the panelists on the various panels, and then the general audience as well. So as we move through that rotation if you'd like to ask a question, please just come up here to the mic, and we ask that you identify yourself.

Everything's being recorded, and we want to properly attribute statements to the right person.

So I think I'll first ask Paul.

TURINSKY: Has EPA had meetings and discussions with DOE on deep boreholes?

SCHULTHEISZ: No, we haven't. We haven't had any discussions at this point. This is really the first indication. We did not before they laid out their RFP or any of their plans to do this, and this is the first detailed discussion we've heard about what DOE is contemplating.

TURINSKY: And if resources were available, is there enough to now begin to address some of these issues, enough information?

SCHULTHEISZ: I think conceptually we certainly could with the provision, of course, that resources are available, which we would say are not. But I think conceptually we would begin to have some discussions about this and try to be more aware of what DOE is doing and the technical issues that are being raised at this workshop are very helpful I think in focusing some of those concerns that we would have.

M. L. ZOBACK: Jean.

BAHR: Jean Bahr, Board. This idea of a controlled area is one that interests me in the context of a borehole. As we heard yesterday, one of the potential pathways for migration of radionuclides from a borehole is the borehole itself and the disturbed zone right around it. Yet typically the controlled area excludes the area immediately above the repository, so I'm wondering if that means that if it came up the borehole it would be part of the controlled area and hence not a problem?

SCHULTHEISZ: I wouldn't say it wouldn't be a problem.

BAHR: What I meant—

SCHULTHEISZ: A different kind of problem I think is what it would be. Yeah, as I said, the controlled area is contemplated as part of the disposal system because the geology is the important factor in whether things move or not, but if it's coming up the top we have--at WIPP we have a similar kind of thing where what we have worked out with DOE and--forgive me because I'm not deeply involved in the WIPP program even though it's run out of my office, and perhaps we might have somebody in the audience who can speak to this more directly.

The primary compliance provision that comes into play is the containment requirements at WIPP. So, what we have is drilling scenarios, because it is in an area that is drilled for oil and gas and historically has been. So what we look at for scenarios are scenarios which would involve the raising of material to the surface. And where those actually happen inside the controlled area or outside--I mean, it must be inside the controlled area because it's penetrating the waste and placement areas, but it does come up to the surface and we judge DOE's compliance based on the releases from those scenarios.

Something similar could be worked out with DOE, NRC to determine if that's the most likely exposure scenario, the most likely failure scenario it has to be considered in some way. And so the controlled area for a borehole, as I said, would be kind of an interesting concept to apply, but we need to really look at the scenarios that would be generating the most public concern.

Tom Peake, who is our director of our Center for Waste Management Regulations has been with the WIPP program since its inception and can talk about this more directly.

PEAKE: Yes, Tom Peake from EPA. The one issue with getting at the controlled area, that's going to be controlled by the release limit, because the standard is a proportional standard. And so you can only release a fraction of what's in the repository. And that's where how you define a controlled area might be very important as to what you're allowed to release to the surface. So I think that's kind of a shorthand for that.

SCHULTHEISZ: Does that at least somewhat respond to your question?

BAHR: Yes. Thank you.

SCHULTHEISZ: Okay.

M. L. ZOBACK: Lee?

PEDDICORD: Lee Peddicord from the Board. Kind of in the spirit of contributing to pages 17 to 18 with questions, and maybe these don't rise to the level, but, for example, back on page 8 in your presentation you were talking about where various authorities come into play and particularly what is governed in transportation and then onsite. The question that comes to mind is when does that pass off occur from a vehicle transportation system to under the management onsite? Is it when the vehicle comes through the gate or when the package is offloaded? This would be something for the lawyers I would think.

SCHULTHEISZ: Yeah. And, again, at WIPP I'm not sure whether we view something that enters WIPP site while still on the truck as being now it's subject to the management and storage. Certainly once they remove it and take it into the areas where they do their characterization and those sort of things, those are part of the management issues. We do not address transportation, the pure transportation aspects under this standard. So exactly where the handoff might occur I don't know.

Tom, does it fall under 191 as soon as it comes through the gate or is it when it comes off the truck? I don't know.

PEAKE: I think it's when it's off of the truck is when it would go. I mean, there's still the one-ninety--

SCHULTHEISZ: Well, not for WIPP.

PEAKE: Yeah, for WIPP our authority is outside the--well, it's when it comes off the truck is when we look at it. So, otherwise it is the shipping requirements.

SCHULTHEISZ: Right. They do have the requirements set under NRC and DOT rules for the packaging and the transportation.

PEDDICORD: Then on page 12 where you talk about the repository limits calculated per metric ton of heavy metal, what if you don't have heavy metal?

SCHULTHEISZ: Well, but cesium and strontium are--well, that is actually a question. What do you consider heavy metal, I guess is the question. If you don't have nuclear fuel--

PEDDICORD: Well, fission products are typically not in the nuclear field not considered heavy.

SCHULTHEISZ: Right. So, that is an interesting question. I don't think we've thought about it that way.

PEDDICORD: And, finally, you talked about the distinction--you kind of separated high-level waste, what's being talked about, and then commercial spent nuclear fuel. DOE has some spent nuclear fuel, some of it pretty bizzare.

SCHULTHEISZ: Yes, and it would apply to that. It would apply to any spent. It's not just commercial spent fuel.

PEDDICORD: Okay.

SCHULTHEISZ: It's DOE spent fuel as well. That's one of the interesting things as it appears to be somewhat of a gap in the statutory setup is the Nuclear Policy Act specifically addresses commercial spent fuel and defense spent fuel. It doesn't address research spent fuel from DOE, so that would be sort of a gray area. If they wanted to use this for some research spent fuel we would say Part 191 would apply, but who would be the regulator? It might be DOE itself unless additional legislation was passed.

PEDDICORD: Feel free to add these to 17-19.

SCHULTHEISZ: Okay. The heavy metal one is a good one for us to think about.

PEDDICORD: Thank you.

M. L. ZOBACK: Rod.

EWING: Rod Ewing, Board. Reflecting on the U.S. program as it developed over the past decades, one of the challenges of developing the repository was the absence of the regulatory framework. Just the hint of the framework, but really it wasn't settled. And then toward the end, in the case of Yucca Mountain, the compliance period went from 10,000 to a million years, and so this creates an important difficulty in terms of developing a scientific basis for understanding how the repository actually will work.

SCHULTHEISZ: Right.

EWING: The BRC has called for generic regulatory framework that could be applied across--I think they've envisioned a number of different repositories, but maybe generic including borehole disposal.

SCHULTHEISZ: Right.

EWING: So to prevent this from happening again, could you speculate on how much lead time EPA would need to develop a standard for deep borehole disposal so that we wouldn't be developing deep borehole disposal in the absence of a standard?

SCHULTHEISZ: Right. Well, the rulemaking process itself takes several years for us to do all of what we need to do. There was discussion yesterday about consent-based siting. When the BRC came out with its recommendations, we did sort of develop a game plan that we would want to follow, and one of the things that we would want to do is to solicit public views on a lot of these issues about what the standard should address, because as many of you know, the standards have evolved. The standards we did for Yucca Mountain, even though those were statutorily site specific and constrained or framed by the National Academy's recommendations, it took very different approaches in some ways from what I've described here in Part 191. So we had thought that we would want to do some public outreach and have some discussions with various experts and various stakeholder groups, public industry as well as academics, and get some of these issues better defined as to how they might be addressed. And, again, we would be doing generally applicable standards. So, the level of detail that you can have to some extent, a "one size fits all" approach. And then as a specific site gets identified, then you narrow in more with what NRC would be doing. And I don't want to speak too much for NRC, but I think they would be thinking the same way. We've estimated that it would probably take us about five years to do a new set of generic standards with that front end public outreach, and we are in no position to do that now.

EWING: Okay. Thank you.

M. L. ZOBACK: Any other Board questions?

SCHULTHEISZ: I'm sorry; if Tom--

M. L. ZOBACK: Oh yeah, sure.

PEAKE: This is Tom Peake again. If I can add something to that? After hearing the discussion over the past couple of days, having had the chance to talk to Dan about this, but it just strikes me as something that we would have to take to our management as to how they would want to approach it. Would we want to spend an effort to just focus on something for boreholes? I mean, if DOE has said that they want to do a mined repository for defense waste or if there's--you know, the BRC has recommended that we develop new standards, would we do something for just boreholes, or would we want to put the effort into just doing a larger effort that would cover new mined repositories and boreholes. So I don't have an answer to that, but it is a thought that has come after listening to this discussion. And so whatever path forward, if there is a decision that new standards would be necessary, it's not going to be quick, I guess.

SCHULTHEISZ: And I'll just say that as far as I talked about legislative authority, we could do this now under our current legislative authority, but Congress is going to do something. They need to do something to turn this situation into something that can be managed, and I think our management would be very much hesitant to go ahead without some indication of what Congress is planning in terms of either a new waste management organization or new processes or a specific authority direction for us.

EWING: So just to be clear as you're speaking, with the DOE plans it's clear we will still need a mined geologic repository. And with the loss of Yucca Mountain or it being setting to the side forever or for a moment, that regulatory framework is gone.

SCHULTHEISZ: The Yucca Mountain is.

EWING: Site specific.

SCHULTHEISZ: Yes.

EWING: So on the EPA plate would be both developing a general standard for geologic repository and this other activity, some type of standard for deep borehole disposal.

SCHULTHEISZ: For boreholes. Right.

EWING: Okay. Thank you.

SCHULTHEISZ: I think so.

M. L. ZOBACK: Okay. I have a couple of questions, actually three. Pretty concise, I hope.

I think for the benefit of the audience, we have a lot of international members here, it was pretty clear in all the EPA regulations that you have a 10,000 year timeframe or window. Can you briefly explain why Yucca Mountain went from 10,000 years to a million?

SCHULTHEISZ: I can. The legislation that directed us to develop standard specific for Yucca Mountain also directed us to contract with the National Academy of Sciences for a study on reasonable standards that would be applicable to Yucca Mountain specifically, and our standards were directed to be consistent with the findings and recommendations of the Academy panel. And when the Academy recommended compliance for individual protection to the extent of geologic stability of the site, which they estimated to be a million years, so that was this very site specific kind of a judgment on their part. We issued our standards, again, for a 10,000 year period and explained why we were not adopting that particular recommendation of the Academy panel and we, of course, got sued, as we always will, and on this particular point we lost and the court ruled that our standard of 10,000 years was not based on and consistent with the Academy's finding. And so it was remanded back to us and the most straightforward thing that we could think of to do was to modify whatever needed to be modified for that period after 10,000 years to go up to a million years for the individual protection limits.

M. L. ZOBACK: Thank you. And those questions come up all the time, and I thought with so many foreign visitors it would be helpful to hear it. So, thanks for that concise summary.

You mentioned that this was really the first time that you'd heard DOE's plans in detail for deep borehole disposal, and I just wondered as we're moving forward is there any reason why they couldn't come and talk to you guys about this?

SCHULTHEISZ: I would say no. We'd be certainly very interested. I don't want get into--

M. L. ZOBACK: Yeah, I'm not trying to start an agency--

SCHULTHEISZ: You know, they mentioned yesterday that, Well, we don't know what the regulatory framework is. Well, this is the existing regulatory framework that would apply. And it applies at WIPP, it would apply to this, and so, sure, I think we're very interested in following the progress of this project, so certainly we're open at any time.

M. L. ZOBACK: Great. Thanks.

And then the final question is you sat on the International Atomic Energy Agency's Radwaste Technical Committee. Did deep borehole disposal come up at all? Is anyone internationally contemplating?

SCHULTHEISZ: Well, the deep borehole is not so much as the shallower boreholes and more in the context for developing countries to be able to manage sealed sources and those sorts of things, so the IAEA has done a number of pilot projects. South Africa has been very active in trying to promote some of these things. So that's really the primary context in which boreholes are discussed. I'm not aware of any of the countries that are looking to develop repositories that are really looking at boreholes as a significant contributor to their ability to do that. So, somebody in the audience might know differently, but I'm not aware of any.

M. L. ZOBACK: Okay. Thank you.

Any staff members? Go ahead, Steve.

HICKMAN: Steve Hickman, U.S. Geological Survey. So, you mentioned that retrieval had to be not precluded for a reasonable period of time after disposal, and those of us who have tried to get things out of boreholes that are lost or stuck know this is extremely difficult. When they're cased it's easier than when you have to fish an open hole, which sometimes is impossible. And so this will determine the requirement for retrieval, a time period over that for which retrieval is required will determine the design. For example open-hole seals, it would be hard to get through those without sidetracking inadvertently getting back to the canisters, and they may be sanded in or scaled in. So do you have any guidance based upon Yucca Mountain or WIPP experience about what such a reasonable period might be? How long? I know you said it would have to be determined by DOE and then approved by NRC, but do you have any guidance to offer?

SCHULTHEISZ: Right. Well, just talking about WIPP, and Tom, again, may be able to talk about how we defined it. DOE does understand that if it was necessary to excavate the mine again to take out something that they would need to do that. I don't think we've specified a time period for which they would do that, and it's not going to be a generic sort of "for this long after disposal," it's going to be site dependent and design dependent. And a reasonable period is hundreds of years? No, probably not. Maybe 50 years, maybe. We haven't really defined that period of time. And this would be one of the things I think that we would look at to see how it could be even implemented for a borehole. Just the feasibility of it is really questionable.

M. L. ZOBACK: Great. Bret?

LESLIE: Bret Leslie, Board Staff. Dan, you did identify that NRC does implementing regulations, and kind of from your presentation you say EPA could start with what it has.

SCHULTHEISZ: Right.

LESLIE: Can you comment about the corresponding NRC regulation and whether NRC--you know, I think NRC's on the record to say that 10 CFR Part 60 they're a disposal that is consistent with the EPA standard you talked about that they would revise it. So even if you're EPA could you--

SCHULTHEISZ: Yeah, you're right, and I don't want to talk too much about NRC, but they have been public. As we do, they have general requirements in 10 CFR Part 60 and then they had Yucca Mountain specific requirements in 10 CFR Part 63. We have implemented Part 191 at WIPP so it's actually operating, so that's one reason why we wouldn't want to tear it up and start over again, because we're using it. We might do these alternative provisions, but we don't want to change 191 too much, because we're using it.

They have looked at Part 60 over the past several years and concluded there are several aspects of it that they would not want to try to license a repository to, that they think it's not current thinking and not implementable the way that it's written. So, the Commission has instructed the staff not to do any work on Part 60, so it's sort of in abeyance until something prompts the Commission to say, Okay, start working on this. But they have indicated that they would not want to implement the current Part 60 to license any kind of earth facility at this point.

I hope I haven't misrepresented anything to him.

M. L. ZOBACK: Come on up to the mic for additional questions.

FREEZE: Geoff Freeze with Sandia. And I'm with DOE--or working for DOE--so maybe this is the very first interaction. But, no, you mentioned the cumulative release standard in 191. You know, most of the international regulations in Yucca Mountain have dose-based standards, so could you comment on your thoughts or the applicability of a dose-based standard for boreholes rather than the cumulative release limits?

SCHULTHEISZ: Right. Well, the original intent of the containment requirements was more for the protection of the population at large and the possibilities that there would be disposal systems that had the potential to disburse radionuclides further away through surface water or whatnot. And the National Academy's panel for Yucca Mountain said that we should not take that approach, at least at Yucca Mountain, that it was more important that individual protection standard was really the more important. And that's the direction I think internationally has gone as well is looking at protection of individuals as sort of the primary criterion for determining safety. So, I can't say other than they're in the regs now; they are applied at WIPP so they can be implemented, but for a borehole, I don't know. Is it the best way to establish a safety objective? I don't know about that now. That's one of the things we would want to be thinking about with new standards is really looking at all the different ways that you can try to determine the safety of a repository and who it's safe for. So, I don't have a lot of good detail on how it would apply to a borehole.

FREEZE: Thanks.

M. L. ZOBACK: Please come up to the mic, so come ahead and then just get in line. We've got about five or six minutes more.

MILES: Okay. My name is Rob Miles. I'm the West Coast Business Manager for Wastren Advantage, but I'd like to make a personal statement not necessarily reflecting Wastren Advantage. I'm basically a third-generation nuclear employee. My grandfather was Chief Engineer of Dow Chemical during the Manhattan Project. My father was the Criticality Mass Lab Manager at Rocky Flats. I wrote the engineering and project management procedures at Rocky Flats and also for Fluor for the Hanford Site, and I want to emphasize how important it is to have a regulatory framework where DOE and EPA agree on the path forward for waste disposition and the DOE complex not only for the DOE defense mission but for the commercial nuclear power industry. I know that United Arab

Emirates and many other nations are moving rapidly forward into the commissioning of new nuclear power plants. Having no waste strategy that has been successful in the last 70 years is a significant issue with the industry. And for those of us who have struggled on many, many projects where this has been the key point of failure, there's no excuse for the academic and regulatory communities to be at an impasse. I'm not here to criticize, that's not my point; I just want to tell you that I know that it makes a great deal of difference in putting together processes and path forwards and safe, implementable working processes to have a good regulatory basis. And this makes a huge bit of difference in the approach maybe not on the initial test borehole, but certainly when we're getting into retrievability or non-retrievability and so forth. Five years may be too long. We really need to do our very best to give the nuclear industry here in America a chance to keep pace with the rest of the world. So that's the statement I'd like to give, and I appreciate your indulgence on that. I appreciate it.

M. L. ZOBACK: Thank you. Always good to hear from the people who are trying to make the things work.

McCARTIN: Tim McCartin, the U.S. Nuclear Regulatory Commission. And at least from an NRC perspective, this retrieval period, it isn't an amorphous time out there. It is tied to the Commission's decision to permanently close the repository. And so during that operational period where you're emplacing waste, you're collecting more information, it needs to be retrievable during that time period and it's only when you make a final decision to close a repository, and so that's what the retrieval period is directed towards. And so it isn't, at least from our perspective, it needs to be retrievable till you get to that time period when you decide to permanently close the facility.

M. L. ZOBACK: Can I ask you a question?

McCARTIN: Sure.

M. L. ZOBACK: So if the explosion that occurred at WIPP had occurred after you sealed the tunnel down, you wouldn't worry about that?

McCARTIN: It's still an operating facility. It's not permanently closed.

M. L. ZOBACK: No, I said suppose it had been closed. Suppose the last truck had been driven in and it was closed, would you not even have known about the explosion because you'd no longer be monitoring?

McCARTIN: Well, the post-permanent closure monitoring is the responsibility of the applicant.

M. L. ZOBACK: Okay.

McCARTIN: There is a point in time when it does not serve--if you've made the decision it's safe to permanently close, then the regulatory, the oversight authority then is transferred to the Department of Energy and NRC would no longer be the regulator. There is a post-permanent closure monitoring program that is to continue after that time period that NRC would approve the DOE's plans for that post permanent closure monitoring. And that, in theory, would capture something that was significant. And as has been stated, retrieval wouldn't necessarily end immediately. It would remain retrievable for some time period afterwards. Would you have to do something? That would be a decision that the Department of Energy would make.

M. L. ZOBACK: So I guess I heard you say retrieval requirements only during the operational phase. Once it's sealed the applicant takes over, but they have to do some sort of monitoring that you would approve. And then if something happened and seemed to be chain reaction and one after one canister started popping and exploding, would they have to have some plan to retrieve or at least go down there, or would you just let them pop one after the other?

McCARTIN: Well, clearly safety is always paramount. And the question is what the regulatory requirements are. From NRC's perspective it's required till the time the Commission makes its decision to permanently close. Afterwards it would continue to be the DOE's responsibility for safety. You would have to make some determination through that monitoring program if something happened what you would do, but that would be--I'm not going to try to speculate what would be done. It wouldn't be under NRC's regulatory authority; it would be under the Department of Energy's authority.

M. L. ZOBACK: I'm just imagining. Okay. Thank you.

EWING: Can I follow up with another?

M. L. ZOBACK: Okay.

EWING: Still in the imagining mode but back to deep borehole emplacement. So, during the operational period let's say a defective canister begins to release radioactivity, perhaps at a very low rate or is stuck, so at that moment one would want to retrieve it. That would be a classic example. But at that moment is it possible from a regulatory point of view to do a safety assessment and come to a judgment that it's better still down the hole rather than to expose workers in the retrievability operation?

McCARTIN: Well, clearly, whenever a situation would arise for a mined repository or a borehole disposal that retrieval should be considered, you would look at all the aspects of retrieval: What it meant to safety of the public, safety of workers, and what would be the best decision to make in terms of protecting public health and safety and the environment. And once you start speculating is there a possibility that you could do more damage by trying to retrieve than leave it there, the decision would most likely be made to leave it there.

EWING: Thank you.

M. L. ZOBACK: Okay. I was responsible for getting us off time, so let's get back on time. Sorry; apologies.

Let's take one more comment.

KAMPS: Thank you so much. Kevin Kamps with Beyond Nuclear. This is a follow-on to the questions about the million-year standard. So, full disclosure, I worked for one of the environmental organizations, NIRS, that filed the lawsuit against EPA in 2002. So, I guess to borrow a phrase from Dr. Arjun Makhijani at IEER, what is the justification for the double standard standards? So, you've got now a million-year standard at Yucca. Unfortunately another part of that lawsuit that we did not prevail on was the 11-mile dilution zone downstream of Yucca Mountain. So why wouldn't the most stringent standards apply to the borehole disposal? A million-year standard, which is still far short of iodine hazardous persistence, for example, and also a more stringent standard in terms of the footprint of the facility, no 11-mile dilution zone downstream.

SCHULTHEISZ: Right. Well, those were Yucca Mountain specific standards and, yes, the controlled area was larger than it would have been under Part 191. As far as essentially saying the million-year standard now is the benchmark, because internationally there are countries that have adopted million-year standard or a different time period. Germany is one that has specified a million years in their 2009, I think, standards. Our concern is also to be able to demonstrate with a reasonable expectation that there is a level of safety. So I can't say right now how we would look at a borehole versus a mined repository, but we are very much aware of the precedent that has been set with million-year standard not only here but internationally, and that will be something that we will need to look at and see whether there is something that we would need to do in terms of a compliance period that would address the appropriate level period of isolation and containment for whatever the waste happens to be. So I can't make any commitments right now, but that's certainly something we would be looking at is the compliance period.

KAMPS: And that individual versus collective dose, are there communities that would be harmed by that? I mean, one of the issues at Yucca Mountain is the Timbisha Shoshone traditional lifestyle, so collective dose to a population over very long periods of time where the individual protection standard does not protect everyone.

SCHULTHEISZ: Right. And that was one of the possibilities that was considered during the original rule. In fact the original proposal only had this containment requirement as a compliance requirement. There was no individual dose standard; there was no groundwater protection when it was originally issued in 1985. I know somewhat proposed in 1982 we did add those and then the lawsuit modified that, but we would look at all of those. As I said, all of the different ways of demonstrating protectiveness to whoever needed to be protected we would be looking at those sorts of things. And our standards, again, would be the generic standards, and then the more specific standards would be NRC-developed and they would work out the specific licensing about who is the receptor, who exactly and where, and all those kinds of things for any particular site.

KAMPS: Thank you.

M. L. ZOBACK: Okay. Thank you.

Now I'm going to turn it over to Jean Bahr, who's going to chair the next panel--

BAHR: It's going to be a little bit of people shuffling, but I think in the interest of time I'm going to do my introduction while that's going on, so I hope my panelists can make their way to the table.

The panel that we're going to have right now is going to focus on hydrogeologic conditions at depth. And the deep borehole disposal concept is based on the premise that it would be possible to find locations in stable crystalline basement where the permeability is very low and where the hydraulic gradients are such that there would not be upward flow through the system, so that means either hydrostatic or under pressure conditions. So what my panel is going to discuss are, in a broad sense, what's the likelihood based on what we know from previous drilling and from a variety of other things about continental crust crystalline basement in stable areas that might lead us to expect that those kinds of low permeability conditions and those kinds of hydraulic gradients exist. And then, more specifically, will be the Characterization Borehole and the Field Test Borehole will the tests that are going to be conducted in those would those be adequate to actually demonstrate that those conditions exist?

So in order to address those questions, we have three distinguished panelists. First up will be Mark Person from New Mexico Tech, who's a Professor of Hydrology there. Previously he had chaired professorships at the University of Minnesota and Indiana University. New Mexico Tech is one of the premier hydrogeology programs in the United States, has been for a long time. Mark has worked on a wide range of problems related to large-scale groundwater flow and sedimentary basins and crystalline rocks, and he's the editor of the journal Geofluids, which is the journal that specifically looks at sort of deeper hydrogeologic problems.

Second will be Mark Zoback, Professor of Geophysics at Stanford and a member of the National Academy of

Engineering. Mark's well known for his work on the state of stress in the earth's crust and the relationship between stress fields and permeability of faults and fractures. He's been involved in many of the continental deep boreholes that have been completed. We saw his name on a number of references and slides yesterday.

And then, finally, Kent Novakowski from Queens University. He's a Professor and Department Head in Civil Engineering there, and Kent has been involved for well over 30 years in both field and modeling studies of flow and contaminant transport and fractured rocks including the Canadian nuclear waste disposal program. He's also done a lot of work in low permeability formations, again, related to both radioactive waste disposal and other kinds of contaminant transport processes.

So, Mark Person is up first.

PERSON: Thank you, Jean. Today I'd like to present a global perspective of what we know as hydrogeologists and people working in the area of geofluids, the interactions between fluid flow and geologic processes about deep crustal permeability, so I'll present first a global perspective on this from a number of data sets from some of my colleagues in the field, and then I'll also talk about some unique characteristics of fault permeability within the crystalline basement, specifically at the interface between sedimentary basins and the unconformities in the Precambrian crust.

Just to acknowledge a couple of my collaborators, Peter Mozley and Jim Evans. We're standing here in front of a well-sealed well as Crystal Geyser.

Today I'll be sharing with you some geologic information from looking at the fault permeability of the crystalline basement, sedimentary basin interface at Las Vegas, New Mexico, and also some more site-specific study trying to characterize the permeability of the crystalline basement within the Truth or Consequences area.

Next slide. Okay. This is a busy slide. There's a lot of information, but basically this is from Stober and Bucher's paper, some German geofluids researchers, published in Hydrogeology Journal in 2007 that characterizes the variation of permeability with depth from deep boreholes that have been studied all over the world, and some of them have been discussed by Steve Hickman yesterday. So what's interesting about this figure is that Stober and Bucher broke out rock types, crystalline basement rock types into metamorphic rocks such as gneiss and distinguished them from other aquifer tests occurring in granite or mixed systems. And so the color is blue, representing granite; red representing metamorphics. Superimposed on top of this are these well-known curves by Steve Ingebritsen and Craig Manning from their first paper in 2010, the Manning

Ingebritsen curve, which argues that permeability should decrease with depth due to increasing overburden stresses. But as you can see, there's a tremendous amount of variability when you look at the hydraulic data from deep boreholes. It spans nine orders of magnitude in the shallow part of the crust. According to Stober and Bucher they argue that that variance should decrease with depth. This purple envelope is meant to schematically show the conditions of variance decrease, although it's purely schematic. There's not enough data really to accurately calculate changes in variance with depth.

But what you can see here is that at 4 kilometers sort of the typical range of permeabilities is on the order of tens of milliDarcys not ultra-low permeability conditions. There are examples of low permeability conditions at these depths, and if you did find these, one would expect to see perhaps anomalous pressure phenomena which you would want to try to monitor for. And that could be very tricky, and I think Kent Novakowski is going to talk about the problems of trying to measure hydraulic properties in tight rocks later today.

I'd like to call your attention to this second graph, or second line, that is shifted about two orders of magnitude, two-and-a-half orders of magnitude to the right. In a more recent paper by Ingebritsen and Manning they argue that the crust permeability is constantly changing, it's dynamic, and that due to earthquakes, contact metamorphism with rapid thermal changes, that the permeability can increase within the crust by at least two orders of magnitude. And so this curve is meant to represent instances, studies that have detected higher permeability conditions that could include induced seismicity, the migration of seismic swarms monitored during earthquakes all point to this idea that permeability can temporally increase for a period of time of months to years before it decays back to background levels. So, the viewpoint of the geofluids community is that permeability is not static; it's dynamic and constantly changing. And really solid evidence for this comes from also geologic studies of metamorphic studies where mineral-filled fractures argue for permeability increase beyond 10 kilometers depth where we would typically presume that the earth's rocks are ductile, but yet you see these evidence of between 400 and 200 degrees where rock are fractured and filled with minerals over these cycles.

An interesting conjecture of Stober and Bucher is that perhaps metamorphic crystalline basement rocks the permeability may decay more rapidly due to the presence of micaceous minerals than granitic rocks, so that's an interesting concept that is maybe relevant to this panel, although micaceous minerals and filling fractures may present some drilling problems.

One of our tasks in this panel was to promote what sort of characterization techniques would be suitable for understanding the permeability conditions in a proposed repository within crystalline rock, and I'd like to provide an example here from Truth or Consequences, New Mexico, where we tried to understand the circulation patterns within the crystalline basement shown here in gray. Through this long regional flow system in this system this would not be a proposed repository site. We believe that the crystalline basement rocks are quite permeable. But nevertheless, developing this sort of regional scale hydrogeologic characterization we feel is important for this type of a borehole waste disposal characterization. And, of course, you have to start with an accurate geologic map of the hydrologics flow system. I know the hope is that it would be a much more local flow system, but one has to consider the hydrologic conditions within the groundwater system, which can be quite long. In this case it's about 60 kilometers, and we tried to characterize the permeability down to a depth of about 8 kilometers. In this area, the Truth or Consequences area, it used to be called Hot Springs, New Mexico, the crystalline basement is actually a geothermal reservoir. We hypothesize that the permeability is quite high because, for example, thermal profiles showing strong curvature typical of an upwelling system, so thermal data suggested relatively permeable actively flowing groundwater, higher than normal temperatures, 41 degrees C at very shallow depths of about 10 meters. Carbon 14 age dates where carbon 14 samples were collected and we found relatively young waters of 6,000 to 10,000 years, and the salinity was about 2,000 milligrams per liter, so this would not be a good site for characterization, but nevertheless it illustrates the sort of procedure that you would want to do, we feel, at a regional scale to try to characterize the hydrologic system and estimate the permeability.

A big surprise for us was when we conducted a pump test this summer. In the crystalline basement about 100 meters depth we saw huge oscillations in the response of the well. So, typically you would expect to see a straight line behavior when you plot time versus draw down in a pump test, this red line. Instead, we saw these huge oscillations which are indicative of inertial effects which only occur in the most permeable type wells, typically in gravels, but this was in fractured crystalline rock. The permeability estimated by Jim Butler at the Kansas Geological Survey was half a million milliDarcys, so that's about 5 times 10 to the minus 10 meter squared. So, tremendous surprise to us that the crystalline basement rocks were so permeable. We think that, and I think the next panel will also argue this, that using environmental tracers such as carbon 14 age dates, helium-3 -4 ratios, helium-4 buildup are really necessary tools to characterize the deep permeability conditions. In this case by developing these regional scale models we were able to match the temperatures within this shallow crystalline basement, the groundwater ages by direct simulations of groundwater ages. This is work from one of my students, Jeff Pepin. So, combining regional modeling of environmental tracers with collection of this geochemical data really helped us to constrain the deep permeability onto 8 kilometers and being about a Darcy, which is quite high, and we were quite surprised. Again, going back to this plot, this is way off the plot, way off the typical values expected. So, this is a tectonically active area but nevertheless we were quite surprised.

Faults within the crystalline basement, as Steve Hickman said, they're hard to image or know where they are. We've been working to try to characterize what is the permeability of faults at the sedimentary basin Proterozoic basement interface at this unconformity and work by Mozley and Jim Evans. Field work shows that interestingly at this interface the bedrock can frequently have a 1- to 10-meter weather zone, and within this weather zone the damage zone is likely to be low permeability. So in drilling your test borehole it might make sense to core the basement at that interface to see if you have a weather zone, because it's likely that this would add some protection to fluids getting into the shallow subsurface. And detailed mapping right at the interface between the crystalline basement and the sedimentary unit Mozley and Evans found that the weathered granite had a lot of clay minerals and they were fluidized. They actually were transported and mixed into the basal reservoir, so we see this granular flow occurring that is quite unique and unexpected. You would normally think crystalline basement to be brittle.

Okay. Stop. Yeah. So, I'm done.

BAHR: Yes. I think we need to move on.

PERSON: Okay.

M. ZOBACK: Good morning. I'd like to continue the discussion of permeability of crystalline rocks from the perspective of the state of stress and geomechanical processes.

If you look at an earthquake map of the Central and Eastern United States or of India and China, you see earthquakes almost everywhere. These earthquakes are in the crystalline crust and tell us that we live on a critically stressed crust. It turns out that the places where the earthquakes are not occurring Indian Shield, Eastern China, for example much of the Central and Eastern United States and Canada, do not have a lower stress level than the place where the earthquakes do occur. Now, the argument for that is a little bit complicated, but I'll actually illustrate it empirically in just a minute.

Steve Hickman introduced the idea of measuring stress at great depth and comparing those stress measurements to the expected frictional strength of the crust. This is a compilation of--it's about 15 years old of all the deep crystalline rock sites that have been drilled at that time, and they all fall upon the expected line for a model in which the stresses increase in the crystalline crust until some well oriented faults start to slip. Most of the faults in the crystalline crust are dead, but some of them are oriented at just the right angle for the contemporary stresses to cause slip on those faults, and that's where all those earthquakes come from. So we're sort of closing the loop by taking laboratory rock mechanics to the field and demonstrating that the basic principles of frictional faulting, studying the lab, are applicable and the kinds of coefficients of friction that we measure in the lab are actually applicable to faults in-situ.

Now, the coefficient of friction, as Steve Hickman introduced yesterday, is the ratio of shear stress to effective normal stress at which a fault slips. This shows data from four different boreholes and it's thousands of faults that have been imaged with different kinds of geophysical tools, so each dot is a fault that's imaged. The data move out because the wells get deeper: Nevada Test Site, Long Valley, Cajon Pass, the KTB site, so the deeper we go the higher the stresses are, and the difference between the small dots and the big dots is whether or not that particular fault has a thermal anomaly associated with it that indicates that there's fluid flow in and out of the well bore. So we're simply doing a binary classification. We see a fault; does it conduct fluid or does it not? It's crude, right? We'd love to measure the permeability of each of these faults, but because there are so many thousands of faults, it was physically impossible.

What the data show in these three sites is that the faults that are hydraulically conductive, the ones that fluids are moving along, are mechanically active today. So the potentially active faults, the ones that control the stress magnitudes, the ones that produce those earthquakes, are also the ones that control fluid flow. And we can go into the geochemical arguments about why that is, but basically by moving every now and then you retain permeability over many, many millions of years, hundreds of millions of years, or you can even reactivate faults that are billions of years old in the current stress field.

This is an older slide that kind of shows one of the Manning and Ingebritsen curves, and the purpose for showing it is it compares directly the permeability of the matrix rocks shown over here. So you get a core sample, you take it to the lab, you measure permeability under realistic pressure conditions for the depth from which it came, and you get permeabilities of about 10 to the minus 19 meters squared. If you look at the boreholes from which these rocks were taken and you look at both permeability measurements either made with packers or estimated from the fusion of microseismic events or whatever, you get a permeability about three orders of magnitude higher. And as Mark just pointed out that we actually look at the very shallow crust up here at 1 or 2 kilometers, you get even higher permeabilities in these, but the point is that these active faults that exist in great numbers at depth weighs the permeability three or four magnitudes above the matrix perm or more, as he indicated.

Now, in this paper that a former student, John Townend and I wrote, we also made the point that to the best it could be determined in each of these deep well bores, there seemed to be approximately hydrostatic fluid pressure. In other words, the fluid pressure at depth was more or less in equilibrium with the column of fluid from that depth to the earth's surface, which means there's a hydraulic connection, okay? So it's just like going down to 7 kilometers in a submarine, okay? The pressure increases with depth due to the weight of the overlying fluid and we have an interconnected pathway, or at least over geologic time, that keeps the fluid pressure approximately hydrostatic.

Now let me tie these two points together. On this plot--you may not be able to see it, but you'll have digital copies--there are some red dots: Red dots in eastern China, red dots on the Indian Shield, red dots on the Canadian Shield. These are places where the building of a dam and the impoundment of a reservoir triggered seismicity at depth. So, the very small pressure change due to the height of the water in the dam, penetrated to depth within a period of a few years and triggered an earthquake at depths of, say, 5 or 6 kilometers. Again, indicating this hydraulic connection between the surface and depths of 5 to 6 kilometers because of the relatively high permeability provided by these critically stressed faults.

Now, this is not a talk about earthquakes; this is a talk about what earthquakes tell us about the crystalline crust, and I want to finish with some recent work that we're doing in Oklahoma. So, this is mostly the state of Oklahoma. The red dots are earthquakes that have occurred in the last five years, the blue crosses are places where saltwater is being disposed of in great volume at depth, and the black crosses are little symbols to indicate wells that are recirculating fluid. You produce water out of an oilfield and you put it back in the same formation that produced it.

Now, this is a very topical issue, because the earthquake rate in Oklahoma has gone from essentially negligible, or having one magnitude four earthquake every decade to one magnitude four earthquake every 11 days. Now, some of us here live practically on top of the San Andreas fault, and I can tell you if we felt a magnitude four earthquake every 11 days, we might think about moving, okay, and this is the stable midcontinent, okay? Far from plate boundaries, a place that hardly has any seismicity at all.

The reason this is happening is great quantities of water are being produced along with oil at shallow depth and they're being injected into a saline aquifer called the Arbuckle Formation, which is thick, porous, permeable, laterally extensive, and under pressured. So, the water flows in under its own weight at tremendous rates. In fact, they put 700 million barrels of saltwater into the Arbuckle Formation in 2014 alone. This pressure is unknown. It's under pressure and it's not measured, but the pressure is modeled to be less than about a megapascal, but it's acting over a very broad area, okay, so low fluid pressure is acting over a very large area in direct contact with the crystalline basement, and the earthquakes I showed you are happening at a depth of about 5 to 6 kilometers, okay? So, pressurization here is transmitted to 5 to 6 kilometers, and in fact it's transmitted almost immediately.

So these are three areas where all the earthquakes are occurring. The blue, again, is the saltwater disposal, and the red dots are the earthquakes. And what you can see in the northern part of Oklahoma close to the Kansas border in 2013 the fluid injection went up immediately and the earthquakes started immediately. In 2014, just to the south of there, the injection rate went up immediately and the earthquakes started immediately. Closer to Oklahoma City the fluid injection built up over a long period of time and the earthquakes began and they built up more slowly and there's a logical delay, because it does take time for the fluid pressure to spread out and to penetrate. But the amazing thing to me is the immediate communication of the pressure associated with this injection in these two areas within a period of months.

So where are those earthquakes and how are they related to faults? So, Oklahoma City is here; the Kansas border is here. This is basically the earthquake area I've been talking about. Again, the red are the swarms of earthquakes; the blue are the injection wells. So, hundreds of wells are injecting this fluid. It's spreading out and the earthquakes are occurring, and they're distributed over a very broad area. They do not correlate particularly well with the map faults, and that's because most of these map faults are inactive in the current stress field and because, as commented yesterday, it's very hard to see faults in crystalline basement, so there's earthquakes all over the place where there are no map faults, basically because people haven't gone looking for them. But the point of this slide is to show you these clusters of earthquakes, which indicate permeable pathways to the subsurface that are really quite ubiquitous, they're quite spread out, and over time there may be earthquakes in other areas.

So I wanted to show this slide to make the point that you can't characterize the crust in one place and predict what it's going to be like somewhere else. And so site characterization is going to have to be an important part of every disposal site, and you have to assume that the stresses are high, the conditions are heterogeneous, and there are permeable faults present in the interval that you're drilling through. You know, you're going to have to embrace reality. You're not going to be able to find these idealized sites without stress, without faults, and are homogeneous isotropic, etcetera, etcetera. This is what the crystalline crust actually looks like, I think.

Thank you.

M. L. ZOBACK: Thank you.

NOVAKOWSKI: Hi, everybody. So I'm going to talk about some of the challenges that we face with measuring permeability and basically the transport properties or the conceptual model of development. In a sense, the site characterization that we need to develop around this particular program.

There's a tremendous amount of experience out there in the community at depth above basically 1 kilometer. Lots of experience with measuring permeability, lots of experience looking at inter-well connections of fracture systems and so forth. But once we get below that, there is some experience, as we've seen from a few boreholes, but the actual technology that's used to measure permeability is a challenge. And, in fact, the technology itself has developed significantly over the last 20 years, and I'll talk a little bit about that.

So, I think we're coming to the conclusion that we should expect a lot of heterogeneity in the deeper subsurface here. And so in a sense, the way we characterize the shallow subsurface for a repository that might be constructed at, say, 600 meters depth, would be the same way, or should be the same way, that we would conduct site characterization at greater depth. We can make that argument. So, in fact what we might see are these fault features that both Mark and Mark have described, but we also should expect to find some very low permeability material in between. Intact granite, if we look at this example right here, this is a plot of permeability with respect to confined pressure, basically.

This is a very famous paper by Brace. And that's taken from core measurements. There's many, many core measurements that have been a core that have been taken out and permeability measured on that core from locations around the world, and when you look at that body of literature, typically the values that are obtained for permeability range from about 10 to the minus 18 and 10 to the minus 21. So, 10 to the minus 21 is very, very low permeability. Anything in this range, in terms of fluid migration, you're talking about diffusion-dominated systems, right, so that's a very substantially lower value than what we were talking about in the general context where the larger bulk hydraulic conductivities or bulk permeabilities that we were discussing just a moment ago with both of our previous speakers.

And again, in this case if you look at these measurements, this is permeability in nanoDarcys. These values right in here would be equivalent to about 10 to the minus 20 meters squared. However, we really don't have, even with this kind of data set, a lot of data from *in situ* measurements or from core measurements from greater depth, but in particular, from *in situ* measurements at depths greater than 500 meters. There's been some recent work in a variety of the programs around the world where continuous measurements of hydraulic conductivity or permeability with respect to depth have been made. And, in fact, that's what we'll talk about here in terms of the challenges.

So, measuring permeability in-situ there are a number of possible methods. DST, that stands for drill stem tests. Those of you who are familiar with the oil industry you would know that term. Drill stem testing it's a standard procedure by which to measure permeability using a drill string. Other methods include slug tests, that's a standard hydrogeological method, and pulse tests. And pulse tests we'll talk a little bit about, because this is the method that really applies to this kind of setting, in particular because of the range of capacity, the range in permeability that you can expect to measure with this.

Right now I'm just going to say that we're going to discard DSTs and we're going to discard slug tests generally. You can actually use a modified type of DST to make measurements in higher permeability, say above 10 to the minus 16 meters squared. The key to all this, though, is the means by which you isolate zones. So, you have to choose a method to actually isolate a zone in which you want to measure this permeability, and that is usually done by means of a straddle packer system. And the interval between the two straddle packer--so, packers are basically pneumatically isolating devices. They're pneumatically inflated rubber glands, often with steel reinforcement to inflate against the wall. It isolates a section so that you're only measuring the permeability between those two packers. And that packer spacing might range from anywhere from something as small as a few meters to, say, in some of the other nuclear waste programs as much as 30 to 35 or 40 meters in spacing.

Testing is influenced by a number of things. Wellbore skin effects: We've heard about the damage zone around a wellbore. That's a wellbore skin effect. In fact, that's, again, a petroleum term that's utilized here, but the damage zone around the borehole during the borehole construction is a skin effect, so it impacts the hydraulic testing. We don't want to measure the skin; we want to know the formation properties. We want to know what the formation actually has for a permeability.

Of course, once you start to get down into lower, lower, and lower permeabilities, the real key is the compressibility of the test section, borehole pressure history and temperature conduction through the equipment. All of these issues contribute to how the pressure changes in the isolated section. So when a pulse test is conducted, so just, as I said, that's probably going to be the most reliable method for certainly the lower permeability zones. Pulse test usually is either an injection or withdrawal of a small amount of fluid. And when I say a small amount of fluid, that could be a few milliliters. In the testing that was done for the Bruce Nuclear Facility in Kincardine, Ontario, they were using something like 50 to 100 milliliters of fluid withdrawal of fluid injection.

This is an example of a system right here. Here's a lower packer and upper packer, and there's the isolated section right here. Of course, it would be much larger than that in scale, right, because I'm talking about something that's typically maybe 15 to 30 meters in length and practice. Then that's coupled to a downhole system that has a hydraulic shut-in valve means by which to generate this pulse and then basically measurement devices on the upper part of the system. That's all coupled to a tubing string that is dropped down the hole.

So we do have some experience in North America and Europe measuring permeabilities down to 10 to the minus 22. In fact this example right here, that's a 3.9. This is a K_f here is the hydraulic conductivity of the formation, so it's a fresh water equivalent to permasone (phonetic). The equivalent permeability would be about 10 to the minus 22 meters squared for this. K_f of 3.9 times 10 to the minus 15, so very, very, very low permeability material that was collected with--I can't recall the exact packer spacing for this, but actually Rick Beauheim is here in the audience and he might know that.

So this is taken as an example from a paper of his in the Journal of Hydrology. The key with this is that there is experience in measuring these very low permeabilities, but the problem is not at greater depth, meaning that the experience doesn't exist at greater depth. And the challenges when using this type of equipment that exists here would be quite significant. Number one, look at the timeframe here. So, this is a testing sequence starting out here with the borehole history, a pulse withdrawal, and a second pulse withdrawal basically occurring over a span of about two-and-a-half days. So that's one test at 15 or whatever meters packer spacing. So, time is an issue, and I'm going to come back to time in a second.

But the other part of this problem--

BAHR: We need to move on--

NOVAKOWSKI: Okay. All right, let me skip. My last point is pressure measurement takes a long time, although we can actually get the pressure measurements *in situ* from the hydraulic testing results.

So just to point this out, there's a model that is used to simulate all this, and that simulation will also produce a formation pressure. So the example here if this is time, you're looking at almost two years' worth of time to actually get to a point where the pressure would be measured. This is a simulated line.

So the challenges really are focused primarily on the issues related to getting the tubing string down a very damaged, damaged borehole and I didn't really get a chance to say that, but I think that's potentially the fundamental problem here.

Thank you.

BAHR: Thanks, Kent.

I'd like to give the panelists a few minutes to just ask any questions or make any comments to each other, and then I think in the interest of time rather than going to the Board, we'll then go to questions from other panelists and then the audience, and perhaps some responses from DOE.

PERSON: Just maybe a quick question to Kent. Mark Person, New Mexico Tech, panelist. This pulse test, is it multiple pulses of fluids or one injection or withdrawal?

NOVAKOWSKI: It can be one injection or one withdrawal. And in fact, I think it could be set up to go either way, but if you're concerned about overpressures in any way, then withdrawal would be the route to go. But the timeframe is important here. So, as I mentioned, for one test you're looking at a couple of days. And I think one of the things that we need to be considering here is actually measuring continuously with respect to depth. So, in other words, we take one pressure measurement and we may want to target something specifically that was identified in, say the optical or the micro imaging logs and test that, but realistically, because we've heard many times that there is issues about knowing where those features might be with respect to depth, we actually need to test every section of that Characterization borehole.

BAHR: And, Kent I think one of the slides you didn't get to, but the chances of intersecting fractures that are maybe sub-vertical is better if the characterization hole is inclined than if it's vertical. I don't know if the panel has any thoughts about that as a characterization strategy.

NOVAKOWSKI: I do. So, again, both Mark and Mark have indicated that there's probably fracture features out there that are going to be near potentially sub-vertical, or not horizontal I guess is the best way to put it. If we're drilling perfectly vertical boreholes, the likelihood that we intersect these features becomes less, especially the very high angle features. So, the standard in the shallow subsurface for intercepting these kinds of things is to drill in an incline fashion. And in fact there shouldn't be just one hole for this. If you're looking for vertical features, there should be more than one hole. And, again, comparing the characterization efforts that we do in the shallower subsurface to that which we might do here, we actually should be considering maybe more than one Characterization borehole, at an incline orientation.

BAHR: Any comments on that?

M. ZOBACK: I agree.

BAHR: Mary Lou?

M. L. ZOBACK: I've got one insight with regard to that. As Mark indicated, the permeable fractures are going to be those that are slipping, and you can tell a lot from earthquake focal mechanisms. And although most of the Central U.S. is strike slip mode, which would suggest near vertical fractures, if you actually look at the focal mechanisms, they typically dip more like 70 degrees or something, so I don't think they're necessarily pure vertical.

NOVAKOWSKI: Right.

M. L. ZOBACK: I have a question for you, though, about the straddle packer tests and the challenge in holes that potentially have really huge breakouts. As we saw, it seems that you have to be really careful placing the packers to make sure that the pulse doesn't just go up the damage zone around the packer rather than into the formation. That's one point. And the other point being that by pressurizing the borehole with the inflatable packer you're just increasing the pressure, the circumferential stress, so you're potentially damaging the borehole even more. Is that correct?

NOVAKOWSKI: Kent Novakowski. I don't know if there's any data that shows that the latter occurs.

M. L. ZOBACK: Yeah, I'm just wondering.

NOVAKOWSKI: I think it's a reasonable speculation especially with respect to the damage zone. In other words, if you were trying to measure the properties of the damage zone, and then this get back to perhaps another point that I'd like to make with respect to tracer experiments, if you inflate a packer and you try and do a dipole experiment--so a concept of a dipole experiment would be to, say have a source of tracer in one zone and then try and force it into the other zone through that damage zone, well, the way to make that happen you have to inflate the packer against the damage zone and you're going to shut things down depending on the nature of those fractures. If they are tensile features, hard to know exactly what will happen there. So there's no question that inflating a packer plays a role here in terms of the impact.

M. L. ZOBACK: Okay. Thank you.

BAHR: Do we have questions from other panelists?

Yeah, just come up to the microphone. We have about 10 minutes.

HICKMAN: Yes, Steve Hickman, USGS. So, a couple of questions: One is when drilling a hole in a high horizontal stress regime you have to drill over balanced with mud pressure to inhibit breakout formation, which could create a skin, so what problems might that induce for doing permeability, especially short-term tests?

And, also, I'd like someone to comment on the value of inter-well testing, since permeability in fractured rock is highly heterogeneous and what you're getting from a single well is an equivalent bulk medium permeability when it's transit times through fractures that matter. So, skin effect considerations and over balanced drilling, and also how do you assess the heterogeneity and fast diffusion times expected to fractures with inter-well tests?

NOVAKOWSKI: Kent Novakowski. First, to address the skin. The development of the skin can be either negative or positive, meaning that could be permeability reduction or permeability enhancement. With the pulse testing technology, really it's a software interpretation, a numerical interpretation. There's a fairly strong reliability of identifying the properties of that skin itself, so in either case, reduced or enhanced.

The inter-well testing is more of an issue here, and I have a considerable amount of experience trying to do inter-well tests in shallow systems. And I think when we look at the deeper systems that we're talking about here, the likelihood for success, although there has been some, the Kola Well is an example of that, I think it's not strong. However, if we intersect features by chance between two wells and, again, this gets back to the number of wells that we might need to actually characterize those properties, then it is possible that you could do a well test between the two. But unless that permeability is quite high, meaning higher than what we've seen really here, I think the success is not likely.

BAHR: Mark Zoback.

M. ZOBACK: We're on a fast track to do the test borehole, but as was said yesterday, before a site was chosen and a repository established, we would do what was necessary. So, I think what's necessary is multiple characterization holes, and then you take the next step. Then you'd drill the repository holes. But those multiple characterization holes could be used for lots of things including well-to-well tests and including monitoring around the vicinity where the waste is actually put when everything is over. So, when you get to that point you're going to be doing things in a very deliberate fashion, and there's a lot of opportunity for that.

PATRICK: Wes Patrick, Southwest Research Institute. Mark, you got at most of the question I wanted to ask, but I would push it a little step further. Having been on the emplacement panel here and wrestled with questions of heterogeneity with depth, which I'm certainly sold on, are there things in terms of criteria that any of the panelists could speak to what should be looked for in trying to locate a reasonable site for this deep borehole field test that would be similar to the kind of conditions one would want to look for at an actual deep borehole disposal site?

PERSON: Which Mark were you referring to?

BAHR: Any of you can tackle that.

M. ZOBACK: Go ahead.

PERSON: Well, tectonically quiet regions are better, but as Mark Zoback has pointed out, there are critically stressed faults everywhere. But on average you would want to look for an area that does not have a lot of active geodetic motion. Rio Grande Rift would not be a good location. This idea of metamorphic versus granitic rocks is an interesting one that I think deserves further study, but there's very little quantitative data to prove out that the permeability decreases faster with depth in metamorphics, but that potentially might be a better venue, gneiss versus granites.

Mark?

M. ZOBACK: My little catch phrase of embracing reality, which actually might make a good bumper sticker, it kind of applies to lots of things. It was really the fact that I think the basic premise that's being put forward is invalid and it's going to trap you in the end. Just accept the fact that the stresses are high, these conductive faults exist essentially every, and figure out how you're going to deal with it and use your test borehole to do that, and then that's going to be the condition which is chosen for other reasons for a repository and you'll have to deal with these same engineering problems again. So this idea that you're going to find this idealized site I think is not a good place to start or a good premise to build on. That was sort of my point.

BAHR: Kent?

NOVAKOWSKI: Kent Novakowski. So, criteria are very interesting. Again, I think we're sort of coming to the conclusion, at least from a site characterization perspective, that we could use similar criteria that we use for shallower repositories for this case. And if you look around the world at most of those criteria, proximity to faults is a big, big kicker. In some cases there's design for the presence of faults in repositories. There's a way you can manage that perhaps through seals, etcetera, but for example certainly in the Canadian perspective there's a 50 meter exclusion zone around the entire area of the repository. That 50 meter exclusion zone is there assuming a diffusion-dominated system, so proximity to pulse is keyed up.

M. ZOBACK: Mark Zoback. Let me clarify. Kent's point's an excellent one. There are some first order things that you would do to site characterization, and you have to do those, but what I'm talking about is sort of a finer scale idealization should be avoided.

BAHR: This is Jean Bahr. Would it be possible to design an emplacement strategy that isolates the fractures that you do encounter in the borehole rather than thinking about a continuous set of canisters going down but limiting the disposal zone to those zones where you identified relatively intact rock? I see some heads shaking.

NOVAKOWSKI: Yes. Kent Novakowski. Yes, I think clearly if you have a fault feature that the borehole intersects, you don't want to have the canisters cross that. And then everything becomes reliant on the seals. But to build a safety case down the road, this has to be very, very clearly thought through, but it's entirely dependent on site-specific data.

PERSON: Mark Person; I'd like to add to it. I worry about if you did find ultra-low permeability rocks that Mark referred to, fracture-free zone 10 to the minus 20 meters squared of coupled phenomena, the thermal expansion associated with the radioactive waste heating up inducing higher fluid pressures inducing failure. These things worry me in tight rocks. Having a permeability too low can induce these unanticipated hydromechanical phenomena that could create permeability out of the repository area.

M. ZOBACK: Mark Zoback. Jean, just to expand on your point, I simply take that the emplacement strategy is going to have to be adaptive to conditions. Period. Right? And it's kind of hard to anticipate what those conditions are, and that's the kind of thing that could be experimented with in the test facility.

BAHR: I think we have time for one last question, and then it's about time for a break.

GARWIN: Richard Garwin, Panel 7. I have a question for Mark Zoback. So if the injection into the Arbuckle formation requires only one megapascal, what is the density of the fluid being injected, because that determines, of course, the pressure at depth. And what do you imagine are the conditions in that formation? Is it dry? Because if so, it may be the presence of fluid and not the additional pressure that's involved.

M. ZOBACK: The fluid that's being injected is highly saline, so it's relatively dense, but also the fluid that is naturally in the Arbuckle formation is also highly saline, and the one megapascal comes from some modeling, and the modeling is not as good as it should be not because the people who did the modeling were not competent, its simply because the models are unconstrained by having a lot of field data. Because this zone is under pressured, you can't determine what the reservoir pressure is from surface measurements. And because it's a disposal zone, nobody has taken the time and carried out the effort to actually put gauges down at depth in order to measure those pressures.

So, less than one megapascal is an estimate. The Arbuckle is saturated with saline brine already. The pressure in it it comes up to within about 400 feet of the surface, so it's fully saturated. That's its natural condition. It's because the Arbuckle formation outcrops at an elevation 400 feet lower than the point where the fluid is being injected. So, it's already got pressure in it. It's almost hydrostatic, not quite, and the fluid you're adding just raises that pressure just a little bit.

BAHR: One last question, Mr. Hardin.

HARDIN: Thank you. Hardin from Sandia. So I'm going to say something a little outrageous. Excellent presentations, but I would like you to consider the possibility that you are asking the wrong questions and that the safety case for deep borehole disposal is really based on a different paradigm. So the question is this. The challenge: If you encounter a site that has heterogeneity, it might have large-scale structures with permeability, but the site over some large area has saline groundwater and isotopic and geochemical evidence of very old water. Now explain the significance of those features that you're concerned about. So, I'm turning your argument around.

NOVAKOWSKI: Okay, you want to start with this?

PERSON: Well, I think in very old groundwater conductive thermal conditions are good. Mark Person, panelist. So, I don't take issue with that that those would be positive features that would give one confidence that the circulation rates are slow. Again, but if you have ultra-low permeability conditions putting hot waste in there potentially could create dynamic permeability conditions that Mark Zoback has discussed that don't require very small head changes, up to maybe only a few meters to cause failure and enhanced permeability. So even if you have low permeability phenomenon, there is this potential for enhanced permeability by hydraulic fracturing.

NOVAKOWSKI: The salinity issue is well understood in fracture systems in the sense that, yes, there is potentially it's a gradient or density gradient down a fracture feature, but in many of these fracture features if they're vertical it becomes more problematic, but if they're less than vertical, it's not so much an issue in the sense that they tend to have the same salinity along the whole length. So what controls the discharge or the migration through that feature then becomes the boundary conditions at each end of the feature if there's a connection. So if the pathway exists, there could be an extra--in other words, I don't know if we could depend on salinity as the preventer of migration in this kind of setting simply because the conditions can change over 10,000 years in a potentially big way.

M. ZOBACK: This is Mark Zoback. I'm not really sure how to respond to woulda, shoulda, couldas. All we're saying is to characterize the site and be capable in the emplacement strategy to adapt to *in situ* conditions. I think it's sort of a no-brainer, and that's, I think, our point. It's just don't create this mythical subsurface condition, and then when you observe something different you're out of business. Everywhere we go we see these permeable faults at depth. Every hole we've drilled we see these permeable faults at depth. Every hole we drill shows that the state of stress is in frictional equilibrium. Every hole we drill shows that the conditions are heterogeneous. That's everything we know. Now, we don't know everything, so maybe these sites exist somewhere, but we haven't investigated one yet.

BAHR: Okay. With that I think it's time to take a break. I'll let Mary Lou give the instruction --

M. L. ZOBACK: Back at 10:15, please.

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

BRANTLEY: If I could get your attention back to our panel. If we could come back to attention.

All right. Thank you. We are now approaching Panel 5, which is the geochemistry of fluids at depth, and we have four esteemed colleagues up here to speak. The questions that we're going to talk about are listed up here. We're going to talk first about the global experience of the geochemistry of fluids at depth. We're going to talk about how we characterize those fluids. It turns out to be very difficult to take samples and to make analyses, so we're going to talk about those difficulties. And we're going to talk about the implications of those conditions, the salinity, the reducing conditions in terms of waste packages that we might put down there. I think we might also hopefully try to address Ernie Hardin's question which, if I got it correctly, was if you encounter a site with heterogeneity but it does have saline groundwaters and isotopes and geochemistry of the character that is desired, what does that mean? So maybe we'll kind of think about that question as well.

So the colleagues that we have to talk, first of all, we have Kirk Nordstrom, who's from the U.S. Geological Survey. He's s Senior Research Hydrologist at the USGS. He's also an Adjunct Professor at Murdoch University in Australia, and I can literally say Kirk's an aqueous geochemist who's worked on practically every problem you can imagine. He's a groundwater geochemist, a surface water geochemist, he's worked on geothermal, lot of work on arsenic, he's worked on mine waste, geomicrobiology, and he's worked really worldwide on radioactive waste conditions in different countries, and disposal issues. He's also literally written the book on the thermodynamics of water-rock interaction.

Our second speaker will be Shaun Frape, who's from the University of Waterloo. He's been there since 1980 where he's the Professor of Hydrogeochemistry and Isotopes. Waterloo is perhaps one of the absolute best places in the world in terms of water resources, and he's written more than 350 publications on groundwater. He's a reviewer of radioactive waste disposal programs in several countries; he's collaborated with Sweden and Finland, USA, and Canada, obviously. He's a fellow of the International Association of Geochemistry and the Geological Society of America.

Our third panelist is Jen McIntosh, who's an Associate Professor at the University of Arizona in the Department of Hydrology and Water Resources. She also has a joint position in the Department of Geosciences and also at the USGS there. And her expertise is like Shaun's in solutes and tracers, and she's an expert in saline fluids at depth.

And then I invited Pat Brady up to be part of our panel, so he's going to give some remarks. He doesn't have a prepared set of slides, so there's no slides out there. Pat is a Senior Scientist at Sandia National Lab. He's also a geochemist. He got his Bachelors at UC Berkeley, and I think he was pulled into geochemistry by Hal Helgeson and got his PhD in 1989 in Northwestern. I've known him, I think, ever since we both got our PhDs. He was a Post-doc in ETH in

Switzerland, and I’m not sure I know what ETH stands for, but I do know what it is. It's one of the premier institutions in the world. He was specifically at EAWAG, which is the water resources part where Werner Stumm was, who's arguably one of the most important water chemists of the last two centuries. He was a professor at Southern Methodist University for three years, and then he's been at Sandia for the last 22.

So we're going to start with Kirk Nordstrom and then go to Shaun and Jen, and with a few remarks from Pat.

NORDSTROM: Thank you, Sue, and it's a pleasure to be here. I'm going to start with talking about how do we sample and the characterization of samples, and that's going to be followed by Shaun, who'll talk about the actual chemistry of some of the fluids that have been found in the deep subsurface and how we get the ages of some of these things. And then Jen's going to follow with other miscellaneous topics that we feel are very important that have to do with gases, hydrocarbons, microbiology, and glaciation.

So there's several sampling challenges, especially when you go to rather deep conditions in the earth's crust. And one of the first ones here that is rarely considered in projects that I'm involved in is who goes first. Who does the first measurements down that hole? What should the sequence of measurements be? We don't usually plan this, and that is a major problem for people trying to collect fluids and keep the chemistry of that fluid as representative as possible of the conditions at depth. So, geophysics they want to go down there and make measurements, but that can mess things up for geochemistry. Hydrogeologists want to make their tests; that can mess things up for the chemistry. So, very careful planning is required on that. If geochemical sampling doesn't have the priority, the sample integrity can be substantially compromised, so this is an important thing to keep in mind.

And important decisions about how to collect the sample, it can be brought to the surface through a sampling line. That's been done a lot of times. Or, downhole in-line sampling vessels can be used. And then if you're bringing the sample up to a sampling line to service, it can be either a push or a pull. You can have a pump down below to push it up or you can pull it up from a pump at the surface. If you pull it up, you're going to take the gases out. When you take the gases out you change the chemistry, so that's not really a recommended way of doing it. It's better to have sampling vessels in place. This has the advantage of keeping the sample close to the temperature and pressure that exists down the subsurface, because you can have sampling vessels, say one- or two-liter vessels that have valves at each end that could close off and keep that sample intact until you bring it up to the surface. Then when you bring it up to the surface, you need to measure the amount of gas separation and you can correct for that on opening. This is commonly done in geothermal wells, wellheads.

A borehole must be large enough to accommodate several sampling lines and lines for the inflating packers, so you're talking about a lot of equipment, a lot of lines going down. Things start to get complicated. And then then you go long distances, you're dealing with a lot of material here. And you might be working at temperatures above 100 degrees, which further complicates things.

So these are things that you have to keep in mind if you want to keep the chemical integrity of these water samples. You want to avoid oxidation from the air; you want to avoid chemical changes from decreases in temperature and pressure; you want to avoid mineral precipitation, degassing, water mixing from shallow depth to deep and vice versa. Drilling mud is always a problem. I remember many years ago that the Swiss decided to use distilled water as their only fluid in drilling. That was great for chemistry; it wasn't so good for other aspects. Containment vessels or sampling lines have to be as impermeable as possible and inert as possible, like Teflon. But if you're talking about a kilometer line of Teflon, there's a fairly big expense. If you're going to collect organic material, that's the only way to collect it that I know of. There may be other plastics out there that I don't know about, but Teflon's the only one that's dependable in terms of not leaching plastic out of the material as you bring the sample up if you're using a sampling line. Microbial samples also should be taken from both the water and the drillcores, and you need sterile equipment to do that.

This is just a sort of packer system. I think most of you are familiar with these things, but just to point out that they're complicated because you have the packers that have to be inflated. And if you have a long, deep borehole, how do you do all--you know, maybe you have, who knows, maybe a dozen, two dozen major zones of discharge that you want to collect samples from. Probably the best way to do it is to start off with sort of a conventional packer system and you find your zone, you pack them off and you collect it, but you do that just down to a certain depth and then drill some more and then collect some more samples, drill some more, collect some more samples. So when you're doing that for 3 to 5 kilometers depth, that's a long way and it takes a lot of time. Why careful planning, again, has to be involved not only for collecting the samples but for going back and forth between geophysical, hydrogeologic, and geochemical measurements.

I should mention on here the Swiss style gold standard, one of the best system of collection vessels that I heard about, were Teflon-coated stainless steel vessels, and I think these were usually two-liter vessels that had remote switch valves. You could switch off both the top and the bottom of the vessel.

The other thing is there's some radioisotopes that you collect, maybe several liters up to 100 liters or so, of radioisotopes that you want to collect for age dating that require large volumes. That's another kind of a problem you have to deal with.

There are some analytical challenges. Samples have to be kept anoxic for redox sensitive species. Gases should be collected during the degassing of the samples of the surface so the subsurface chemistry can be properly reconstructed. High salt concentrations are an analytical nightmare. Now, we can dilute the samples, and that has to be done to get into the instrument working range depending upon the particular constituent that you're analyzing for, but once you dilute it other constituents go out of range because they're too low. So, these are tricky things. Also, high salt concentrations can interfere with some trace element determinations, and isotopic determinations can also experience interference when you have very high salt concentrations.

What are the implications of these expected saline reducing groundwaters at 3 to 5 kilometers depth? High salt and high sulfite concentrations we know, and especially at higher temperatures, will greatly increase corrosion rates for most inexpensive metals comprising canister material. Also, you're going to have chloride, sulfide, possibly bicarbonate, and organic complexes may form and keep the radionuclides and other metals dissolved and highly mobile.

Now, we came here not knowing exactly what the materials were going to be in the canister since we've learned about cesium and strontium, that changes the picture a little bit. But there's other things that might be in addition to the cesium and strontium, and we need to know what those are in order to predict how mobile these things are likely to be and how corrosive they're likely to be. So the quantitative predictions of mineral solubilities requires geochemical modeling suitable for high ionic strength solutions and possibly at higher temperatures and pressures.

Now, a lot of this has been done over the years, but we're still in a state where we don't know everything we need to know to be able to do this quantitatively. Thermodynamic properties of fluids, fluids chemistry, minerals, mineral solubilities, especially solid substitution, salt solution minerals that would update radionuclides are incomplete. There's some nice series of thermodynamic tables, especially those put out by the NEATDB, that's the Nuclear Energy Agency Thermodynamic Database, and they've been doing compendiums of everything from uranium-- the last one I think was iron. These were very good, but if you look up these, there are some missing enthalpies, entropies, and heat capacities. Those are thermodynamic properties that if you don't know those, you don't know how to estimate what mineral solubilities and other properties would be at higher temperatures and pressures.

Only two methods we know of, the Pitzer method and the SIT, that's Specific ion Interaction Theory, are adequate to model these water rock interactions with high salinities or brines, but the necessary interaction parameters are not all available. And then there's a question of internal consistency of the data. It's always an issue. It's less so with a Pitzer and SIT, but there are several Pitzer databases and Pitzer codes, and SIT maybe there's more consistency, but you have to check these and make sure that they are internally consistent.

Solid-solution data is important for uptake of radionuclides. We have some information on this, but only limited in terms of the aqueous-solution/solid-solution properties, and modeling is certainly more qualitative than quantitative with these particular materials. Numerous assumptions, such as gas-solid-fluid equilibrium even at these higher temperatures. You know, we generally say if you get up, say, 200 degrees or higher, we can pretty much be assured many times of mineral solubility equilibrium, isotopic equilibrium and so forth. But in that range below that, we tend to get disequilibria, and then there's also the problem that when you put a drill hole down you release the pressure down at depth, and things are going to change as well. So, there is a major assumption about whether we can use equilibrium properties or not.

Then there's retardation factors or distribution coeffients, and these are often too condition-specific to be helpful. A lot of these are not known for situations involving brines.

And I have this cartoon kicking around; I just needed an excuse to show it, so I'm showing it here. You see a couple of coal miners and there's this guy in a hazmat suit behind him with a barrel there and it says, "Don't mind him. As we take out the coal, he fills in the spaces with nuclear waste."

Thank you.

EWING: Next.

FRAPE: Thank you to the Board and the panel for inviting me, and away we go. Let's see whether I can make this work.

I'm just going to put everything up here real quick, and I've been assured that you have all of these in front of you, so let's just go through and hit the high points.

First off in this diagram, other than the fact that if you're a hockey fan you will notice this is in the Treatise of Geochemistry, and you will notice that the national colors of several countries are up here. Unfortunately, we ran out; there can only be one country in red, so I apologize to any members of the Russian Republic that are here. So, that was the high point.

Okay, going back here basically above 1 kilometer first is saline waters. The summary: What are you going to drill the borehole with? Those waters up there at the top here, these fresh to slightly saline waters, surface waters, are going to be your drill waters. It's going to be a big borehole exploration. All of that water is going to be interacting with the waters down here. So right off the bat, you've created a disequilibrium situation. I'm very familiar with these; I've been working on this for 35 years monitoring boreholes.

Down below here we have saline waters; we have dual porosities; we have a matrix porosity, which is really important, because many of you I heard yesterday were going to analyze the core. That's good. That's your matrix. That's your diffusive porosity. That's in equilibrium with the matrix minerals. And then there's the fracture porosity, the fractural waters. They could be dynamic, we'll see that in a second, or they may not. And what are they? They're calcium or sodium chloride sulfate type brines. So, they're quite saline. You can see here that basically we have different trends. If you look at the Canadian Shield, some of the deep boreholes in Western Europe basically are less saline. They're not fresh; they're less saline. We'll see that in a second. So the deep boreholes of the world as I found them, some cases are sparse data due to sampling difficulties. We've seen that.

Often drill fluids are involved. That's why I brought that in. Drill fluids are involved. That's your near field, and it's going to enter my far field basically unaffected. Samples often are representative of long borehole intervals, so perhaps we're going to get around that, perhaps the hydrogeologists and everybody have ways of monitoring that.

The Kola, this can be summarized very quickly. Numerous faults, most of which appear to be dynamic. Interesting thing to note here is this dilute saline waters that came in at about 6 kilometers raised the whole level of the borehole about 80 meters, as I understand it, and at the bottom it's high temperature. And all the way down through quite heterogeneous all the way through the borehole.

The Urach-3 borehole, basically, very nice job of drilling here in the sediments, and then we got into the crystalline and had a little wander, but I learned yesterday that we can control that, we think. So we'll just see how the foliation affects things and various things. I've never seen a borehole that actually went straight in the crystalline, but maybe there's a first.

So, anyway, and note the important thing here is the geochemistry. Much more dilute; however, we had difficulties getting samples. There was a lot of drill water in the borehole. Same trend. There was a lot of drill water in the borehole. There's a theme here, okay? Again, temperatures, and at the bottom, pretty hot; at the bottom basically we have the same sorts and lots of gases.

What are some of the other characteristics? The nice thing about most crystalline waters is they have a number of unique isotopic signatures, so you can trace them when they enter the near field or you can trace them in the far field. You can tell whether it's a sedimentary water or a crystalline water in most cases. In many cases there's associated gases, lots of associated gases, and Jennifer is going to talk about that. Lots of gases. That's another take-home message.

I haven't been blown up yet in a mine in 48 occasions being underground, but I've come close a few times. Lots of hydrogen naturally occurring; mafic rocks love hydrogen. Individual fault systems: Rock types retain distinctive signatures. So let's just go quickly to this diagram at the bottom. This is a borehole in Mihkali in Eastern Finland. You've got this in front of you. Look at the ultramafic rocks. Watch what happens here. It's calcium chloride, and then all of the sudden it's a sodium chloride. Look at the magnesium in those mafic rocks. Isn't that great? Fantastic; pH, E_H changes. Fantastic. So, that's an open borehole, and every time we went back into it to sample it a week apart, it looked just like that. So, there's something going on there. I don't know what; we didn't have the wherewithal to monitor that aspect.

Going through quickly, another series: Age dating. I was asked to talk a little about this. Noble gas residence times and closed versus open systems. Very important. If you get a closed system, if you want to see something, this Holland paper, basically, in which with the Xenon isotopes a variety of Xenon isotopes, they calculate that their waters are about 1.5 billion and some of their other noble gas isotopies 1 billion. They change them around even down to 900 million. I don't think there's anybody in the room that would be too upset if they got any of those kind of numbers, but I just thought I'd throw that in. There is some humor in this, you guys; I hope you're seeing that. I love it when people start arguing over these kind of numbers. Look at this one; oh, what a shame. Look at the differences here in some of the noble gas model calculations. It might be 10 million or 100 million years old. Wow. That's tough. So, anyway, that's just a little bit of the noble gas. This is actually, for those that like to hurt themselves, this is actually a really great paper if you want to see the calculations. It works really well.

Chemical constituents: I've heard this many times so far in the last day-and-a-half, basically it takes a long time to drive the salinity; or does it? At those temperatures, it may not. There's a lot of reasons that it might or might not be. It might recur fairly rapidly. You'll have to ask Kirk about that. *In situ* rock water interaction, I just showed you that on the previous slide, so, there's some differences there. And the take-home message, age dating highly saline deep fluids is challenging, or you shouldn't try it, really, honestly. It's good fun.

And I was asked to say a little bit about fractured minerals, so let's just look at these; let's just put them all up here. They are good redox indicators in some cases. They control redox or try to control redox in other cases. Everybody in the shallow programs, the shallow radioactive waste programs, is fascinated by redox front.

Direct dating: The only advice I can give here is that I've seen many programs that have used multiple trails of dating and invariably one or two things don't match other things and it gets them in trouble. So it might be worthwhile thinking about what you want to date or think you're dating before you wade into it, because you will get differences. There's no question.

Fluids and geochemical history, I love ^{18}O and calcites. If you just do the calculations, the geothermometry calculations, you can get pretty well any kind of fluid you want and you'll get yourself in trouble. What you need, and what we started doing a long time ago, Alex White and I, is looking at the fluid inclusion filling histories. Fluid inclusions are formed at the very end in the calcites. They're very easy--well, they're relatively easy to spot. They're little guys; they've got bubbles in them. The bubbles form basically as it cools. The bubble exolves from the solution. When you heat it up and you put the bubble back in, you get the filling temperature. So, let's just have a look at this as an indirect age indicator. The higher temperature events, which were reflected in the fluid inclusions, for instance, this inclusion here about 250 or 220 degrees C. Well, basically you take away one of the unknowns up here; it'll give you an idea that it was a higher temperature geological episode that formed that calcite. You go to your tectonics guys and ask when was the last high temperature geological episode? Oh, 1.8 million years ago.

Congratulations. You just indirectly dated everything. What else can you use fractured minerals for? Well, they're kind of fun. I love fractured minerals; they're my favorite.

Controls on fluid transport: So, you've seen a variety of this diagram actually in the presentation just before us, Mark. That's a surface outcrop basically in the Black Forest area. It's full of zeolite. They have plugged the matrix, they plugged the fractures. What do zeolites have? A lot of water. I'm not sure what happens when you dehydrate a zeolite if you make it really hot. There's some more zeolites. Laumontite--isn't that beautiful--on a vertical fracture at Chalk River plugging the fracture, impeding the flow. Not sure what would happen if you heated it up.

And this is my favorite. You are 500 meters down underneath the Greenland ice sheet, and that's gypsum, a highly soluble mineral plugging fractures. There are 280 fractures over 300 meters of gypsum in this hydrothermal and anhydrite originally, now gypsum. What does it say about the stability of the water underneath the Greenland ice sheet? It's pretty darn stable.

So, thank you.

McINTOSH: Hi. I'm going to finish up our panel's talks by talking about some additional issues that we thought were important to cover, specifically the presence of gases, microbial activity, and the impacts of glaciation.

So, the presence of gases, such as hydrocarbons and hydrogen, are important to consider in deep disposal of radioactive waste, because they can affect redox conditions, pH, and microbial activity, which could impact things like the integrity of the seals and the transport of radionuclides. It's also potentially a safety concern as high gas pressures and significant rises in borehole fluids have been observed in other deep drilling projects and have led to several accidents and sampling difficulties that Kirk mentioned.

So what's known about gases and deep boreholes? Basically they're abundant, and many of the samples that have been collected from the deep drilling projects most of the saline fluids are associated with large quantities of methane, which is usually a dominant gas, hydrogen, higher-chain hydrocarbons like ethane, nitrogen, noble gases, and carbon dioxide. And I'm just showing you two examples here from the Kola deep borehole in Russia. They found at shallower depths, from 1 to 4.5 kilometers, it was mostly methane, nitrogen, and hydrogen. But, interestingly, at greater depths over 4.5 kilometers, the gas composition switched to more hydrogen, helium, and carbon dioxide.

In Finland in the Outokumpu Deep Drill project, they found the exact same thing, that at shallower depths, less than about 1.7 kilometers, there was a lot of methane, nitrogen, carbon dioxide, and some helium. But at greater depths up to 2.5 kilometers, again they found mostly hydrogen with some nitrogen, methane, and helium.

So what's the origin of this natural gas, specifically the methane and any higher-chain hydrocarbons? Essentially they found all three different types of gas. So, in the Canadian and Fennoscandian Shield and the South African craton, they found both abiotic gas, which is formed by water-rock reaction as well as biogenic gas, which is formed by microbes that degrade organic material and make methane and carbon dioxide.

There's also been evidence of thermogenic gas, which is formed by organic matter heated up at high temperature and pressure, and some of the crystalline bedrock sites, for example in the Canadian Shield. And interestingly, in some cases, there's been evidence of natural gas that's forming in source rocks and reservoirs and overlying sedimentary formations and then migrating down into underlying Precambrian basement rocks, and this example comes from the Forest City Basin in northeastern Kansas.

So how do we distinguish the origin between these three different types of natural gas? Well, most folks look at the gas composition and the isotopes. So, for example, you could look at carbon and hydrogen isotopes of methane and ethane. And that's important, but it's difficult to interpret those gas isotope signatures to try to distinguish between these different gas sources. And there's a lot of other processes, such as mixing between gas if you have multiple types present; migration of the gases that can lead to fractionation, and oxidation. So there's a lot of evidence of anaerobic oxidation of methane and the presence of sulfate in some of these deep environments for example.

So we add additional tracers to the gas isotopes to help us interpret their origin. For example, noble gases are very helpful. It's already been mentioned in terms of age dating, but also in terms of the source of gases and fluid migration. So, for example, noble gases can help us identify gas from the crust to the atmosphere in the mantle. And recently new clumped isotope methods might potentially be promising for distinguishing between gas sources as they can tell you the temperature of formation of gases, for example.

So, moving on to microbial activity. It's important to consider, because increased microbial activity can alter the subsurface geochemical conditions, specifically pH and redox, which can effect solubilities such as corrosion of the canisters, which you might assume is going to happen anyway so that's not so important, but it could potentially affect the integrity of the seals, for example, and the transport of radionuclides.

Increased microbial activity has been shown to lead to biofilm growth and clogging on porous spaces. This comes from more of the CO_2 sequestration world, so that may be actually a positive thing. And, importantly, any drilling activities and downhole instrumentation and sampling activities could potentially introduce non-native microbes into the subsurface. This has well been shown in other studies. It could also introduce carbon sources, which is energy and electron acceptors such as sulfate as well as organics, which was mentioned yesterday. Those are nice examples from Finland and Outokumpu deep drilling project where they brought up microbes from the drilling fluids, enriched them in the lab, and then added methane and sulfate, and the idea was that maybe you would open up multiple fracture zones within a deep borehole and you'd have mixing of fluids. And what they found is these microbes, the one in green, are the ones that were activated by the introduction of methane and sulfate.

So what's known about deep microbial life? Essentially they're found in most deep subsurface environments, even in crystalline bedrock. This is a compilation from a recent review paper that was published that I've tried to simplify here, and what's important is that these are all deep crystalline environments where samples for microbes have been collected up to 3.4 kilometers in depth. And at every location they found detectable methane. Some cases low concentrations, and in some cases up to 40 millimoles per liter. And in many of those locations they found methane cycling microbes, so these might mean microbes that both make methane or microbes that oxidize methane. And, interestingly, in a few examples indicated by "No," they found no microbial cells, but it was questionable if this was due to the fact that they were present but in very low densities or if they had sampling issues or if there really was an actual lack of microbial activity. Interestingly, microbial population densities, even in these deep crystalline bedrock environments, are similar to deep sedimentary basin environments and oligotrophic marine sediments.

Where they found microbes, they're primary dominated by sulfate-reducing bacteria and methanogenic Archaea. As Kirk and Shaun already mentioned, there's plenty of hydrogen around to fuel this microbial activity. There are similar concentrations in deep crystalline bedrock to hydrothermal vents at mid-ocean ridges that we know are very active in terms of microbes.

The high salinity in these deep fluids doesn't seem to be an issue. They found halophilic bacteria that can survive whereas it's temperature that seems to be the limit of life at depth in the earth's crust, and it's thought that microbes can survive only up to about 115 degrees Celsius.

So, this is an interesting couple examples from, for example, in Finland where they've looked at microbial activity between different fracture zones in the deep boreholes, and what they found is that the microbial communities, one, are different between different fracture zones, as indicated here, but also that the deep microbes are very different than the shallow microbes. And an important point is that the microbes that they measured are characterized from the borehole fluids were different than the microbes that were living in the fracture zones and likely different from the ones that were living on the surfaces of the rocks.

Finally, I want to talk about the impacts of future glaciations, so this may or may not be important depending on two things. One, the location of the repository site; and, second, the time scales that's important for ensuring safe and effective storage of radioactive waste. So, this is a figure that comes from some of the handouts that we got that's showing the depth to crystalline bedrock, so as I understand it, DOE is considering less than 2 kilometers of crystalline bedrock from their surface, which would be this tan color to pink. So, essentially this area. And what I've overlain on here in black is the maximum extent of Pleistocene glaciation. So, everything to the north was glaciated within the last 2 million years. So there's other countries in northern latitudes like in Scandinavia and Canada that are very concerned about the impact from glaciation. We're currently in an interglacial period. The next ice age is expected within the next 100 to 200,000 years. So, again, this is where the time scale becomes important for safe and effective storage of waste.

There's been many studies nowadays that have shown that continental glaciation altered both the subsurface hydrological as well as geochemical conditions and may have led to things like deep brine migration and enhanced microbial activity.

Several studies have been done both in sedimentary basins and crystalline bedrock looking at the isotopic composition and the salinity of fluids to identify these glacial meltwaters penetrating into the subsurface. And I just want to summarize quickly here to show the depth of penetration in sedimentary basins. Where people have looked, it looks like these glacial meltwaters have penetrated up to about 1 kilometer. And in crystalline bedrock they found similar things, that glacial meltwater, for example in the Con mine up in Canada, has gone down to 1.6 kilometers. So this is relatively dilute, relatively young water that's penetrated to that depth. Even though these repositories are going to be probably 2 to 5 kilometers in depth and meltwater didn't get that far, there could have been other perturbations too, for example brine migration at greater depths.

So, I think I'll skip the panel summary, unless you want me to go through it, and save time for discussion, because I don't know if we have time.

BRANTLEY: I think we probably should keep going and bring Pat up here so that we have time, because you can do that in your key issues this afternoon.

McINTOSH: Yeah, that's why I thought I'd skip it.

BRANTLEY: Thank you.

We invited Pat very recently, so he has no PowerPoint.

BRADY: No slides for you all. Well, to start off, I thank Sue for having me as a late addition to the dance card. Sue's research has been an inspiration to me for the last few decades. At the same time, it's an honor to be on this panel and in front of this Board speaking today.

I think I speak for all of the Sandians and the other DOE folks and the folks from Sheffield that are involved with the deep borehole project in telling you all how excited we are that you all are here and that the NWTRB chose to have this conference with these people in this place. You see, this is probably the last time the scientific community is going to get a big peek at the deep borehole field demo project. We're on a very tight schedule, as has been emphasized before. We have a lot of work in front of us, and we don't get many chances to get the outside input from the scientific community. If two years from now, three years from now, we can look back and say that in a technically defensible fashion we measured the right things and used them in the right way, it's going to be because of this Board and these panels.

Now, I've read through all of my other panelists' presentations, and I agree with all of them. And this isn't just a matter of me flattering people, because we actually started thinking about a number of these problems back in November. We had a Science Needs Workshop; a number of people here came to Albuquerque, and we wrestled with some of the same things you all wrestled with, though you all identified a few more.

Let me walk through just a few of them and add a few clarifying comments on where we saw something that you all saw and that our panel said, well, you rank it high or rank it low and so on. Okay, the number one call that came out of the Science Needs Workshop was the number one thing that Kirk Nordstrom said. It's very important. Sampling for the geochemistry of fluids is not easy. There are a lot of complicating factors. Getting good, reasonable data, that went to the top of everybody's list.

The thermodynamic database: You're right; all these waters are going to be high temperatures, 100 to 150 degrees Centigrade. The salinities are going to be 5 times seawater or higher. One has to use a Pitzer database or an SIT, and the fact of the matter is all the data we need isn't always there.

Okay. Corrosion rates came up. We didn't give it as much weight because, again, we take no credit for the lifetime of the steels in the package though we recognize, yes, they will affect the ambient geochemistry and the complexing potential, the fluid for the radionuclides.

Solid solutions; I'm going to come back to that one. Yeah, that one's an important one. It was mentioned that surface complexation models done at high temp--well, something better than KDs at high temperatures and low EHs. As a surface chemist I'm, "amen," but, boy, that's a tough one to measure and we recognize that. But there are a couple of radionuclides it's particularly important for.

Aqueous Complexation: What are the high sulfate concentrations going to do for some of the--oh, not so much sulfate as sulfide. What is that going to do for complexing some of the radionuclides? Something that Shaun pointed out, too, just the uncertainly in some of the bulk ion concentrations, that's a very big concern. My own favorite, it's what are the sulfide levels going to be? What are the bicarbonate levels going to be?

Jennifer pointed out the biological component. We recognize that's there. Our problem is not so much what to study but what not to study. There's so much we could look at in trying to understand how deep subsurface halophilic microconsortium behave, where do we stop? And our answer was, well, we stop with things that effect dose, like what is their ability to produce organic acids that can complex some of the cationic radionuclides and so on.

All right. That's, in a nutshell, what came out of our Science Needs Workshop. And since I was the note taker then I didn't get to put in my pet geochemistry ideas, but since I'm behind the microphone here, I'll throw them out as something for you all to think about. When we did the early solubility calculations and the retardation calculations in that 2009 report, the ones that caused the most headaches, strontium-90. Since the bicarbonate levels are kind of hazy, it's hard to predict if strontium carbonate forms is it going to limit the strontium levels. Kirk Nordstrom pointed out the importance of solid solutions; strontium would be the big target there. And, also, the strontium's going to go into the clays if there's bentonite in all and so on.

The last one that I'll throw out was the iodine-129. Iodine-129 is an iodine that forms no low-solubility solids. Most of the other radionuclides in the lower redox states are less soluble and they absorb more strongly. Iodine-129 rattles through. But there is some evidence that iodine-129 withstood to metal oxides like might be present in the trace components on the steels. And we did some work at Sandia a few years ago in the borehole project trying to chemically dope bentonites, specifically this would be absorb iodine-129, so I would throw out that one of the areas this research will end up with, this project will end up down the road, is trying to figure out how can we take advantage of some of those backfill sealing materials and make them chemically more important.

That's it. Thank you.

BRANTLEY: Okay. Thank you. At this point we open it up for questions among the panels. Do we have any questions that you'd like to address to one another?

McINTOSH: I think they talked offline quite a bit, coordinated--

BRANTLEY: No more to Pat or Pat to you?

McINTOSH: This is Jennifer McIntosh, University of Arizona. In the documents that we were given for the meeting, what would be the best thing to look at in terms of what DOE actually has planned in terms of the different types of analyses that you would do to characterize these sites?

BRADY: I would throw that to Dave Sassani. I should have mentioned at the start our geochemistry team Dave

Sassani's the head; Kris Kuhlman is the guy in charge of the characterization; and then Payton Gardner is the--

SASSANI: Hi. Dave Sassani, Sandia National Laboratories.

I mentioned the document. It's Kuhlman, et al, 2015. It was attached to the request for proposal on July 9th, 2015, and that Kris's document lays out the testing program for the Characterization borehole, and I think that's a great one to look at. That would be comments on that and input, and, in particular, the question that I had to this panel, and I really appreciate all the presentations. Very, very good stuff.

The question I have, and Pat brought it up from our Science Needs Workshop, my primary aspect that I think we could use any input on here because it is so challenging, is the sampling, particularly of fluids. I mean, Kirk covered a lot; Shaun, and then microbial aspects, but the sampling of those fluids, particularly in deep borehole systems, we can't get enough input on that. That's the question I would put to the panel. And that's almost rhetorical right at this moment, but any input you can give us on that would be vastly appreciated.

BRANTLEY: Okay. Go ahead, Kirk.

NORDSTROM: Kirk Nordstrom, USGS. Thanks, David. And I appreciate that request for assistance, because it's a very complicated issue. It's a hard one. I think what you have to do is you have to get, to start off with, a geophysicist, a hydrogeologist, geochemist and others who are going to use that borehole. You get them together in the same room and say, How can we optimize this operation? I've never seen that happen. It may have happened somewhere at some time, but I have not heard of it. That's where you start. And then from there you have breakout groups that attack the different parts of it knowing that they're part of this more integrated program. And then beyond that, this is just sort of my opinion in thinking about this challenging sort of project, is, as I mentioned, you don't drill the whole borehole at once. Go down in steps. What those steps are, don't know. And it probably depends upon what you find when you go to a certain depth. But I think you need to do a step-wise thing and, in addition to that, once you get to temperatures close to 100 degrees, then you want to switch over to more of a geothermal type of set up, so that means switching your whole equipment. Those are just, as I say, just some ideas off the top of my head.

BRANTLEY: Okay. At this point maybe we'll open up questions from Board members.

Gerry.

BAHR: Jean Bahr, Board. Given the challenges in sampling, can any of you comment on the timeframe for the

Characterization borehole, which the drilling will start about a year from now in September and it's scheduled to be completed, I believe, in February or March; is that correct?

BRADY: Jean, if you could call Kris Kuhlman, I think he's the right fellow.

BAHR: Yeah, I was asking actually the panel for their thoughts on whether that's going to be adequate time to do the kind of sampling that needs to be done based on your experience with other projects.

NORDSTROM: Kirk Nordstrom. My thoughts are it's not nearly enough time allowed. How much time is needed? Again, extremely difficult to say, so part of it depends upon what you find when you get down the hole. Part of it depends upon how the whole planning goes on using the hole to characterize the subsurface conditions.

One of the things that could be important is--and adds to the time--is when you hit, say, a permeable fracture zone you have this fluid chemistry. I mean, how much of that has mixed with another water with drilling fluid with something else. So you need to monitor that for a while and see that the chemistry is constant and maybe represents the actual water in the rock before perturbation. How long that takes, I think you guys can add to this, but I think it depends upon what depth you're at for sure, and it also depends upon the hydrogeologic emissions where you've hit a permeable fault zone that might be sub-vertical and you've got stuff coming down pretty fast, or some other kind of condition. But I would say that the timeframe that we've had described to us would not allow for a lot of these things to happen.

BRANTLEY: Another question? Gerry?

FRANKEL: Gerry Frankel, Board.

So, somehow last night I ended up at dinner with some fraction of this Board and started a back-of-the-notepad calculation that touches on what Pat talked about, the effect of corrosion. It turns out there's something like 7 million moles of iron to dissolve. And the iron, I think, will precipitate out as hydroxide. There's a lot of hydrogen gas, maybe about, I don't know, 10,000 moles per year, let's say, of hydrogen gas. What's the impact of that? Certainly you can test the local environment by drilling down and using your techniques, but changing it by the reactions that are taking this. By-the-way, I ignored the casing. I don't know, maybe the casing's an equal amount of steel. So, we are changing not just the heat and the radioactivity but also these corrosion reactions. Is there any impact of that?

McINTOSH: Yeah, sure. This is Jennifer McIntosh. I'll start off. I can imagine multiple things that we've talked about today. So, one from hydrogen driving water-rock reaction to hydrogen driving microbial activity, and so that's why I think kind of the take-home message of our panel would be to characterize what's present, the microbial activity, but then the modeling component as well, because it doesn't sound like there's going to be necessarily observational data that's going to be coming out. And so, again, measuring what's *in situ* at present and then using modeling to try to predict what these reactions are going to be. But knowing what microbes are present and how they're living off of hydrogen today and how they might be perturbed, I could imagine laboratory experiments as well as modeling would be really important for that.

Maybe the others could talk about the impacts of hydrogen and water-rock reaction.

FRAPE: Don't look at me.

BRADY: You go for it.

NORDSTROM: This is Kirk Nordstrom. I don't pretend to have much expertise in this. When I consider these calculations, I get really nervous about the amount of combustible or explosive gases, because you've got the hydrogen and the methane that are dominant, depending upon which depth you're at. And, to me, that's kind of scary, and I think Shaun has had some near misses on that sort of thing.

FRAPE: Do you want me to comment on that?

NORDSTROM: Yeah.

FRAPE: Shaun Frape from Waterloo. Every borehole in the deep Canadian Shield they've ever sampled has hydrogen and methane in different proportions. Most of the boreholes from surface to depths in Finland some of them are actually bubbling. It's very nerve-wracking when you're putting steel tools down a borehole basically and banging around the sides, because sometimes it just spontaneously combusts. I've been lucky; I've been in situations where gas pressures have driven 800 feet of NQ borehole rod out of the borehole, curled the rod up, and then the explosion started. And the driller that was escorting me around basically had no eyebrows, no hair, and said it was really exciting. And, so, I've got lots of those kind of stories. It's been fun 35 years of doing this kind of sampling.

One of the things that I could say about that is I believe there were some calculations done in the early days by Mel Gascoyne of AECL on the amount of hydrogen created in a deep repository. And I'm not sure whether the people have seen those calculations, but at one point I believe he had enough hydrogen that he could blow the shaft seals, and I think that's pretty--you know, some of the discussion I heard yesterday about sealing boreholes, it's not just about sealing the boreholes; it's about where does the stuff go. We saw that this morning with the earthquake predictions. There's already a lot of hydrogen and methane down there. Where's this extra hydrogen going to go? It's like sort of one of those subway cars. You just keep putting it in; it's got to go somewhere. So, yeah, it was fun at dinner doing the calculations, because I sort of figured where we'd end up.

Just 30 seconds here, the other thing I think I emphasized is please label your drill fluid with numerous tracers. Label and measure everything that comes out of the borehole, because eventually the plan is you're not going to take credit, I guess, for the--I loved that when I heard that word yesterday. So, therefore, it's going to end up, we will figure, in the far field, and when it does, whoever succeeds me in the world when I retire, basically will be stuck with the "What did you put down there, because I'm trying to trace this for you and I have no idea where it went, because I didn't know what the starting material was." So, it's fun to be a detective, but it's easier if you've got the gun already.

BRANTLEY: Okay. Pat, then Mary Lou.

BRADY: Yeah. First of all, in performance the hydrogen's our friend, because by moving around it can impose the lower redox state. But you're right about the potential for it being a bad thing. And I think Dave Sassani's going to mention some of it this afternoon, but I know Ernie Hardin has been leading the calculations where you start off with the mass balance and then you go into, well, what's the hydrogen production rate from the corrosion? You bound that with the corrosion rates and then subtract out what diffuses into the rock to try to get a handle on it. Now, we don't have the answer yet, but we are aware of it and looking in that direction.

M. L. ZOBACK: Okay. Continuing with my sort of tongue-in-cheek question of yesterday related to microbial activity, and maybe this is a follow-up given there's going to be hydrogen bubbling everywhere--

BRANTLEY: This is Mary Lou--do you want to identify yourself?

M. L. ZOBACK: Oh, sorry. Mary Lou Zoback. As you should know by now, the crazy person. I'm not from Pennsylvania.

Okay. I asked yesterday about the potential for microbial activity impacting the concrete portions of the seals, because I Googled it and microbes eat concrete, and I got 330,000 hits, and I was told it doesn't matter. The cement doesn't matter. Well, I just Googled asphalt, and microbes eat asphalt as well. So, we've taken out two of the three diagrammatic seals potentially, so is this an issue? Could microbial activity, which I guess would be enhanced by extra heat energy and maybe a lot of available hydrogen, could they impact the seals?

McINTOSH: This is Jennifer McIntosh. I think that was one of my major points is that the microbial activity, if you enhanced it, they could be doing things like producing organic acids, carbon dioxide, things that could impact the integrity of that seal. Well, do I know if the seal is actually going to fail? You know, I don't think I can say that on the spot, but I do think it's something that's important to consider.

M. L. ZOBACK: Especially if the explosion is going to pop it out anyway.

BRANTLEY: And I think Pat wanted to say something, also.

BRADY: Yeah. Everybody shows those pictures of the Roman aqueducts that have been sitting there for 2,000 years, but there's also like the Detroit sewer that collapsed in just a few years because of exactly that, the microbes breaking down.

Now, the thing to keep in mind about the seals is something that I said the other day. These seals don't have to last a million years; they have to last through the thermal pulse. So, we're talking about performance of a few hundred years. And, yes, it's important to convince ourselves one way or the other that the microbes are going to destroy a seal in that amount of time. And so, like I said before, we're trying to figure out how do we--we could spend all of the money just studying microbes at depth. How do we focus on those specific futures that might affect performance, and Jennifer nailed one of them right there. It's the seal's performance. And, also, the production of the organic acids; what does it do to the pH by changing the CO_2 partial pressure.

M. L. ZOBACK: Okay, thanks.

BRANTLEY: Do we have any questions from the audience? And, if so, why don't you come up. I think either Shaun or Kirk had something more to say.

NORDSTROM: Kirk Nordstrom. Just a quick comment. One of the things that puzzling to me is the discussion of the temperature maximum that's reached. So if it's cesium-strontium, it goes through this thermal peak, but if the material is sitting at, say, 4, 5 kilometers depth and the temperature's already 100, 150, that's not a peak; that's going to be maintained presumably for a long period of time, and I was just wondering what discussions there have been about what temperatures are expected for the canisters.

SWIFT: This is Peter Swift, Sandia. That will come up briefly in Panel 7. I'll have a discussion of the estimates of thermal effects. But the answer would be 150 to 160 degrees C would not be unreasonable.

NORDSTROM: Kirk Nordstrom. So that means we're talking for a much longer period of time where, whether it be microbes or other reactions that are catalyzed at high temperatures would continue to go, not just 300 years.

BRADY: You take the 100-degree baseline and it's a 50-degree kick-up, and that lasts about 300 years.

BRANTLEY: Is there a question from the audience?

TOM: Tom Paces from Czech Geological Survey. What is your opinion about the depth of the interface between the brine and freshwater? In the Canadian Shield it is, let's say, 1 kilometer-and-a-half and then there is probably a diffusion gradient to freshwater. And do you think this depth is typical for these fossil waters in the world or perhaps sometimes it could be much deeper, which we suspect in the Bohemian Massif that it will be below 3 kilometers, and in that case, if we would have interface at, let's say, 4 kilometer depths, then the chain of the containers would be divided into a regime which is in freshwater and regime which is in saline water with severe consequences to interpretation of corrosion and the behavior of these certain smectites. So, I think this is very crucial, because, of course, we know all that this fluids are the deep reactive part of the repository. So, what is your opinion about the depth?

NORDSTROM: Kirk Nordstrom. That's a very good question, Tom, and from what I know it seems like the depth to the saline or brine layer can be highly variable. One thing we do know is whenever we drill deeply we will eventually always hit a brine. But where that is depends on a whole bunch of factors: The hydrogeology of the region, and maybe if the area is perturbed by mines or other things, this plays a role. So, that's one thing. And where that is in relation to contacts between sedimentary rocks and crystalline rock I think is also a hard thing to pin down, and it's going to vary from place to place.

The other thing that I would say is that there's been a lot of discussion about this density stratified brine layer, but we know that it moves, and we know the pathways that it can move. And, in fact, sometimes this stuff comes out near or at the surface and it's found in mines sometimes, and it's pushed by hydrologic gradients if you have a large regional head pressure and some mountains that pushes stuff and so it discharges in lower areas, that can happen. There can be thermal gradients that are just enough to push that stuff up. So, there's no simple answer to that question, and you have to look at case by case.

FRAPE: Shaun Frape, Waterloo. I can add to that. A couple of the cases I didn't show of boreholes at Outokumpu deep borehole, the 2.5 kilometer, actually has a couple of small reversals in salinity where there's less saline waters underneath more saline waters. We've seen that in a number of cases, most likely controlled by the geology. Always remember in these cases that've you drilled into it. It was happy before you got there. You drilled a big hole in it;

you perturbed it, and so basically the gig's up at that point. One of the analogies I used is from a gas or from a pressure point of view could you assure me that if you put a straw through the top of a champagne bottle you could get to the bottom without losing any of the gas or champagne? If you can do that, then you're not going to have a problem in your borehole and you're not going to have anything happen. I don't think that's a showstopper, but I think you guys are probably prepared for that. That's the impression I get. But these big regional systems, Tom, as I showed in the one diagram, that's vetted data that's in the treatise. It's, for instance, in mine openings, and the Con Mine is an example places like that. The boreholes that were sampled are well out away from the workings so what you're seeing there is what actually occurs in these environments. So in most of the other data that's suspect that has tritium in it and things like that at depth is over there, because they are mined openings. They're pumping thousands of gallons of brine a day. And you saw the different trends in different areas.

So, at depth they're all saline, seawater, at a couple kilometers I would guess in most of the stuff, and the surprising thing is when you see these brines up in Finland and a couple places we have 60- to 100-gram per liter waters 30 meters down. Hell, I've got 200-gram per liter waters 40 meters down just outside of Toronto in the Paleozoics. I mean, that's not a surprise. And what Kirk's referring to is that one of the earlier studies I did was on what they call "moose licks" in the northern--and if you don't know what a moose lick is, I'm not a hunter, but if you ask the hunters.

M. L. ZOBACK: I'm going to guess it's brine near the surface.

FRAPE: It's brine near the surface that the animals like them.

BRANTLEY: I'm getting all sorts of signals, Shaun. I'm supposed to be cutting this off.

FRAPE: So, the stuff comes to the surface.

TOM: Okay. Now, I have--

BRANTLEY: We actually have to cut our panel now, because we have--

TOM: No, no, I have completely different question.

M. L. ZOBACK: So, we're out of time.

TOM: I can't--

M. L. ZOBACK: No.

BRANTLEY: No.

TOM: It's very brief. Why do we consider the depths from 3 to 5 kilometers and why don't we consider depths 1 to 3 kilometers? I never found any reasonable answer in report which I read.

BRANTLEY: Okay, so we'll let that question float.

TOM: Can anyone explain this?

BRANTLEY: We'll let that question float.

M. L. ZOBACK: That's a great question for discussion, and we will save that for when we have our broader discussion.

Could I have my Panel 6, Multiple Barriers, up to their seats?

And thank you guys very much.

EWING: Come to the table, and to save just a few moments, let me start the introduction.

Panel 6 is on multiple barriers. In a moment I want to say a little bit about the multi-barrier concept. We've been discussing the seals, but in this panel we want to expand the discussion to wasteforms and containers. For the panel we've invited Dave Sassani, who you've already met, Senior Scientist at Sandia, a geochemist, and a person I've known for many decades in various repository programs.

We also have Neil Hyatt, who's the NDA, Nuclear Decommissioning Authority Research Chair, at Sheffield University and Director of the Immobilization Science Lab at Sheffield and with considerable experience and great expertise in wasteforms.

And then we have Narasi Sridhar, presently a consultant with DNV GL, which I'm not sure what it stands for, but Sridhar is an expert in corrosion, electrochemistry.

He was with the Southwest Research Institute for 18 years, and in his present capacity is very involved in safety analysis of many different types of technological systems.

Now, I want to say a little bit before we get to the speakers about the multi-barrier concept, because I think it's behind some of the confusion about how long seals should last. So, I was first introduced to the multi-barrier concept more than a few decades ago by Rustum Roy, a Professor at Penn State. And I remember the lecture very well, and he presented the Russian doll concept, so in his honor I brought a Russian doll. And the concept, of course, is very simple-minded. You have a series of barriers, one over the other. First you have the geologic barriers; then one can imagine maybe the over-pack or the backfill, and then the properties of the waste package become very accordant. And then finally, and this is a very general statement, you might have the wasteform, which contains radioactivity. And there could be other barriers depending on which national program we look at.

So, this concept and this lecture goes back probably over 30 years ago, so it's very simple-minded, but it does have certain characteristics. First, there's a redundancy built into the approach, so there's the expectation of redundant barriers, one catching what another might let through. It's also a way of handling the uncertainty in the analysis, because a mistake you make with one barrier might be compensated by getting it right with the next. And also it speaks to the question of the possibility of accidents, because you can imagine a defective canister or the backfill not in place properly, and so it would come into play.

So, that was the old approach. Over time in the United States it evolved into a more sophisticated analysis where it was a total systems performance approach. The barriers are still there and in the system, but the efficiency or the effectiveness of the barriers varies as analyzed in a probabilistic way. It's all rolled together and then you look at the final answer, which is whether you meet the regulatory requirements.

What's important about the present way of doing things, it means that if you're in a repository program and you get underground and you discover that the geology is not what you expected, let's say the infiltration rate is much higher than expected, then one can imagine other barriers or other approaches. You could change to a more corrosion resistant waste package, you could have drip shields, but the important point is you can walk around your repository, you can look, you can measure, and then you can adjust your multi-barrier system to give you then finally a safe performance.

So the question that we have with deep borehole disposal is which approach is most appropriate. Is it something that looks more like the original idea of these one barrier nestled over the other, or how will we adjust to surprises in the deep borehole program as we go along. What are our options? And this is why I think this panel, although we're examining or discussing something that hasn't been discussed so much, it may be that the older concept with the good wasteform, a good waste package, may play a role in a system in which it's very difficult to go back and change what you're doing.

And this explains also--you know, Pat Brady keeps emphasizing, correctly, that the seal only has to last for 300 years, because the system then will return then to its original condition. Another person might argue, well, I'd rather have a seal that lasts 100,000 years just in case the system doesn't return to the conditions that you anticipate. So think of our discussion as providing input to trying to decide between the two approaches to the multi-barrier system.

So, with that little bit of lecture I'll turn to Dave, because we want to be sure to get the latest information and more detailed information on the barrier systems that are anticipated in the deep borehole.

So, I'll take my doll away.

SASSANI: Very good. Thank you, Rod. And this is excellent, because the current universal canister for cesium-strontium capsule we’re incorporating kind of looks like this Russian doll. It has about three or four layers, because the cesium-strontium capsules are already in two layers, then there's the universal canister, and then there'd be the waste package. And if the bag is the waste package, that's appropriate also, because we don't take any credit for duration of the waste package. Very good. And I'll have to say I don't think it's an either/or. I think although in the regulatory framework that all changed, I think in terms of the technical evaluation of the safety of the systems, we still look at it from a total system performance assessment and we look at the multiple barriers as well as all of the features, events and processes that may actually be important for performance of each of those aspects of the system.

This is me again, and I'll thank the Board once more for inviting me to come up and talk with everybody. I really appreciate it, and I'm really enjoying the panels. In particular, the panel just before this one on geochemistry, which is near and dear to my heart. Lots of very good stuff.

So, I'm showing a diagram here which is the disposal post-closure conceptual model with the various components. We've seen this a number of times before. The whole idea here is robust isolation from the biosphere. And remember, again, here's the Burj Khalifa Tower not part of the surface facilities and not indicating that we're in Dubai.

And then here's some levels of other repositories. I think this one is WIPP, and I think that's Oslo. In any case there's the depth where they occur, and we've seen lots of diagrams of the properties changing as you go deeper in the crust. And this is what I want to emphasize is we're looking for sites that have fewer major faults, less heterogeneities, not an idealized site that's going to be a homogeneous perfectly uniformly crystalline granite with not a fracture in it. So when you're looking at various sites, you're choosing among them and you're trying to find a place where you're going to have success in demonstrating the types of properties you would like for this sort of a disposal facility but not an ideal location; it's the crust of the earth. We're going to find what we find, and it's very important to get underground, get that borehole in place, and make the observations.

So, in the hole we have the wasteforms and waste packages below 3 kilometers, and we have the sealing zone here, which are the explicit seals with various materials, probably at this point cements, concretes, and clays, smectites not bentonites, but in this zone with various multiple layers. So, the seal zone itself has multiple layers to account for some of this multi-barrier aspect and to have defense in-depth with various materials. I tend to prefer earth materials. I'm pushing for not a whole lot of organics in these because of the issues we've been talking about. And those are referred to as the engineered barriers, and they're the things we're putting in there, and there's the natural system, which is comprised of overlying sediments, crystalline basement with various properties that we're looking at moving towards the most attractive version of those properties we can find in both the hydrology and the geochemistry.

So here's just a little bit closer look at our schematic of that. You know, the seal zone, what I really am taking away, here we are between 2 and 3 kilometers, a kilometer of seals. I'm pretty sure most repository systems would really love to be able to have in place a 1 kilometer diffusive path length as a barrier, so that's the seal zone. There's the waste disposal zone. The waste package primarily, in the concept as we currently implement it, it provides structural integrity for the emplacement removal operation protection. We assume it to rapidly degrade after emplacement and sealing of the system. We don't take any performance credit for the package at all at this point. There's some issues we actually are investigating in terms of the corrosion of these materials, generation of hydrogen gas, but that's different from the actual post-closure performance keeping radionuclides isolated unless, of course, it creates some kind of catastrophic event, which we don't think it will at this point.

There's the inventory and the wasteform. Currently our primary one we're looking at are the cesium chloride-strontium fluoride capsules. High-level waste previously we had evaluated commercial spent nuclear fuel. This is no longer being considered by the Department of Energy for deep borehole disposal. That's why it's grayed out, and there's some other aspects.

Post-closure release pathways in the undisturbed scenario primarily looking at what we can do in terms of sealing. We expect that this is a very likely pathway because of the disturbed zone and the fact that we will have to seal the hole, but we may not seal the hole to the same low level of permeability that the bulk permeability of the host rock represents. To the surrounding host rock in the disposal zone you might have some diffusive transport. We've looked a little bit at that. And then in gray again, the one other aspect to consider is a potential high permeability pathway that could cut through the disposal zone and maybe make it to a sedimentary aquifer.

Okay, so there's a biosphere. I'm not really going to go into that very much, but basically we assume that the water's withdrawn right above the seal zone.

Primary barrier in our system for consideration is the geologic system. That's a big tenet of geologic isolation, but the multi-barrier aspects are considered within this aspect. We have very isolated, reducing, low permeability system with a long transport pathway that's likely diffusive.

So in terms of the canister materials, the concept for the test packages are basically use of drill pipe. This is American Petroleum Institute 110. Ernie mentioned it earlier. It's an alloy steel. There are possible alternatives to be used that we are still considering. This is just the reference case. None of this is defined in stone; there is possibility to do other things. There is universal canister materials work going on within DOE-EM looking at packaging their wasteforms, looking at stainless steels, and then it would go into an overpack for disposal that looks like the test canister.

Again, the performance goals are really so the package does not crush under the high-pressure environment and it can support the package weights above it. There will be bridge plugs in between about 40 packages, but it's for structural stability and safe emplacement and handling of the wasteforms. Lifetime of the packages, as far as we can tell at this point in these environments, is approximately decades. That's very short. It's not really a post-closure performance parameter.

So what are we looking at in terms of wasteforms? It's the DOE-managed small wasteforms potential candidates, the primary one being cesium chloride, strontium fluoride capsules. I know these are more complicated than just your off-the-shelf non-radioactive cesium-strontium salts, but in terms of these materials relative to some of the other wasteforms, they are relatively well understood, straightforward materials. Also looking at untreated calcine. Other salt wastes which are more complex from electrometallurgical treatment of sodium-bonded fuels. Other DOE-managed SNF, which some of the CSNF is a good analogy for some of it, but others are metallic alloys. And also some vitrified high-level waste that has not yet been made, but that would involve packaging it for deep borehole disposal and probably facility changes, so that's way down on the potential list.

Performance goals are driven primarily by the natural system. Degradation rates of the wasteforms are not the primary barrier, although we have incorporated them for spent fuels in the previous work. We rely more directly on the geologic conditions in the crystalline basement for low solubility limits on many of the radionuclides, particularly the redox sensitive ones. Also rely on slow transport via diffusive flux and interactions with seals materials. There's retardation through the seals for some of the radionuclides, and it's low permeability and potentially sorptive reactive for some of them.

So degradation rates, previously we've looked at spent fuel. These were very slow degradation rates. We'd probably use a slightly higher distribution of those relative to salt systems that we use, datasets from KIT on degradation rates of commercial spent fuel in a salt environment. Currently what we're looking are the cesium chloride-strontium fluoride capsules. Not really any degradation rate limits on these guys. Very rapid cesium chlorides of salt that is a very, very soluble molal solubilities. Strontium fluoride may have a solubility limited control on it. It's kind of millimolal solubility. And again, as Pat mentioned, you might actually have other phases that come in for solid solutions. Cesium and strontium have aqueous ions interact with the clays, and if any of the clays are altering the zeolites in the seals aspect, that would be good. But, primarily, it's solubility limits which are low for redox sensitive radioelements and possibly for strontium in this case.

And that's about it. Thank you.

HYATT: Thank you. Okay, well good afternoon, everyone. Can you hear me okay in the back? Very good. So I'm just going to begin by thanking the Board for extending the invitation to join this meeting, and then I'll just dive right in and start talking about the role of the wasteform potentially in deep borehole disposal.

So the first point I'd like to make is a little bit of terminology. What do we mean when we're talking about wasteform, so this is a definition which is relevant to the U.K. program, so it refers to a passively safe material which ensures physical containment and chemical retention of the waste. So this implies some element of engineering design and materials processing. So we will refer to a glass as a wasteform. I would say cesium-strontium capsules are not a wasteform; they have not been designed for the purpose of waste disposal, and one should properly refer to them as a waste, because a wasteform had a designed, engineered property.

So, Rod hinted at the role. I'll explain very well the multi-barrier concept in radioactive waste disposal and the importance of the wasteform, and this arises primarily from the relatively shallow mined disposal concepts where we have uncertainties on matrix diffusion, sorption, and redox conditions in the host rocks, and the groundwater flux is not negligible, so the role of the wasteform of contributing to the safety of the facility is important because it's the primary barrier to radionuclide release and should therefore be of low solubility.

So in terms of the deep borehole concept, so apologies for my material science summary of the very complex and interesting discussion of some of the earth science we've had, but I'll break it down like this. So, static groundwaters, density stratified to an extent, long return pathways and return times to the surface for radionuclides release and reliability reducing geochemistry are some of the features. And so, in essence, the deep borehole concept relies primarily on the geological barrier. And so one of the interesting things then that one might conclude, as I extracted this from one of the reports that we were circulated with, is that because deep borehole disposal offers potential advantages regarding confidence in the performance of the natural barrier system, there's potential for direct disposal of some wasteforms, wastes, without the need for further waste treatment.

So in that context then, is the wasteform redundant? What is the role of the wasteform? What I hope to give you an idea of is that I think the wasteform remains important in this concept, because it allows you to adjust the flexibility of the concept, to respond to discoveries that you will make along the way in your program, as Rod has hinted at, the robustness of the operational safety case, and the post-closure safety case will be improved, and it will allow us to make more efficient use of the disposal system resource. So, if by conditioning the waste appropriately we can minimize the volume, then that means more packages in a given available repository space, fewer emplacement operations, and so on. And, finally, public confidence, and that's a factor I'll return to at the end.

So just looking very briefly at a very high level at some of the properties of the wastes and the wasteforms, of course, we have the cesium-strontium capsule, so high solubility of that material. Dispersibility would be high, because it's hygroscopic, obviously not fissile. In terms of the untreated Idaho calcines, solubility will be more dependent on the local geochemistry. Again dispersibility is high because these are unconsolidated wastes. Plutonium, of course, is not under consideration at the present time, but deep boreholes have been proposed as a means of dealing with plutonium stockpiles, so that's important for the U.K. So, here the issue of the fissile material might be important.

So what could be the drivers for having a robust and possibly safe wasteform, and I'll come on to passive safety on the next view graph. Well, we'll minimize the radionuclide source term; that can only enhance the post-closure safety assessment. We'll have reduced impact of container damage during transport handling and emplacement if the waste is not dispersible or soluble. Confidence in the recovery of maloperations, for example a stuck container; confidence in the waste package passive safety, so gas evolution form waste packages because you've removed the inherent chemical reactivity through your conditioning process; confidence in the post-closure criticality by the addition of neutron poisons, which can do if you are fabricating a robust wasteform, and it will facilitate retrievability if we can be sure that the wasteform itself remains integral over the desired lifetime.

So, of course you've got to trade this off against the risk and benefit associated with doing your waste processing process. So one thing I'll highlight here, and I'm just placing to something that was raised by the last panel, the alteration mechanisms of wasteforms under the conditions that we expect in the disposal zone in concentrated brines and realistic temperatures are not well known, but we have very robust wasteforms that have been developed for shallow repositories, and our expectation is, from what we understand, these will perform very well.

Okay, so why do I think passive safety is important? Well, nobody's going to hopefully dispose of a drum like this that was disposed of at WIPP down a deep borehole, but of course the reason we had the thermal excursion in this waste package at WIPP and then the release of activity outside, was because there were incompatible constituents in the waste and they reacted. So that led to a significant recovery program in terms of cost and time allocation.

Another one that's of interest is the Goiânia incident in Brazil. So, this was a theft of an abandoned hospital radiation source, a cesium chloride capsule, in a standard IAEA capsule, so something that shouldn't be easy to break into, so 44 terabecquerels of the 50 that were in the capsule when it was stolen and paraded around this town were accounted for in the recovered contamination, so 6 terabecquerels were still out there. Consequence of this: 250 people contaminated; 4 deaths; 3,500 meter cubed of radioactive waste.

So the point I want to make here is the passive safety understanding your waste package in terms of the wasteform, removing the chemical energy by appropriate conditioning, and having it in a non-dispersible form I think is very important for waste emplacement operations transport and so on.

Okay, so what could you do? I'll run through this very briefly. What options do you have if you were to desire to condition these wastes? So, some work done over 15 years ago at Missouri, Rolla University, by Delbert Day's group showed that some iron phosphate glasses have a very high capacity for dissolving cesium chloride and strontium fluoride. The processing conditions are such that very little that they can measure the cesium-strontium volatilization, and these proved to be highly durable with respect to the state-of-the-art borosilicate glass.

Interesting thing if you delve deep into the paper is that the performance of the wasteform in terms of the release rates and solubility is not very sensitive to the composition, so you can process a wide range of wastes using this wasteform and have confidence that your product will be robust.

Okay, so a different approach might be you could dissolve the cesium chloride and strontium fluoride then use a commercially available ion exchange material, such as one of these, or natural clinoptilolite just in a simple column to extract the activity and concentrate it. You could then convert this dispersible powder to a stable glass or ceramic wasteform process called hot isostatic pressing, and that has something that's beginning to be commercially developed as a mature technology for waste processing. So, these materials are extraordinarily robust in terms of their solubilities.

So, other options: One for the calcine and sodium-bearing waste and plutonium. One can use a glass ceramic material where you have a ceramic phase which has natural mineral logs that will incorporate long-live radionuclides such as plutonium, some of the minor actinides. The glass phase will scavenge all the rest of the components of the waste, and we know that we can fabricate these wasteforms to good tolerance on a scale of 20 kilograms, and then recent work has demonstrated that this can be scaled up to a hundred-liter package. That package was a hundred liters when it started its life, post-processing only 30 liters. That would certainly fit down a borehole.

I'll skip over that, just come to the summary. So, deep borehole disposal concepts place greater reliance on the geological barrier, but we have plausible materials and processes for treating and packing the potential borehole wastes.

A robust wasteform, as the radionuclide source term, will mitigate against residual uncertainties in the disposal system, so I'm in favor of multi-barriers and reliance on multi-barriers, and it should also help us make a more robust operational safety case.

I'll just close with a final point that a credible post-closure safety case should feature a mechanistic model of wasteform evolution. Even if it's not important, we should demonstrate very clearly that we understand the reactivity of the wasteform under those disposal conditions, and you should have an R & D program to deliver that. Because if it's just a black box, I don't think that invites great public confidence in understanding that we really, truly can be sure about what will provide radionuclides to the environment as a source term, so I think that's very important.

Thank you very much for having me.

SRIDHAR: Okay. In order to move things along, I'll start. I want to thank the Board and the staff for inviting me.

So we jump to the first question, how much reliance should be placed on the EBS. I've been psychologically whiplashed on the Yucca Mountain program in terms of the reliance on the waste package. First there was detailed subsystem requirements and then we were told to go away because no credit was taken for the waste package. And then when the near-field environment uncertainties increased, everybody said, "Oh, we love you man, come back. Do something." And then, you know, you do some overdesign, and so we have a drip shield and extra design features that may or may not be needed if we do a systematic approach from the beginning. So the thesis of my presentation today is that my recommendation would be to go in with some credit for the waste package and to do the waste package design more systematically.

Okay, why do I say that you need a waste package designed more systematically? Well, we talked a lot about the degradation of packers and seals, but the most important thing that I feel hasn't been discussed is the relation to the interfaces. Most engineering problems occur at the interfaces and crevices, whether a steam generator or pipelines or oil and gas production tubing. A lot of the problems occur at the crevices. So I think the pathway for radionuclide migration is not going to be the main pathway through the seal itself, but a much quicker pathway will be through the interface between the seal and the casing or between the seal and then the waste package, and the reason is because the casing will undergo crevice corrosion in the alkaline environment that could be created by the seal. And this is shown in this graph, but it's not meant for the borehole environment; this is for the Yucca Mountain study, but basically the idea here is that when the pH exceeds about 9.6, this depends on the temperature and the chemistry of the environment and so on, but at this pH you shift from uniform corrosion of the carbon steel to a highly localized corrosion. And depending on the species concentration, especially chloride total carbonate ratio, you can exceed several orders of magnitude in terms of corrosion rates. So, the crevice corrosion between the seals and the casing as well as other metallic materials needs to be carefully considered in terms of the total system performance assessment.

And this is borne by these observations: I don't particularly like this table because it gives corrosion engineering a bad name, but because it's a mish-mash collection of experiences. But these are all the geothermal well experiences by Smith and Peter Ellis, and if you look at, for example, Salton Sea, geothermal extremely high chloride concentration, very low pH; serious corrosion of steel as well as even some of the corrosion resistant alloys. And, of course, you can go down to more benign environmental conditions. But in a lot of those cases there was quite a bit of localized corrosion of the steel, so that's something that needs to be considered.

There was also microbial corrosion, but it was only observed in the surface facilities not in downhole equipment.

Okay, so how do you systematically consider failure modes in this case, and this sort of puts it in more of a thermodynamic framework, although the processes are highly kinetic and so these boundaries can shift. But, basically, the point I'm trying to make is that for any material that is a depassivation pH, and that really means that above this pH you have a protective film that reduces the corrosion rate; below that pH you have a really high corrosion rate. And for steel, the depassivation pH could be around nine-and-a-half, depending on the temperature; for stainless steel it could be quite a bit lower, but below that you have very high corrosion rate, and because of that you're generating a lot of hydrogen. And if you have sulfide reduced sulfur species on the surface of the sample, that promotes the hydrogen entry into the metal; otherwise, the hydrogen atoms will recombine and go into the gas form and so you get this form of cracking called sulfide stress cracking. And this is the one thing that the oil and gas industry worry about a lot, so there's a lot of information on this. But that occurs below this depassivation pH.

Above the depassivation pH you are nicely protected by a passive film, but you get this other cracking mechanism called stress-corrosion cracking above a certain potential, and that's something that needs to be considered in highly concentrated chloride environments.

Now, if you have a galvanic couple where you're reducing the potential of the steel below the hydrogen line then you can get hydrogen evolution on the steel, and that leads to another form of cracking called hydrogen embrittlement. So, the point of this slide is that you can put these failure modes in a systematic framework and look at it as a function of materials and local chemistry, and this shows some ways of modeling stress-corrosion cracking of a function of H_2S and chloride, so I think these tools exist.

Now, a lot of the discussion occurred about reducing environment. From a corrosion engineer's point of view I think that means absolutely nothing, because corrosion is an oxidation process and, of course, you have to support it by a reduction process. So, it really means how corrosive can an environment get in terms of corrosion potential. And so in a nominally anoxic environment, the question is how anoxic is the environment, and that really depends on the material. So, this is a low chromium stainless steel, and you can see that even 50 ppb of oxygen can raise the corrosion potential by 50 millivolts, and that really causes this material to crack. And so when we are testing this kind of a low-grade stainless steel, we go to extraordinary lengths in the laboratory to avoid oxygen. But if you can have a higher grade of stainless steel, or you can have carbon steel, they are more forgiving to oxygen. So, the anoxicity of the environment is really material and environment dependent.

There was some discussion about hydrogen generation, and I did the same kind of calculation that Gerry did, and found out that you get tremendous amount of hydrogen, but really that needs to be mitigated, because as you generate hydrogen, the local pH will increase. That'll reduce the hydrogen generation rate and also reduce the corrosion rate of steel and, of course, the hydrogen pressure will create the back reaction, so there are some opposing forces to tremendous amount of hydrogen generation that needs to be considered. I know Peter Grunfeld had done some calculations, and that should be thought about a bit more carefully.

Okay, so the next question is what characteristics of EBS are important. And, really, there is a lot of emphasis placed on mechanical failure, things that fail catastrophically, but what we need to think about more carefully is this environmental-assisted cracking problem where things happen over a long period of time, so you get these environmental effects on this mechanical behavior, slow degradation of these processes. And so that needs to be thought about a little bit more systematically.

Okay, then the third question is really what is our knowledge regarding the characteristics of these systems. And, of course, we can utilize experience from the oil and gas production operations on what characteristics are needed, okay, and my point here is that we do have modeling tools to look at these systems.

So my conclusion, based on these ideas, is really that there are many uncertainties in the performance of plugs and capsules and so on, and so I do think that you will be forced at some point to give credit to waste packages. And you might as well do it, accept the inevitable now and try to do a better job.

And the one side point I want to make is in designing this systematically we have to look at what kind of other things we put on it, and yesterday there was a mention of melting lead around the capsules that sent shivers of fear through my spine, because lead and some of these materials don't behave too well together and lead in reactor systems as well as other places have caused a lot of environmental cracking problems. And silicon carbide is bad news, because silicon carbide tends to pull the potential up galvanically, so if I were a corrosion engineer, I would say, I have a metallic object. Don't put any other electronically active things around me unless you can think about the design properly.

Okay. The only last slide I have is further consideration. I think my experience with engineering system is that it's a mistake to close things and walk away. I don't think we know a lot about how things behave in a complex environment, so I think we need to make provisions for monitoring. Of course, monitoring can be done by building satellite wells and see how things come out, but our experience in Hanford is that we have experienced leaks in these radioactive tanks. Some of them leaked 10 years after putting them in the ground or putting the waste in them, and after 60 years we still don't know what is the real failure mechanism. There is no way to find out. And we suspect that some of them are due to stress-corrosion cracking, but that would be one of the problems that would be fatigue problems because of the loading and unloading of these tanks. So I think it's very difficult in a deep borehole maybe to directly monitor waste packages. I'm not sure, but that's something that my recommendation would be to give some consideration.

Thanks.

EWING: Thank you very much.

So, following our standard procedure, I'd invite first the panelists to ask one another any questions.

SASSANI: This is Dave Sassani, Sandia. I have a question and Neil or Narasi, this is probably more in your area, but either can answer it. And it's really just kind of an "out there" question, because in these kinds of systems with these types of brines, and as we've seen in these deep fluids, you have a hydrogen pressure because you've got water and you've got an equilibrium between water and oxygen and hydrogen, and you're in a reduced system if you have magnetite in any of these rocks or if you have mafic rocks with iron titanium oxides and things like that, you create at equilibrium hydrogen partial pressure. So, it looks like any metallic aspect that we put down in the system--I'm not going to go to copper, but any iron-based metallic is going to corrode. Has anybody ever looked at forming on some kind of a steel canister an oxide layer, your passivation film sort of, but like a magnetite layer that would act as a buffer? I mean, it steps you from a very reduced material iron to a reduced material magnetite, which is not below the stability field of water and might put you more in equilibrium with what's in the rock. Is that something that's easy to do? Unlikely to work? What do you think?

SRIDHAR: I'm not sure from the borehole perspective anybody has looked at it. From a pipeline perspective, magnetite scale has always been bad news mainly because magnetite scales are defective and so they have second redox reaction within the scale. So what we have measured, for example, is if you create a magnetite scale on a steel surface and you measure the corrosion potential, which is the mixed potential to the production oxidation reactions, that potential is always higher because of the second redox reaction. And in the pipeline case for example, one of the mechanisms for stress-corrosion cracking that has happened in natural gas pipelines is where there is a scale present on the surface that is not--no. Typically when you coat the pipeline, you're supposed to blast the scale off and create a virgin surface on which you can coat. And whenever there is a scale present, particularly a magnetite scale, there have been problems.

SASSANI: Okay.

SRIDHAR: So I think creating an intentional magnetite scale may lead to unintended consequences.

SASSANI: Sure.

EWING: Thanks. Other questions among the panelists?

Okay, we'll move to the Board. Board questions?

Yes, Lee.

PEDDICORD: Lee Peddicord from the Board. A question to Neil. In the U.K. are you facing any wasteforms that we might not have here in the U.S.? I'm thinking of something associated with Magnox or AGR. And then the derivative of that is might there be some lessons learned that you would encounter those that could benefit us?

HYATT: Okay, so Neil Hyatt, University of Sheffield. So, yeah, we have an inventory. I'm pretty sure there's nothing too dissimilar, so when you run a fuel cycle the way that Western countries have who have had nuclear defense programs, tend to end up in more or less the same place. So glass, some amount of spent fuel, some metallic spent fuel, which I guess perhaps would be a bit more comparable to some of the fast reactor fuels in Idaho.

And so your second question was is there any lessons learned in terms of the management of those materials that might be relevant here?

PEDDICORD: Especially if you have something unique.

HYATT: Yeah. I don't think there's anything specific that I can comment on that, no.

EWING: Other Board questions.

BAHR: May I?
EWING: Yes.
BAHR: Jean Bahr, Board. So one of the considerations for the deep borehole disposal is the economics, and so how much are you changing the cost of this kind of a process if you do have to go to a more robust wasteform? And I don't know if that's a question for David or for the others.
SASSANI: Well, I'll just comment on the aspect of cost. Yes, I mean, one of the cost-savings aspects is these wasteforms would not be put through their dispositioned wasteform treatment that's currently on the books. And currently cesium-strontium capsule are destined to be put back into waste glass or they'd be in the vitrification process. Calcine wasteform, the disposal disposition pathway, I believe, and anybody from DOE, please correct me if I'm saying anything incorrect, that's a hot isostatic pressing process. Those involved facilities, some of which would be built for other purposes, but the hot isostatic pressing I think is primarily driven by calcine. So there is some cost savings on that end, but also, more importantly, there's handling aspects that are involved with that, worker health and safety also. So those tradeoffs would need to get looked at in detail. I don't know about these processes.
SRIDHAR: This is Narasi Sridhar from DNV GL. I don't know about the repository environment, but when we looked at

cost of materials for oil and gas production going from a carbon steel string to corrosion-resistant alloy strings, the material costs are negligible compared to the total project cost. When you look at the total fabrication and down time and all those kinds of things, they are significantly higher than material cost.

EWING: Sue?

BRANTLEY: Sue Brantley, Board. So we talked a lot about hydrogen and then we heard about methane this morning. What else can be in the gas that would be problematic? I'm still sort of fixated on the fact that the borehole is the easiest place for anything to get to up to where I live, and so what kind of gases could get up? Maybe they'll never get through the seal, okay, but if I was going to worry about something getting up, what could get up that I should be worried about?

SASSANI: I'm not sure that I can tell you what you should be worried about. What they thought about and been primarily--

BRANTLEY: Well that you should worry about.

SASSANI: I'm not sure we worry about it; I think we consider it and try to figure it out.

BRANTLEY: Exactly.

SASSANI: The hydrogen and methane I think are the two big hitters, primarily from Shaun's commentary about issues about safety even at the wellhead. I mean, there's a lot of wells that have been put in that have steels in them. You know, I don't know how common of an issue that is, but depending on what they're using the wells for they may actually account for all that already.

BRANTLEY: I guess I'm asking you to educate me about are there radioactive gases like a very trace amount that could get out or little particles or something?

SASSANI: No. At those kinds of geochemical conditions, I don't expect you to be generating any gaseous materials. On an unsaturated repository in Nevada that we evaluated, there was consideration of generation of CO_2 at the source term, but it is a very oxidizing environment. I don't think that's very likely in this case. And in CO_2 solubility in the actual groundwater would be very high, depending on the pH in any case, so I don't think you would evolve a separate phase.

You know, if I had to think about what other aspects, just from the wasteforms, that you might wonder about, having those other reducing materials in there you might think about reduction of any sulfate that's around and H_2S, but, again, H_2S solubility under most conditions is high enough where I don't think you're going to evolve a gas in any sense. So I think hydrogen and methane are probably the two big ones.

EWING: Other Board questions?

Okay, from the panelists in the audience?

Roland. Please identify yourself.

PUSCH: Pusch; Sweden. Mostly recovered because of doctor. There's a special saying used in the U.S. to cure throats, like Dr. Sloan's liniment. Used on the body, actually worked on my throat also.

This is similar to the performance of clay, so I come back to the role of the clay seals. When they're put in a borehole for separating canister units, and the questions that arose in Sweden some 20 years ago were whether the hydrogen pressure could be so high so it could displace rock as a fractured rock. And the key answer to that is that there's a limit. The hydrogen gas will lead its way by piping through the lining, to the clay isolation. And there's pressure, there's critical pressure, and almost the same as the swelling pressure of the clay. So, it's the density of the clay; it's very high, something off to 1900 between 2000, maybe 2,100 kilograms per cubic meter the swelling pressure is on the order of 10 to 15 megapascal. That's a critical pressure. If that pressure is reached by the hydrogen, it percolates through the clay in a peristaltic way, so there's a little bubble moving through, and then the channel is closed. Then not until the pressure is built up again hydrogen gas continues to move through.

EWING: All right. Thank you.

Any comments? Or you--

PUSCH: Yeah, I had one more thing. My throat was not enough good in the previous sitting here to have a comment on microbes. In fact, microbes are in the bentonite clay from the beginning, so we thought for the system that contains a certain number of more microbes that can come alive or die off depending on the nutrients that are available in the system. But the major thing is that with the high density comes the impossibility for the microbes to move through the system, because the voids are so extremely small, so there's no way.

EWING: Okay. Thank you.

Comments from the panel?

Other comments from the audience?

LESLIE: Bret Leslie, Board staff. This is a question for David and Ernie. What you've described in terms of coming up with your multiple barriers is for the undisturbed case, and I think Rod touched upon it a little bit. Unless you don't have any scenarios that have a probability of 10 to the minus 8, then you're okay. You know, you've kind of neglected the error in waste emplacement aspect for post-closure performance because of the probably that you're going to get something stuck and it's going to release and it's not your nominal case. And so you need to think about what is your dominant contributor. Is it that 5 kilometers or is it because of this low probability what are the consequences? And I understand you guys might be looking at it, but I think it's a little unfair to say the undisturbed case is really what should come out and this is what we're designing for. You have to look at the total system and all the failure mechanisms.

SASSANI: Thank you. I'm going to pass this off a little bit to Peter Swift, but I believe the undisturbed cases is relative to human intrusion, but I'm not quite positive. I'll let Peter address it.

SWIFT: Peter Swift, Sandia. And I'll try and be quick about it; it might come up again in Panel 7. But the distinction between the operational safety assessment and the post-closure safety assessment is one that is separated in U.S. regulations for better or for worse, and I think it's very likely that the largest doses will occur during operational events rather than in the long-term post-closure. I think that's actually fairly standard in the nuclear field. Risks once you get underground are fairly low.

The event of something leaking in an aquifer, getting stuck on the way down, that would actually be an operation event. It would not be an undetected event. We would know; it would be in the evening news, and it would be mitigated. People will be drinking bottled water. It would be a very bad thing. But, still, the radiation dose is not directly comparable from that to the long-term dose tens of thousands of years from now from a geologic pathway.

EWING: Okay. Thank you. Please step up. I just want to make a comment. I'm keyed by the word "undisturbed case." So, the undisturbed case is the successful case. Everything's put in place and it works. And as it's designed, the packages have a lifetime of decades. And inside the packages for the cesium chloride you have a very soluble material, which will go into solutions. So the undisturbed case is one in which at least the cesium is in solution in a brine.

Would that be fair?

SASSANI: That's correct, yes.

EWING: Okay. Thank you.

Next question.

PATRICK: Wes Patrick, Southwest Research Institute. Sridhar, you may or may not be the one who wants to field this entirely, but I was drawn to your comments that I would agree with, first, that monitoring release in and of itself is necessary but insufficient and, second, you called for monitoring the waste package, which I think is a good idea as well. Much of the discussion in two of the panels today have been dealing with the uncertainties in both the temporal variability and the spatial variability of hydrologic and geochemical properties that are going to drive everything that your panel has talked about. What are the views of this panel on what other things ought to be monitored on an ongoing basis as perhaps early indicators of corrosion processes or changes in that spatial diagram, Sridhar, that you laid out. Would that be beneficial, and if so, how might you approach it?

SRIDHAR: I recognize that to monitor waste package directly in a deep borehole you have to hang in cables or wires to do that and that may provide leakage pathways. I think this was mentioned yesterday. So there are some pros and cons that one has to weigh. But you can also measure, for example, pressure changes. Lot of hydrogen is released, that's something that you should be able to see. Potentially there could be other ways of monitoring fiber optic devices and so on. So, I don't think I have an answer. I think there are some pros and cons, but those ought to be considered at an early stage in the engineering process. I don't know whether I answered your question.

EWING: Dave.

SASSANI: Yeah, Dave Sassani, Sandia. One of the things that I've been thinking about in past couple days of discussion, and it relates a little bit to Sue's question and this one, is that with our system for the test hole, the Characterization borehole, so gas monitoring at the surface, given both helium and given that we expect hydrogen to be generated, hydrogen gas, in the field test might be, obviously, a good thing to do while you're testing in terms of the borehole and personnel safety. But even for a disposal hole once you close it and you put all the seals in place, having some kind of monitoring at the surface for gas migration out of that borehole would tell you a lot about how well your seals are performing and those kinds of aspects. And it's completely non-disturbed type of monitoring I think you could do.

EWING: Other questions from the audience?

So we've arrived at the end of Panel 6, and I thank the panelists for their contributions. And don't leave yet, because Mary Lou has instructions, so thank you very much.

M. L. ZOBACK: We ran a little bit into our public comment period and I apologize for that. We do have one person signed up, but he has deferred to the end of the day. Is there anybody else of the public that would like to comment now on what they've heard? We welcome you to the microphone.

Okay, not seeing a large rush forward. Before we break for lunch, and we only have an hour for lunch, so probably the local facility will be the best. But I want to remind the panelists and the moderators that you're meeting together for lunch. You're lunching together today to work on your key points that you will report back after we return. We'll return with one final panel looking at efficacy of deep borehole disposal and risk analysis, and then we are going to have about an hour-and-a-half long session where the panels will report back on what they have--based on what they bring to this discussion and what they've heard, their key points and recommendations, and then we'll have a closing comment from DOE.

Thank you. See you back at 1:30.

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

AFTERNOON SESSION

1:30 p.m.

EWING: If you'd please take your seats, we'll start in just a moment. All right. Let me welcome you back to the last half day of our two-day workshop. We'll begin with Panel Number 7. Panel 7, the title is Efficacy of Deep Borehole Disposal and Risk Analysis. And for this panel--we're still waiting for one of our panel members--but I should say we're having this panel discussion out of courtesy to the audience because we've already determined our highlights at lunch. Okay. And I think Bertil is still writing them, so he'll be here in a moment.

But let us begin. And the panel members are, first, Peter Swift who's spoken to us a number of times. He's a senior scientist at Sandia and the National Director of the Used Fuel Disposition Campaign for DOE.

Bertil has just come in. He's a chemical engineer by training, but he's had 40 years experience in the nuclear waste field working for Kematka Konsult. And he's been a--well, you look at his resume you'll see he's been a PI on quite a number of international projects that have to do with radionuclide transport and groundwater flow.

And then finally Richard Garwin joins us. Dick is an IBM Fellow Emeritus. He has a wide portfolio of research interests stretching from nuclear weapons to nuclear energy. And we're very pleased to have him participate.

So with that introduction, let's begin, and the first speaker is Peter.

SWIFT: Oh, you're ready for me.

EWING: Yeah.

SWIFT: Thank you. And happy to be here. I want to start by acknowledging Geoff Freeze.

Geoff, are you there somewhere in the audience? Raise your hand.

Nope. Geoff stepped out. Geoff did much of the work here, so I'll surprise him when he comes back.

And just to introduce myself, I am a geologist by training; and it was some years ago, but my academic work was actually in exposed Precambrian basement rocks in the Rocky Mountain West. I'm pretty familiar with the heterogeneity of what's out there. I know that some of the pictures you saw earlier today of metamorphics, I'm very familiar with what may be down there.

And I took a fairly linear approach to Rod's charter here. I wrote out the five questions that are in the agenda, and I'm going to very quickly actually try to say something about each of them. So these are--should be exactly what's in the agenda. I'm not going to go through them, just start right in on it.

So advantages and disadvantages of borehole disposal, the advantages side there, you can read them for yourselves. But I'm an advocate of them. I think the advantages are pretty striking: the conceptual simplicity; minimal reliance on engineered materials; the long transport pathway; the modularity, that's the "pay as you go" option, that you make your holes one at a time; and a low potential for future human disruption. That is in contrast or can be contrasted with shallower mined repositories.

Disadvantages, and these are all real: no field scale demonstration to date; unproven operations, both those are things that the field test may actually help resolve some questions about; small capacity of individual boreholes; the incomplete regulatory framework, and this last one, less amenable to long-term retrievability. If retrievability is your first priority, boreholes are probably not your choice. Another way of saying that is if you're going to put things underground, make sure you meant to. You don't plan on getting them back.

All right. Second question was dose estimates in comparison to mined repositories. And the first thing I'll say here, you can't read these and that's deliberate. They're small. Don't spend a lot of time trying to overanalyze them. That gives them more meaning then perhaps they have. The examples here, the left side here, that's a borehole. And that's an Iodine-129 dose out to 10^7 years. This is the Yucca Mountain dose estimate. This is a French repository concept in clay.

The take-away messages, all of them are below regulatory limits. All of them are, by their national standards, safe. So we're not arguing that boreholes are safer or less safe than repositories. At this level of resolution which is about appropriate from back where you are out in the audience, they are all safe.

Something that is worth noticing here, though, is that there's a whole suite of things that are released from a repository in an oxidizing environment. And almost nothing gets out of a reducing environment except the Iodine-129 and that's our Chlorine-36. It's the much lower curve there.

So what's missing there? There are no actinides and there's no cesium, no strontium, no technetium. The things that fill up this plot over here are, darn, not getting out of the borehole in our analyses. Oh, back up, sorry. One other thing, if you're trying to do rigorous comparisons of these, it's a bad case of apples and oranges. This is for spent fuel in a borehole, but it's only 174 metric tons. This is for 70,000 metric tons, and this is for--the French example is for about 28,000 metric tons.

All right. I was asked to say something about what are the key uncertainties. And with respect to this is the long-term postclosure performance. And first one, the site characterization, these are uncertainties that do get resolved or at least get reduced if not fully resolved when you actually make a hole and characterize it. So they're not the residual, irreducible uncertainties you think of as we have to live within our safety analysis, you know, after we fully characterize the site. We'll go out and do something about these. Does the site have favorable properties? Is there the old saline groundwater that we would like to find? Is there low permeability rock? Are there fast transport pathways that we need to be worried about?

Then the rest of these uncertainties are ones that are likely to still be with us after we've characterized the site. And in the natural system, iodine sorption, given in the previous plot we saw that Iodine-129 was likely to be the most mobile species and largest contributor to long-term dose. That was based on the assumption that it has absolutely zero sorption in the natural system, and for that matter also in the engineered system.

And this plot here on the right, that's a calculation of a long-term dose assuming the top curve assumes zero iodine sorption and the red one is a .01 k_d value, sorption coefficient. And the yellow curve, it's a .1. These are very small amounts of sorption, drop your iodine dose, orders of magnitude. So that's, you know, something to think about. If it's there, it's real.

Lateral diffusion, analyses to date, our analyses have not accounted for radionuclides, primarily the iodine, that might diffuse laterally into the wall rock. We'd send it up the hole. That's--if there's--as the permeability in porosity that there's likely to be in the wall rock, particularly as you get further up in the hole, the lateral diffusion is going to be large.

In the engineered systems uncertainty in the waste inventory, what's there; waste form degradation, how well will it perform; seal performance; and again, iodine sorption. If we were to have something in the seal system that sorbed iodine, we would essentially see this effect over here.

This plot here, it's a dose plot, and it shows--it was originally designed to get at the sensitivity to the seal permeability. And this was an analysis done, now, what, four or five years ago now where we deliberately raised the seal permeability to what we thought was pretty comfortable--well, it's not going to be any worse than that, 10^{-12} m2. That would be a fine--essentially a fine sand filling the hole, a fully failed seal system. And what we found, first of all, this is the Iodine-129 dose, we see some other species showing up now in larger quantities. We see technetium starting to show up, chloride, and Carbon-14, and selenium at the very bottom there.

The--so but the peak dose, the top, is actually still quite low. But it's got a characteristic shape to it here. That this is out to 10^6 years here. It's a long-time scale. That shape tells me right away that we're limited by something else. In this case it's the waste form degradation rate. When a dose curve plateaus like that, go look to see it's a release rate that's limiting it. In this case it is the assumed dissolution rate of uranium oxide that we had in this analysis. So if we had a waste form--this was a spent fuel analysis--that was dissolving more rapidly, and we had a, frankly, unlikely, improbable, unrealistic, fully failed seal system, it could have gotten higher than that.

The point of all that, these dose results are--we know what they're sensitive to. And to a large extent, those things are covered by assumption and well-informed assumption, but until we have a field test and we have real data, we're going to be living with fairly large uncertainty in what the performance estimates really are.

Go back to this one just very briefly. One of the reasons I'm not spending a lot of time trying to compare doses across these things is that I don't think that's going to be a discriminator between the concepts. There--mined repositories and boreholes can be designed and constructed I believe to be safe and produce acceptably low long-term doses. So I'm not looking for a dose estimate to tell us which one we should choose.

Effect of sustained elevated temperatures was the fourth question we were asked to comment on. And so what we have here are some model results that, again, you can't quite see them. And that's okay. You've got them in the handouts. On the left it's a spent fuel disposal case. And on the right it's cesium/strontium capsules. These are thermal hydrology results and the left plot here shows temperature as a function of time at the 4,000-meter point. That's halfway into the disposal zone. And the number of boreholes in the array determines this effect in here. So if it's a single hole, you only get a single peak and it's quite early. And if you have multiple boreholes in a disposal array, you get a second peak as the--essentially the thermal front from the adjoining holes which is the one you're simulating.

Peak temperatures there, 150, 160°C. Ambient temperature around 120 at 4,000 meters. Again, that's an assumption based on a geothermal gradient. We want to verify what that really is in the hole we work in.

These are calculated fluxes at various depths in the borehole, water fluxes, upward flux. The units are cubic meters per square meter per year. And the simple message here is as you go further up the hole, so from here going upward to shallower and shallower points in the hole, the flux decreases. It's going off laterally into the--into the more permeable upper level rocks. That shouldn't be a surprise.

Here's the cesium/strontium case. Again, at 4,000 meters peak temperatures in, again, in the 140, 160º range and the different radii of where you are at the center of the hole or 1 meter out. And the groundwater flux, again, the thermal pulse is over essentially by 1,000 years here in this case, also in the first thermal pulse is over quite early there. Again, it's a fission product decay pulse.

And that's it for me. I'll ramp up with an observation that the last thing we were asked to comment on was the effect on the DOE's program of the lack of international experience. And I'll note that actually there is significant international experience in deep scientific drilling. A lot of it is right here in the room. And the DOE is happy to draw from that experience. We are drawing from it. We are familiar with the literature. We are collaborating, for example, with the ongoing Swedish Collisional Orogeny drilling program. And we are collaborating with the team from Sheffield who is here now. But we agree, there is no international experience on implementing deep borehole disposal. Nobody has done it, therefore, we are proposing a field test. And that's it.

EWING: Thank you.

Bertil.

GRUNDFELDT: Good afternoon. I'm going to talk about a comparison between two disposal concepts. One is the KBS-3 concept in mined repository, the one that SKB in 2011 submitted a license applications for. And the other one, deep borehole disposal, of course. This is a piece of work that was completed last year. It's based on an update of the report that Fergus Gibb was referring to yesterday. Unfortunately, much of this work has been written up in my native tongue. That's Swedish which means that it's not very accessible to this audience with few exceptions.

And I'm going to focus on aspects of long-term safety. And there's a lot of other things in this broad comparison. They've been talking about siting. We're talking about construction. We're talking about handling of the waste. We're talking about nuclear safeguards. We're talking about physical protection and all sorts of things in the report. But I'm going on focus on a few aspects of long-term safety.

So this is my outline. First of all, why is SKB at all involved in deep borehole disposal? They have submitted a license application for a mined repository. Why do we do this piece of work? Then just a quick view of what are the concepts that we compare in the report. And I'm going to put, pose three pertinent questions, go through the safety functions, and then put the three pertinent questions about deep borehole disposal and see whether we can find some answers on those or not and why we are left with unknowns. And then finally some conclusions for the Swedish situation. And I emphasize this is for the Swedish situation, and it differs both politically and in terms of geology and the intermingling of those two things.

So why is SKB involved in deep borehole disposal? In 1984 a new act came in to forth, it's called the Nuclear Activities Act, and it required that any license holder or owner or a nuclear reactor should run a diverse research program necessary to take care of the waste from the reactors in operation. And directly after the enactment of this law they started a safety study of the concept called WPK which is something completely different. It's even more shallow than the KBS-3 project. And this safety assessment was run for two or three years, and then the concept was discarded.

In 1989 the PASS Project, Alternative Systems Study I think is translated into in English, was launched. And this was referenced yesterday very kindly by Professor Gibb. And this was published in 1992 then, and it contained a ranking of several concepts.

And then another issue is that an EIA, that's an acronym, that's Environmental Impact Assessment. Or rather, kind of maybe an Environmental Impact Statement and that we should have an S at the end instead. It said in the environmental code that it should involve description of alternative embodiments of this sort of project. I think I have the translation correct into English in this case. And there's been a discussion between the authorities and SKB whether deep boreholes could be one of those alternative embodiments.

SKB has sometimes claimed that this is a different strategy and as such they were not required to include that in the EIS. However, it has been requested during the process of public consultation and the handling of the license applications by the authorities that we do some work on the boreholes as well. And the ambition is to follow the international development and to evaluate the international development rather than running a research and development program on their own aiming at a Swedish facility in this context.

So the concepts compared then, that's, first of all, the KBS-3 concept. There's some text strings there in the upper figures on the left-hand side you can't read. It doesn't matter because it's Dutch and Swedish. And oh, sorry. I do the same thing as everybody else. Kind of small keys.

This one has a machine for emplacing the waste in disposal holes in the floor of tunnels. And you see here a prototype of that machine being tested in the Äspö Hard Rock Laboratory. It's a this is a concept that is becoming technically rather mature, the testing equipment in the Äspö Hard Rock Laboratory.

The other concept is a modification of the American or the Sandia reference design published by Arnold et al. in 2011. The modification comes from the fact that we do not want to consolidate the fuel to dismantle all the fuel elements then consolidate the fuel rods in the canisters simply because it threatens to create personnel doses. There's about three or four million fuel rods in a Swedish program to be handled. And some of these will be swollen from the by the in the in core operation. It will be curved. There will be curved fuel rods and so forth.

And the modification of the system then is that we added another half-inch. We went back to the design by Brady et al. to 17 1/2-inch boreholes instead. You can't read this text either from back there, but they're in English.

So for these two, what are the important safety functions? And we made a sketch here on the right-hand side showing then a canister, a KBS-3 canister in a borehole in the bottom of a tunnel, embedded in a bentonite, compacted bentonite buffer. This is a typical Swedish canister containing 12 BWR elements. I should say also we have predominantly BWR since the Swedish company ASEA-Atom was the manufacture of BWR reactors in competition with General Electric's at its time.

So and this sketch here shows the stretch of a deep borehole disposal needed for the same amount of fuel. That's 12 fuel elements. So it's two BWR elements per canister in this case. Had we stayed with the reference assigned from Arnold et al., we would have only had the possibility to put one element in each canister. And that would have increased the number of boreholes very much since we have a lot of BWR fuels.

So the main, the crucial safety function for the KBS-3 repository is the containment in a corrosion-resistant copper container that is protected from the groundwater chemistry by the bentonite in the compacted bentonite buffer. The rock is providing reducing conditions. It's been a lot of mention during this meeting that the boreholes have an advantage here. It's that they provide reducing conditions. I will make the claim that we will have reducing conditions right underneath the overburden where the bacteria has done their job chewing up the organic content of the soil. And what possibly is left after that is taken care of by minerals containing ferrous iron. So we do we are pretty sure that we have reducing conditions also for the KBS-3 case.

Low flow rates and the secondary safety function is retardation. There's been many many safety assessments have been performed for this concept, both in Sweden and in Finland. Finland is working with the same concept. And, by the way, they filed an application for a license in 2012, and this spring, their safety authority sent a letter to the ministry saying that we believe it's okay to give a go ahead for this project. So this is where the Finnish project stands right now. So there might be quite soon a decision by the Finnish government to go ahead with the KBS-3 repository.

For deep borehole disposal then, we have noted that the dimension here are such that it's hard to create an efficient engineered barrier system that would provide retardation and provide proper protection for the canisters. There's several speakers have indicated that you might change to a copper canister to increase the life of the canister in this concept. I would say this copper canister would be, lie there unprotected against the sulfide content in the groundwater and so forth. So copper would be pretty useless as a corrosion-resistant material in this concept.

Stagnant density stratified groundwater, I think that's very different. Yes? To okay. I'll go a little faster then. These other three questions, we need to pose them. Is there sites available for density stratification where this groundwater is density stratified in the right way and is not stable over time? What does the repository itself influence on the groundwater stagnancy? And what are the sealing needs and challenges?

We have worked with this model, and it's based on the information from four named boreholes. It was set up in 1998 by a group at Uppsala University, a team of geologists. It says that in the coastal areas of the Baltic Sea where the landscape is flat you have a halocline at about 1,000 meters depth. This is a little bit blurred by diffusion and so forth. But when you get further inland and when you get more pronounced topographic relief, this halocline dips. And this is the, this borehole has been referred to as Siljan by several speakers here. And that's a Gravberg borehole.

This picture has not been contradicted by newer observations. I can qualify that later on in the discussion if wanted. And then both in Sweden and in Finland we are looking at washing out and land uplift that might affect the situation over time.

Influence of deep other repositories, and you have thermal buoyancy. It has been talked about a lot and has been deemed not to be extremely detrimental to the system. And I tend to agree with that based on the modeling that we have performed. Something that hasn't been mentioned is gas evolution from corrosion of canisters and also casing tubes. There's a lot of steel surface down there creating hydrogen. And I would argue that there is a certain risk that this will strive upwards and bring with it contaminated fluid from the borehole upwards.

And this describes then the KBS-3 concept exaggerated at the position hole, otherwise to scale. And this is the situation at some arbitrary time in the future. Only a couple of canisters are assumed to be broken in the next 1 million year about.

In the case of deep borehole disposal, the canister will start to corrode. The material will get thinner, and there is about 60 tons sitting on top of the bottom-most canister. So at one time the material will be too thin to carry that weight and will breach. If you we anticipate that corrosion, the common corrosion will eat the material in about 1,000 years. It's reasonable to believe that this situation appears within, say, 1,000 years or maybe a couple of thousand years or something like that.

So we wouldn't let this is then, of course, the instant release fraction in the fuel consisting of the cesium and iodine and things like that. And this is a situation where it could strive upwards. You have breakout in the borehole like this, and we haven't seen yet really how we should do to despite Roland's comments about the bentonite and the perfectness of that. There might still channels left in this situation that are available for the upward flow induced by hydrogen.

So in conclusion, it's difficult to design and implement an engineered barrier system providing long-term containment. There is a risk of contamination in groundwater around the deposition zone within the next thousand years. Repository introduces buoyancy forces from which can create vertical transport, and there are channels available that because of the different boreholes and breakouts. And the depth complicates both site investigations and, last but not least, also the disposal process. And we have seen some of that in this meeting.

There was a question about dose calculations. And we don't yet have a full range of scenario analyses to base those on, so I would say that it's a bit premature to start to compare calculated doses which also Peter alluded to in his presentation.

All in all, we have found that there are too many question marks here to pursue this concept as an alternative to KBS-3 in the situation where SKB and Sweden is currently. Thank you.

GARWIN: So my Email address is here. And here you'll find a compilation of various papers including this one pretty soon. But I've added to the seven pages that were distributed which I think are more important comments than the ones that you have.

So you've been hearing about the experimental program in support of deep borehole disposal of smaller DOE managed waste forms. And my interest has been for 20 years deep boreholes for our disposal of excess weapon plutonium.

And there you have questions of nuclear criticality and long-term isolation with principal components half life of 24K years and 6K years respectively.

The typical 1 percent plutonium content of spent fuel provides challenging thermal problems for late times, that's for early times, but excess weapon plutonium has less thermal problem mostly because there's much less of it. So 40 metric tons of weapon plutonium is committed for disposal under an agreement with Russia, and mostly by conversion to MOX and burning and commercial power reactors. But it's good to understand for the future, for British plutonium, and so on, what the options are.

So one would start with metallic plutonium from the weapon pits, the cores of the nuclear weapons. Although, in some cases it would be converted to hydride and then to oxide for disposal. But a plutonium bearing waste of low density containing a small concentration of plutonium would drive up the cost of deep borehole disposal where volume is extremely costly. So I consider here the disposal of encapsulated metal, not pure plutonium for an important reason, but perhaps plutonium/uranium alloy with depleted uranium.

Now, here comes an interesting question because the time horizon of concern for non-retrievability is not just a few half lives, 24K years, but much longer because plutonium-239 decays to uranium-235 and eminently weapon-usable fissile isotope with a half life of 700 million years. None of us will be around. The human species will not be around. Who knows what's happening there. But nobody would allow us to put weapon-usable uranium into the ground, so one needs to worry about it. This will not be weapon-usable uranium because it will be diluted with depleted uranium. So it will be low-enriched uranium.

Now, I think that a lot of programs have suffered because we haven't done the exploratory work even though we're not going to be able to continue with every program, but we need to do more exploratory work in general. And let's see here. So these are,these are the questions. To what extent can the integrity of engineered capsules, steel for strength surrounded by a thin layer of copper or gold, perhaps, be guaranteed for 50,000 years or more? And to what extent can the resulting low-enriched uranium be guaranteed against criticality with thermal neutrons because of neutron absorbers in the rock? But we already have some experience of uranium going critical in the ground two billion years ago in Gabon where the low-enriched uranium was in the range of 3 percent because it hadn't decayed. And probably for 100,000 years these natural reactors operated at power of about 100 kilowatts in a kind of percolator mode.

But it's in the security and environmental interest of all the world's inhabitants to reduce the nuclear weapon threat posed by stocks of civil or military plutonium. And even though our Department of Energy has no deep borehole program in mind for disposal of plutonium, the experience that we gain this way may be helpful.

Let's see. So instead of the details of package design and criticality calculations for the disposal, I'm going to show you some remarks on the basis of things I heard here. So under the reducing conditions at 3 to 5 kilometers' depth, there's a likelihood of hydrogen bubbles from the steel of the casing and of the capsules to come up the borehole through cracks. And as Bertil just showed, it can reach the surface. But this ought to be evaluated including the scrubbing of any untrained radioactivity by the large surface area of the torturous path. And counterintuitively, taking measures to increase the local porosity of the crystalline rock in the disposal zone so that the waste can access a cylinder of 5 meters diameter centered on the borehole rather than the borehole itself of half-meter diameter might eliminate the formation of hydrogen bubbles and resulting transport via buoyancy. And it would not increase the overall transport through nominally unfaulted rocks.

Now, as I commented, the seal concept of rock melting appears vulnerable to the shrinkage-produced cracks in the rocks surrounding the melted and refrozen rock as well as to the microporosity in that surround rock associated with the 570ºC alpha-beta transition in quartz.

A third point, a second point is if a satisfactory technical approach is found for the experimental wells and the definition of a disposition program, it will be carried out by individuals and contractors with human and corporate properties and tendencies. So BP and its associates have paid tens of billions of dollars in damages and fines for the consequences of the deficiencies in cementing, testing, and other inadequacies. And the outright cheating by Volkswagen on its emissions-control software are only two examples that mandate that DOE or whatever agency carries out the disposition activities must have and must exercise current insight into the detailed conduct of the program.

Finally, is the concept of multiple barriers optimum for deep borehole disposal. If seclusion by dense saline fluid at depth is effective and sure, is it worthwhile to investigate and to invest in lesser engineered barriers other than casing removal and nominal seals on the well? The waste package emplacement would be accompanied by the supply of dense saline fluid in the dispositions zone to maintain from the start the density gradient barrier. But the flow of water along faults in the disposal zone can convey dissolved or suspended waste to large distances horizontally, nominally horizontally.

Even if such flow cannot lead to the surface in the vicinity of the borehole because of the fluid density, the acceptability of spreading of waste to large distance at the depth of 3 to 5 kilometers must be evaluated. So you can get rid of the hydrogen transport probably by increasing the porosity to a few meters in the neighborhood of the borehole, but you don't get rid of the possibility in any of these approaches, from flowing water through faults in the disposal zone.

So thank you very much, and we'll all accept questions.

EWING: All right. As is the standard practice now, I'll open discussion first to questions among the panelists.

SWIFT: You know, we should have been ready for that. And you go ahead. You go first.

EWING: Okay. Don't be polite.

SWIFT: Yeah. And I'm

EWING: Because we've presented two very different perspectives on the same topic, yeah.

SWIFT: I'll take a question then. Peter Swift, Sandia. The question I have has to do with your models, which I have read your reports. I'm familiar with the analysis you did on hydrogen gas generation and bubble flow through the annulus upward. But it wasn't clear to me what happened in your model when you, when you exited the top of your waste disposal zone. And it's my belief that as those bubbles--and I agree, hydrogen gas, if it's inevitable, if you have corrosion in oxygen-free environments you'll get it.

But I think to the extent that we get hydrogen being generated, it will migrate upward in the annulus until the reaches more permeable rock where it will laterally diffuse. And I don't think it's going to go all the way to the surface as an intact bubble. I think as soon as it hits overlying strata, be it sedimentary rock or more fractured granite where the permeability is sufficient for it to migrate upward, it's going to. And did that happen in your model?

GRUNDFELDT: Bertil Grundfeldt. We actually didn't. We stopped short of modeling the fluid dynamics in the system because that's a very complicated model, rising bubbles that are, you have a large difference in densities between the stagnant fluid and the bubbles themselves. That's one difficulty. The other difficulty is that bubbles tend to coalesce and all that sort of the things. And you have a large difference in hydrostatic pressure from the bottom to the top which will cause the bubbles to expand and also to vent out. So we stayed short of that in the analysis. But the Swedish situation is, maybe in geological situations, may be a little bit different from the American situation. We have the crystalline rock all the way up to the Quaternary layers in a large portion of the areas that could come into question for this. So everything that was between Precambrian and Quaternary is washed away and has formed an alliance in Germany.

EWING: Okay.

SWIFT: Do you want it back?

GRUNDFELDT: Not necessarily.

EWING: All right. Dick, you have a comment?

GARWIN: Yeah. Dr. Garwin. Yeah, Peter, I've thought about this. And first you have to use three dimensions. So where it says plug flow, it's not plug flow because in three dimensions the bubbles are going up and then, a different azimuth, the fluid is coming down. So it's not driving it ahead. But we're engineering this disposal system and just as I proposed, increasing the porosity at depth in order to get rid of the bubbles all together. Surely you should communicate from the borehole to the formations at the top above most of the seal structure to avoid the hydrogen coming out at the top. Or at least you consider it.

EWING: Okay. Peter.

SWIFT: Yeah. I'll add one more thought on that, that gas generations issues are not unique to boreholes. Anything where you put iron underground in reducing environments you are likely to get gas generation corrosion processes. What's unique here and I find this refreshing is that the problem is the boreholes are too tight, they're too good. And I'll take that criticism happily having worked for more than a decade on a repository project that was fully gas permeable. It's refreshing to have one, I had it early in my career also on WIPP, but the problem was it's tight enough that maybe you do have gas pressure build-up. And, you know, it's, but it's not a unique problem. Any repository has to at least be aware of this possibility.

EWING: Okay. Other questions amongst?

GRUNDFELDT: Bertil Grundfeldt. Yeah, I agree. It's not unique. It's been an issue in low and intermediate-level waste disposal for decades. But it's a mechanism in addition to thermal buoyancy that might create a vertical driving force through the borehole, also for contaminated groundwater, not only for gas, for a gas phase. So it needs to be included in a future safety assessment to all the system.

EWING: Right. Other points amongst you? Okay. Let me pose a question maybe to stimulate discussion among the three of you. So you've done essentially what we've asked, that is to comment and compare the different strategies. And so we see dose curves. And you gave the appropriate qualifications to, you know, don't read them too carefully. But still we have the dose curves which show that everything works regardless of the approach taken. And then there are lists of advantages and disadvantages which one could quibble over, but still they make sense.

But I guess my question is if we have different kinds of waste in the United States. We have a lot of different types of waste, that's part of dilemma for the U.S. program, and we have different geologies for mined geologic repository are a deep borehole, how should we conceptualize the comparison? You know, what is it, dose? Do we just want to get the doses calculated more, I won't say accurately, but more completely? Is it a list of pros and cons? Or is there another way to conceptualize the problem of different types of waste, different types of disposal strategies? So any comments are welcome.

SWIFT: Well, and perhaps one of them should answer first. I do have an answer.

EWING: Okay.

GRUNDFELDT: Yeah. Bertil Grundfeldt. We were, at the beginning, there was a wish from the safety authority to produce something that could, let's call it the safety assessment look alike in order to qualify the systems selected by SKB. We were reluctant to get into that because there's a tremendous lack of knowledge about the, how the world down there looks and works. So any safety assessment at that point in time would have been pure guesswork.

So instead we embarked on doing this comparison of more qualitative comparison but backed up with what if calculations on certain things that we felt that we had a handle on. Like, we could look at the gas evolution. We could look at what happens in, if the canister gets stuck in the hole, like a "what if" scenario. We could look at the thermal buoyancy. We could do, make an appraisal of what you, your scientific data there is, and so forth. So all of these issues we could handle and back the comparison with all.

EWING: Okay. Thank you.

Dick.

GARWIN: Dick Garwin. Well, having thought about this conceptualization, but I think that dose probability distribution is the answer. Now, in order to determine dose probability distribution you have to go into great detail for every option. And you need to do engineering variations on those options in order to reduce the metrics for dose probability distribution which is not the average dose but maybe the maximum plane crash dose, you know, would get people's attention. And went on to divide between the dose to the general public and the dose to the project personnel because those have different impacts as well.

But I think that what has been missing in all of the discussions thus far is what was mentioned by Mark Zoback and maybe a couple of others, namely, the fact that this dense saline water really does flow in the couple of kilometers of disposal zone. And I didn't see any analysis of the value or the penalty associated with transport of waste to large distances in that zone.

EWING: Okay. Thank you.

Peter.

SWIFT: Yeah. The question I think, Rod, came down to how should we choose among these options for different waste forms.

EWING: Essentially that.

SWIFT: And I don't think we're in a position to be choosing at this time. Tim Gunter made the point in his opening remarks that our goal now is to expand our options, now to multiple, viable options. We're not trying to limit our options. We're not trying to select the best option. We're trying to make sure we have enough options because, frankly, we have relatively few right now for disposal in this country. And if we can add one more to the table, that would be a good thing.

I don't disagree that any of our existing high-level waste forms could go to a mined repository. There's isn't something out there that can only go to a deep borehole. And I think there are a variety of mined repositories at work. I don't think you need a special repository for this one and a special one for that one. But the more we can do that will give us more flexibility, more choices we could make, that would be a good thing.

One other point there, the DOE isn't and no other agency is going to pursue a disposal option if analyses show it to be unsafe, either operationally or in the long term. That sort of is a given. So we, it isn't necessarily a question of which one is safer. The one that's implemented will be safe, at least in the context of meeting applicable regulatory requirements.

Then the question is how straight forward is it to demonstrate that safety? Can we make a convincing case for it? Can we convince you, for example? And those are, those are real questions.

EWING: Yeah. Good. Thank you. So let me throw it open to questions from the Board.

Yes, Sue.

BRANTLEY: I just would like to hear you, Sue Brantley, Board. I just would like to hear a little discussion of the retrievability issue. Seems to me that the deep borehole idea maybe has issues around retrievability. Would you be able to get the stuff back out?

SWIFT: Sure. This is Peter Swift. I'll take it first, but others also. In my mind retrievability is primarily a social question. And, therefore, in the end, a political one, do we want to be retrieving it? I've seen arguments from some that it's too easily retrievable, for example, weapons material. Even a borehole is too easily retrievable. Well, I take the common sense approach that I think most of us do that if retrievability is your first priority, a borehole is probably one of your last choice options because it's going to be harder. It's not going to be impossible.

During the operational period as long as you've got the hole open and the hole is fully cased, you haven't pulled casing yet, there are engineering techniques for going down the hole and fishing things back out. Are they perfect? No. But they're pretty darn good, actually, at getting stuff out of the holes. Once the hole is sealed, yeah, it suddenly got dramatically harder to get anything out of it.

But we could make choices in sealing that would make it either harder or easier to recover anything out of the hole. You could basically design the hole with seals that were very difficult and they would divert your reentry away from the target zone. Or they could tend to focus your reentry attempts back down the hole. And so there are choices we could make there depending on what the policy goal is.

One last thought there, that we really need regulatory guidance on this one. And, Dan Schultheisz, thank you. A great presentation this morning.

There still is an ambiguity in the precise wording of the assurance requirements in 114, 191.114 which do not apply to an NRC-regulated facility. So we have to go to the NRC to find out what the retrieval requirements are, not the EPA. And we're so I mean, we are waiting to hear on that basically.

EWING: Okay. Other responses on retrievability?

GRUNDFELDT: Bertil Grundfeldt. We have just said that this is obviously harder from in a deep borehole than in a mined facility. Both projects would be costly and difficult to carry out, of course, but it's definitely harder in a deep borehole.

EWING: Another question?

Mary Lou.

M. L. ZOBACK: Yeah, for Bertil. My question is looking at your, it was a great presentation to summarize everything the way you did, so I really appreciate it. And looking at your direct comparison, the KBS-3 concept and deep borehole, the issues regarding safety seemed to be around the conditions in the borehole. But I thought I'd heard, and maybe I just misheard that there was also a lot of concern about emplacement.

GRUNDFELDT: Yes.

M. L. ZOBACK: Did that factor into the decision too?

GRUNDFELDT: As I said, the comparison we did was much broader than the long term. We have a chapter on siting. We have one on construction. We have one on handling and handling safety. We have one on long-term safety. We have one on nuclear safeguards and physical protection, one on timeline and costing and so forth. So we tried to cover the whole set of a project to see where do we stand with this concept; where do we stand with that concept? What is the difference in maturity in the two concepts and so forth?

M. L. ZOBACK: So did you carry out a quantitative risk assessment to compare which factors were more important than others?

GRUNDFELDT: Not really. Not really. But with regard to handling safety, we did a back of the envelope calculation of what the doses could be if you have a canister or a string of canisters stuck. And we back calculated what the probability could be for that to be acceptable where there is criteria that we had in the switch regulations. And that was the background to my question yesterday about the probability of success and failure that was calculated in fault tree analysis.

M. L. ZOBACK: Okay. Thank you.

EWING: So let's open questions to the audience panelists.

Yes, Fergus. Please identify yourself.

GIBB: Fergus Gibb, University of Sheffield. A couple of questions for Bertil, I guess, on hydrogen generation.

The first one is if the annulus around the base packages is filled with the material that is less permeable than the host rock, where is hydrogen likely to go? And the second one is that as we heard this morning there could well be a significant amount of hydrogen already in the host rock. So why will the hydrogen generated by corrosion not just equilibrate with that and migrate out in the far field?

GRUNDFELDT: It could well go into the far field. Well, the first question is that, the answer to that is that we have been working with the reference design published by Arnold et al. in 2011, and there, you really have a drilling mud in the annulus itself. So we haven't analyzed molten lead or anything like that. And of course, hydrogen might go into the rock. We haven't precluded that at all.

We have, as I said, stayed short of actually analyzing the fluid dynamics of the transport and look down there to generation. And the results we came to is with the assumption that we have regarding the corrosion rates and things like that is not, after one, two, three years, something like that in that order of magnitude, the hydrogen partial pressure will reach the hydrostatic pressure and start to form bubbles. And the amount of hydrogen will in the order of a hundred years be sufficient to empty the void space of the drilling mud in the hole. So that's the sort ofthe range or the order of magnitude of the amount of hydrogen that you have. And you have it's actually three surfaces of steel corroding, and that's the canister outer surface of the canister and both sides of the casing tube.

EWING: All right. A last question from the panelist or audience? So we're right at the break. So we'll break now. I want to thank the members of the panel. And we'll start promptly at 2:45, and the panel reporters should be at the front. Thank you.

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

KEY OBSERVATIONS

M. L. ZOBACK: Okay. I see we've got everybody pretty well-trained. When the music begins, you all know what to do. So thank you. We're moving now toward the closing of the workshop, and I know many people have planes. I know a few people have already had to leave. But we now have about an hour and 15 minutes allocated to, I think, a really important portion of the workshop, and that is letting our panelists now reflect back to us, to all of us, all of us in the audience, what they feel, based on their presentations but also listening to other presentations, what they think the key observations are on their topical area regarding the planned deep borehole test project, but more importantly, deep borehole disposal in general.

So we have asked one member, usually self-appointed or so nominated by the other two, members of the panel to make a presentation. This was, these were largely done over the lunch hour. I think some panels started a little earlier, but so don't expect them to be very exhaustive. But not only do we have these observations summarized, Eva our new, I would say, swift runner--went back to the office, had them all duplicated, and you all have copies of them. So this is pretty unusual in a meeting to have a summary of everything before the end of the meeting. So first of all, I want to say that's really a first for us and a very exciting first. And the only constraint the panelists were given was that they had to be able to present it in five minutes. So that kept things pretty short and crisp and concise. And I've looked at the recommendations, and I think they are that.

So I'm going to just let you all know who's coming to keep things moving rather than introducing people one by one. I'll ask that when they come up they can remind people who they are. But basically we voted that foreigners speak better for us than we do. Four of the seven are non-U.S. Claus Chur will be speaking first for the panel on drilling experience. And Claus is with his own consulting company now, long-time drilling engineer. Next, we'll have Doug

Minnema from the Defense Nuclear Safety Board, and he'll be speaking on the emplacement issues. Then we'll have Nick Collier from University of Sheffield, U.K., speaking about borehole seals issues. Panel 4, Mark Zoback, geophysics professor at Stanford University will be speaking about the hydrologic conditions at depth. Panel 5 will be reported by Kirk Nordstrom from the USGS, hydrologist with the USGS, a hydro aqueous geochemist--let me get my terms right--from the USGS. And then Neil Hyatt also from University of Sheffield, U.K., will be talking about Panel 6, the multiple barrier discussion. And finally, Bertil Grundfeldt from Kematka Konsult in Sweden will be covering the issues related to efficacy of deep borehole disposal and risk analysis.

So we'll begin with Claus, and you each have five minutes. Thank you.

CHUR: Yeah. Mary Lou, thank you very much. On behalf of the Panel Number 1 members, Steve Hickman, Eric van Oort, and myself, I would like to thank the organizers of the Review Board for an excellent workshop. I think the presentations and contributions from the audience were really high class. And I also would like to thank the--your staff for having organized a perfect workshop here.

So what are the key observations of our panel? Oh, I have to switch it on. So that's probably what can happen in your borehole. Oh, here we are.

So we found that the drilling of the wells is such, from a drilling perspective, is feasible, can be done, will be done, and actually no new technology is required to perform the drilling program. I think, we think it's a very good approach that the proposal is to stick to the industry drilling standards and practices. This makes it at least much easier on the drilling sites. It does not add additional complications we would find in other parts of the project.

We recommend that you should use state-of-the-art technology, not looking so much on the dollars, but taking the best technology which is required or fit for purpose, especially to do the directional control, minimize vibrations in the hard rocks, use downhole motors, automated drilling systems. Also check on the availability or suitability of PDC bits and others. Also remind that crystalline rock is sensitive to water similar, not the same, but similar, like in sediments. So you must design a proper drilling fluid. You certainly cannot drill just with water with respect to the breakout bore stability issues.

Secondly, plan for the unforeseen. Develop drilling, completion, and a sealing plan based upon real downhole conditions. An idealized homogeneous granitic basement under low differential stress just does not exist. You should also anticipate high differential stresses which then finally leads to the breakout situation we have seen during the workshop in a couple of slides.

You will likely experience fracture zones with probably heavy fluid influx or even losses. You should plan also then what consequences that would have for the drilling process and be prepared not only for the drilling process, but also for the completion and emplacement of the canisters and the sealing there afterwards.

Stress and permeability measurements should be performed as an integral part of the drilling program. And even if unlikely, however, blowouts can happen. So again, plan for the unforeseen and plan accordingly.

Our third observation is that an integrated approach is needed for the whole lifetime of the project, for the drilling, for the completion, and the emplacement phase. And when we say project leaders need to own entire process, I think we're coming back to the point from Richard Garwin early made this afternoon with reference to BP and VW. Certainly you can subcontract services, but you cannot subcontract responsibilities. So the lead of the program must stay in--the hand of the project leader must stay in DOE if that is the one which is selected.

Very important and I would like to underline the point Peter Swift made earlier, the regulatory requirements for retrievability have to be made clear for the people who have to plan on the project. I think any uncertainty here will only cause additional money and will cause additional problems for the scientists and engineers involved in the project and will be difficult to resolve later. We also recommend that a peer review on the drilling program should be done including a comprehensive risk analysis.

Observation number four, field test site needs a detailed, 3-D characterization combining all available surface space and downhole methods. You should select the location then for the field test to be most likely representative for potential disposal sites in the U.S, so try to achieve a maximum transfer value. If it then comes to the point to the waste disposal sites, each waste disposal site will also need one or more characterization holes and use an adaptive well design based on the site-specific situation.

The last point, many questions still remain about seal design and implementation. What's the impact on breakouts, tensile fractures? What is the role of time-dependent failure and thermal stresses? How do we test integrity of the seals over long time scales? And what's the sensitivity of cement, for example, and other sealing components?

Last point, you might consider to increase the engagement in geomechanical and geological aspects of the project. Expand your efforts to characterize geologic and geomechanical risks. Better involve experimental rock mechanics and fracture/fault characterization, hydrology and geophysics. And it's just an idea, as an example, there is a lab in Switzerland in Grimsel who is working on these sealing issues between steel casing, bentonite--sorry, smectite and crystalline rock at depths.

Finally, we would recommend that a long-term, downhole monitoring is established to ensure containment at relevant time scales. Thank you very much.

M. L. ZOBACK: Thank you, Claus.

Next Doug Minnema from the Defense Nuclear Facilities Board Safety Board.

MINNEMA: Thank you. I guess I didn't step back fast enough when it came our turn to pick speakers. Oh, it was already on the first page.

We have--the first point I want to make, and it is a repeat point that you've probably--you've heard a few times already. You will hear it again. I don't think we can emphasize enough the need to design and execute this field test as consistent as possible with existing or anticipated regulatory requirements. They really drive all of the data needs that you have and things that you would have to be able to demonstrate if you want to demonstrate capability. We've actually added one more objective. We originally talked about placing design and science objectives at an equal footing. We've added operational to that also because I think all three of them need to be viewed equally in the process. They should not be subservient.

Simulate all aspects--we debated a little bit the word "all," but simulate all aspects as best as possible. If you're going to treat this as a demonstration of a nuclear disposal system, you really need to try and ensure that you have demonstrated all of the key elements of a nuclear disposal system.

And I'm emphasizing engineering controls, and we, again, can't emphasize that enough. Administrative controls are very vulnerable to failure when you least want them to fail. So engineering controls or elimination of hazards are really your first priorities in all this.

And buttons are too sensitive on this. It jumps back and forth very fast.

Solidify the emplacement mode recommendation. I think where we're looking at here is right now the current design talks about either one package or 40 packages in a drill string. It seems like to us I think we are looking at the two extreme ends. And one has advantages and disadvantages. Forty have advantages and disadvantages. Is there a happy medium in between? I think a little bit more analysis. So we think more analysis going into that and taking into account the near surface operational complexity and risk would be very helpful for you.

Also I think in our panel and also in one of the other presentations, there was discussion of additional other ways of emplacing material besides the wire line and the drill pipe. And I think we would strongly encourage that you go--that the project go back and look more at those and develop some rationale as to why they've chosen what they've chosen.

As you know, our panel was focused specifically on the emplacement mode of the activity. What we would strongly encourage and the three sub-bullets here are examples. Spend a little more time thinking about the measures that you could put in place to mitigate the risks during that emplacement mode. For example, hanging 40 packages from a drill and drill pipe, it's actually going to, as currently envisioned, it's going to hang there for about 40 days until you get that pipe fully assembled. There are risks associated with that sort of thing that you, we would encourage you to spend some more time with directional drilling, monitoring descent rates, various tools and capabilities over there.

In terms of organizational culture and safety, this is actually a very important element that will come back and haunt the project or the final operation if they don't think about it early. So we would encourage that you'd consider designing your organizational structure to support the culture of safety that you want within the facility. It is an organizational problem. It is not an individual training problem. And so we would encourage you to think a lot about that as you go through the project because that will help lay the foundation for how it actually gets done in real life.

Associated with that as you do your field test operations after you've drilled and when you start thinking about practicing emplacement, various modes, you really to want have a strategy for how you're going to integrate the handling of the packages along with the remote handling capabilities and the nuclear aspects that you're going to have to deal with in real life. Again, it's something you want to focus on ahead of time.

And then the last thing we want to say, plan for contingencies. Now, DOE is, as I said yesterday, DOE is a dynamic environment. Schedules, budgets change very regularly. You want to provide provisions to recover from minor and major events remotely. And you want to recognize that the little things can turn into big things very quickly. Thank you.

M. L. ZOBACK: Thank you. Next up, Nick Collier from University of Sheffield on seals.

COLLIER: Yep, seals. Thank you very much.

So and now we're trying to summarize what we discussed in our session yesterday was not very long. So apologies if we've left things out and certain things were fresh in our minds yesterday. So we sort of focused our key observations and also taken it a bit further and made a few recommendations as well. So I'm sorry, I'm just going to say a few words about here. Does it matter which of these I use? Okay.

So we start off by sort of summarizing the current concepts, and rather than leaving the hole open after drilling, the concept involved, assumed process. So our drilling engineer, Paul Bommer, recommended that of course, it be filled well with compacted solid material using cementing techniques including squeezing and verifying cementing seals outside of casing. So to do--basically, to do as good a job as you possibly can do if that's the way that it's going to go.

Similarly, the current concept uses drilling, well as far as we could make that, or we're aware the concept, drilling mud to seal the packages within the disposals. And then that's just basically a mixture of water and bentonite. Sorry, Roland, for using that word again.

So we recommend here that assessments of other materials is made. And I went through some of the possible matrices that are being investigated, the lead-based alloys, cement grout, compacted bentonite. I'm sure that there are others as well.

So then we've gone to some further recommendation. So consideration should be given to other advanced borehole sealing concepts like some of those that, again, we discussed yesterday, the rock-welding concept and compacted bentonite systems. That's for the sealing of the borehole above the disposal zone, the work being done by Olympic Research in terms of thermite seals. And, you know, hats off to the DOE. They are following this up as well. They are funding work on these things.

Just a couple more I think. So some further recommendations, so we recommend detailed seal development and testing programs. We touched on, briefly, long-term testing and how to possibly accelerate methods to carry out performances testing. I think that's quite a big one here. How do you do that? I mean, just like with the GDF concept, how do we test for performance over hundreds and thousands of years? It essentially needs assessment methods to work up for that.

That can fit in well with modeling. I know it's just as well I'm not a modelist. I won't even begin to recommend ways to do that. I'm sure there are--in fact, I know there are modelers out there that could put forward suggestions for that. But that could be used to assess long-term performance.

And last but not least, I think this might be the most important one, we need to know what it's like down there. We need to know the composition of the groundwater, if the hole will be flushed with water after it's been drilled. We need to know how long it will equilibrate for the density and the salinity stratification to reestablish itself. We need to know temperature and pressure. So that we felt was quite an important point as well.

Okay. I think that's it. Thank you very much.

M. L. ZOBACK: Okay. Thank you. Next Mark Zoback from Stanford University.

M. ZOBACK: Well, Panels 1, 4, and 5 all dealt with geologic characterization, so you'll see some overlap. Available evidence indicates that drilling emplacement and monitoring strategies must recognize that high stress levels, potentially active faults, and highly permeable fractures and faults persist to 5 kilometers depth. These features represent potential pathways for migration of gases and brines.

Transient hydrologic phenomena such as gas generation and seismicity can significantly increase permeability. This has been documented in crystalline rocks in the upper few kilometers and may also occur at greater depths.

Measurement of permeability and formation pressures may prove to be very difficult within the disposal zones due to borehole quality, heterogeneity, and very low permeability. We anticipate that a long time will be required for hydrologic testing and characterization at any proposed disposal site.

Adequate assessment of heterogeneity at a proposed disposal site should include multiple Characterization Boreholes and contiguous measurements within the disposal zone.

Emplacement strategies, monitoring and safety assessment will need to be adapted to deal with hydrogeologic heterogeneity encountered at the site in question. And long-term groundwater residence times in millions of years inferred from environmental tracers in pore fluids, such as noble gases and various isotopes, do not preclude the potential for active flow through interconnected permeable pathways from disposal depths to the near surface. In other words, the pore fluids can be old, but you can still have permeable pathways in the near vicinity. Thank you.

M. L. ZOBACK: Okay. Very concise. Panel 5, Nick Nordstrom from the USGS, and Nick--Rick--Kirk--I don't have my glasses on, whatever you are.

NORDSTROM: You got it. We got it.

M. ZOBACK: I probably got it.

NORDSTROM: Again, I'd like to thank the Board for organizing this excellent meeting, very much needed, and should be very helpful for all.

Take home messages, to keep them really simple, we embrace some keywords and phrases used by previous people. For example, Steve Hickman used the word "surprise." In geochemistry when we look to the subsurface, same thing. Wherever we go we found surprises.

Secondly heterogeneity, everyone's been using that word. Same thing in geochemistry.

Third thing, to use Mark Zoback's phrase, we embrace realism as well. Just deal with what you find.

So very quickly, we have a verbose panel here, obviously, can't control themselves. But we emphasize the need for careful coordinated planning among geophysics, hydrogeology, geochemistry, microbiology--I forgot to put rock mechanics in there. Sorry. And that's very much needed for sampling analysis and the modeling work.

It's important to introduce multiple tracers during the drilling and emplacement of waste so we know how much was down there, how much is mixed with the background groundwater.

Measure everything. Don't necessarily know beforehand what will be useful, so there's some betting that's involved. You know, make your laundry list and then say, okay, here. We think these things are really important.

Make a priority list.

Next, the importance of slanted boreholes for characterization, we certainly support that. Otherwise, you have a very high probability of missing a permeable fault zone. And more than one, multiple boreholes for characterization and monitoring.

You need large-scale hydrogeological characterization and modeling for long range transport. Sue was very insistent on a very good question which is if we identify that there's this high salinity, reducing groundwater down there at depth, isn't that sufficient to say that's a good, stable environment? And I said maybe, but we're talking long-term here. So the hydrogeology is really important. It goes with the geochemistry. And that means large, regional, hydrogeologic picture needs to be done. Part of that would be collect baseline data, gases and solutes for example. There's usually some shallow wells around. That will help your investigation. And then try to get a groundwater model on a regional scale to get a big picture of how far could that deep stuff really go.

Need borehole tests that are more realistic for storage of radioactive waste, heater and tracer experiments. And always ask yourself the question of what do you need to make it a successful and translatable proof-of-concept project.

Next, how will drilling and emplacement of waste alter the subsurface conditions? Clearly it will. How much and how does that disturb the geochemistry that has to be monitored and watched? Gases will be present and it could be a safety storage concern in repository or near-surface environments. And that's been talked about.

I'm very glad that Narasi talked about metal embrittlement because I'm familiar with that, and that's a very dangerous thing and needs to be considered.

Deep borehole disposal, cesium/strontium solves a short-term problem. This may actually work out pretty well for that in my opinion, but there's longer-term issues. And if you're using other types of radioactive waste, that changes the problems and the things that you need to consider.

What are show stoppers? They would include things like if you find low-salinity water, say less than sea water; if you find detectable oxygen; if there's evidence of young meteoric water at depth in your system; if there's an upward hydraulic gradient; soluble pathways which may be caused by gypsum dissolving in the fracture; large fault zones and fracture zones, of course; and high heat flow.

The next one we really didn't talk about, reverse geology. But we think we've been talking about maybe sedimentary or even some metamorphic rocks above a crystalline basement. But there are crystalline basements that are above sedimentary rocks. We know this happens. We don't know if we go out into Kansas whether we're going to see one of those or not. But the only way you're going to find out is when you drill that deep hole. Where do these things occur? They've been found in Appalachia. They've been found in the Himalayas and a few other places. They're older, thrust-fault zones where older crystalline rock comes across sediments.

In some locations saline fluids closer to the surface may also have dilute waters at depth. So not only reverse lithology, but reverse hydrology has been encountered. So if we anticipate that we might see these things, that's a surprise that we can get ready for. It will likely take several years to adequately plan for coordination of sampling activities with the drilling.

And finally, the last one here, predicting solubilities and mobilities, we have a good start down that path of having properties that we can use to predict solubilities and mobilities. We just need to improve them. So there should be more work on that aspect as well. Thank you.

M. L. ZOBACK: Thank you.

Neil Hyatt, University of Sheffield for Panel 6.

HYATT: Okay. So to run through our observations--can you hear me okay?

M. L. ZOBACK: Yeah.

HYATT: That's okay? Okay.

So the DBD concept is intended to be multi-barrier but with primary reliance on the geological barrier. And the conclusion of the discussion in our panel was that more systematic consideration of multibarriers should be carried out at an early stage. To do this, ideally we need a good understanding of the geochemical environment to achieve this to understand the interaction with the engineered barrier system. But we recognize this has considerable uncertainties, and that's been outlined very nicely by Panel 5. So these difficulties could be mitigated by more robust waste packages and assigning appropriate credit to performance. So there is a performance credit there to be realized we feel.

Surface monitoring of gas production would be valuable to assess evolution of borehole seals and engineered barriers. And also, monitoring of Eh and pH during operational phase would be helpful.

So a key advantage for deep borehole disposal of cesium/strontium capsules or possibly a driver is potentially earlier disposition, but this is subject to uncertainty. So when I reflect on the discussion we've had over the last two days, you know, when I walked in I had a sort of--I guess I had an anticipated time schedule of maybe a decade. And that, to me, on reflection seems rather optimistic. So I think what's come out of the discussion between all the panels is that we should plan for that to be some considerable time I guess.

So if that opportunity for earlier disposition goes away or the driver goes away, then are we really sure that a near-surface disposal strategy for cesium/strontium capsules perhaps might not be more appropriate. So in that case these capsules probably would be acceptable for direct disposal after extended storage to allow decay heat to dissipate, otherwise, could require some alternative treatment.

So, in fact, you know, when I reflect also on the U.K. program, the concept of decay storage is become more important. So we have fuels sitting in reactors we're allowing to undergo decay storage. And also in the Scottish disposal policy, near site, near surface storage is a central tenet.

Okay. So conceptual--there's a conceptual safety challenge in assuming initial--the initial repository state involves dissolution of radio cesium/strontium in solution rather than being retained as a solid. So that seems to me at least to be rather weak ground to be starting from. Materials and processes are available to adequately condition proposed wastes for deep borehole disposal to improve passive safety.

Understanding wasteform evolution under deep borehole disposal conditions is a knowledge gap, including absence of associated thermodynamic solubility data as pointed out by Panel 5. The seal/liner/rock disturbed zone is a likely pathway for radionuclide migration. And conceptually this is thought to be within engineering capability to manage, but this remains to be demonstrated.

Microbial degradation of engineered barriers in the seal zone could be important and is not well understood. And ultimately, reliance on engineered barriers should be proportionate to the performance capability.

So thank you.

M. L. ZOBACK: Great. Thank you.

And Bertil Grundfeldt for the final panel.

GRUNDFELDT: What do you say, last but not least?

M. L. ZOBACK: Yes.

GRUNDFELDT: So we've chosen to summarize the points of view here under the various questions that were issued in the program. The first one was advantages and disadvantages. And the big advantage, of course, is the claimed passive safety that the system is meant to introduce. A big "but" is that there is neither site characterization nor safety assessment yet performed, and this has been pointed out by other authors. And safety assessments and the interaction with design is very often an iterative process and very necessary iterative process. I suspect that after this five-year program by DOE, there will be a need for a next program and a next program and a next program before we arrive at an operational facility and in between safety assessments.

Calculated doses mean little without developed concept and site. And also we need to have a developed set of scenarios to work with in a safety assessment. We need to conceptualize the models that we use in the safety assessment.

Expected uncertainties was the next question, and it was commented in the group that operational risks are likely to dominate. My comment is that postclosure risks may well pop up when we have a better understanding of the scenarios that need to be assessed. We have a knowledge gap in that sense yet.

Effect of sustained high temperatures, well, it's hard to tell. It depends on waste form, and it needs consideration of course. You have material issues. You have fluid issues. You have all sorts of issues with temperatures. But I don't think that we have a final consensus on that point.

How would lack of international experience influence on the DOE program? Well, of course, there's no benchmark available, so DOE is first in line for this particular concept. So we wish you good luck. Thank you.

M. L. ZOBACK: Okay. We have a considerable time now for some discussion of what we've just heard. Let's see. We've got about half an hour. And, I'm sorry, I was going to come up here. Is this one on? Both of them, yeah.

As the panelist are getting their seats and their identities assigned to them, I first want to invite any of the panelists that maybe feel like a point they really wanted made maybe was glossed over a little bit. I think everybody did a fantastic job, but is there anything any of the panelists might like to add to what was heard, what was reported here? All right. Good. That was an amazingly efficient lunch meeting today. I think everyone--huh?

Oh, Fergus. All right. You didn't get to eat lunch with them did you?

GIBB: No.

M. L. ZOBACK: Okay.

GIBB: Yeah, Fergus Gibb, Sheffield. Just a small detail, really, about the characterization issues. One of the things that I believe is very important to characterize is the damage zone around the borehole. And it's not an easy thing to do, but it's important to know both the extent of the damage zone and things like its permeability. And it's fairly well-recognized in the drilling industry that depending on how you drill the hole, you have some control over the damage zone.

For example, if you percussion drill, then you create a pretty big damage zone. The other extreme, if you core drill with diamond bits, you minimize the damage zone. And one of the side benefits of coring is that you create a damage zone outside the hole, but you also create one in your core which better is the one outside which you can bring back up and get a handle on how severe the damage zone is likely to be.

And I would say when it comes to the time to drill both the characterization hole and the full-scale demonstration, please, core some of the disposal zone.

M. L. ZOBACK: Okay. Thank you. I think I'll ask Claus Chur if he'd be willing to respond to that.

CHUR: Yes. Certainly coring probably is the drilling method which gives you the most information in all kinds of respects. However, coring as you know is frequently done in the mining industry. It's more diameterous. So it won't be possible or difficult to get down to 5 kilometers. It has been done in the KDB project down to 3 kilometers, but there's a special design to wire line drilling, drill string, and coring equipment. However, as you propose, and certainly I think it will also be considered that certain sections of the well will be cored, absolutely.

M. L. ZOBACK: Okay. Mark, did you want to make a comment?

M. ZOBACK: Yeah. Well, I keep trying to separate, you know, whether we're talking about the test facility or an eventual repository site. But--

M. L. ZOBACK: Both.

M. ZOBACK: Yeah, in the latter, you know, with--the idea of there being multiple characterization holes, obviously coring would be an important component of any science program.

I think a tougher issue to get our--you know, any kind of constraint on is the issue that Steve Hickman talked about. We know mathematically that as breakouts form, they want to keep forming. And the way they stabilize is that the rock deforms inelastically behind the breakout and absorbs some of the strain energy. This is why breakouts tend to be more severe in crystalline rock for equivalent stress and strength ratio, you know, values is because they have less ability to absorb the strain energy ductilely than, say, sedimentary rocks.

And so we are going to see the, you know, the failure zone, but there's going to be a failure zone behind the failure zone which is not--you know, the rock hasn't fallen into the well bore, but we have enhance permeability there. And that's something, you know, I think we should start thinking about. I think we can do laboratory tests. I think we can do modeling and sort of anticipate that. We have a couple--you know, we have a couple years to work on it and start thinking about that very seriously. Because seeing one or two orders of permeability outside the zone that is clearly broken out might not be unreasonable.

M. L. ZOBACK: And I just wanted to add that, you know, this was a major issue brought up with regard to the seals as well. So--

HICKMAN: Yeah. And this is Steve Hickman, USGS. Just to amplify in that concept, I think it's important to test seal performance under the real biaxial horizontal stress that you're going to see at 3 to 5 kilometers which means being in the borehole. Laboratory tests are going to be important. I agree looking at stress relaxation in cores is going to be important, but that's an isotopic expansion. The differential stress behavior around a borehole is going to very much depend upon how deep you are, how the rock behaved brittlely versus ductilely and the horizontal stress ratios and amplitudes.

So seal performance in the lab is one thing, but the ultimate test is going to be downhole at 3 to 5--or 2 to 5 kilometers. Or 2 to 3 depending on where your seals are.

M. L. ZOBACK: Right. Okay. Claus.

CHUR: Well, I'm going to comment on the coring. Of course, it easily can be done on the characterization hole, but with respect to investigation of the near borehole damage zone and the 17 1/2-inch, that is really a challenge. It hasn't been done so far. The biggest cores which have been drilled in--as I'm aware of both with the KDB, they're both 10 3/4. Of core section in--for a specific application, such a core barrel could be built. But it only can be, I think, used very few times because it's very expensive.

M. L. ZOBACK: Good. Any other points? This is everybody's workshop. So I really encourage those of you in the audience that heard things that you feel are important that maybe didn't come up here. You know, come--

Dick, thank you.

GARWIN: Richard Garwin, Panel 7. So I wondered on the coiled tubing approach the problem announced there was fatigue life of the tubing, but it wasn't very expensive anyhow. But it seems to me if you just double the arc radius over which the tubing is deployed and the radius in which the tubing is coiled repeatedly at the drill site, you will eliminate fatigue as a problem because fatigue life goes exponentially with the stress. And that could reduce the stress. So I'm asking the emplacement panel that question.

M. ZOBACK: Okay. Nick?

COLLIER: Yes. I'm not on that emplacement panel, but I'll attempt to answer. Yes. It would make sense, would it not, to increase the radius would reduce the fatigue. Yes. That's all I know on that. I'm afraid that I don't know anything else on that one.

M. L. ZOBACK: Fergus, you were the one that brought it up. Do you want to--do you have anything to add?

GIBB: Yes. Fergus Gibb, Sheffield. Yes. Absolutely right. I mean, you can take measures to reduce the fatigue on the coiled tubing. You can also play around with the diameter and the wall thickness. And strangely enough, the smaller the diameter, the less the fatigue. Of course, the less the load it can take. But basically, that's right. You can take measures, but at the end of the day--we got some estimates. I can't remember the exact figures, and I can't remember whether it was in pounds or dollars, but 4 or 5 kilometers of I think it was 2 1/2 coiled tubing and without electrical conductors, the cost was somewhere between 150 and 250,000. I can't remember whether it was pounds or dollars, sorry. But it doesn't make that much difference.

With that particular tubing you could get I think it was 170, 180 round trips. And to replace the tubing it's working out around about couple of thousand pounds or dollars, round trip, which is nothing.

COLLIER: I think it is worth considering, also--can I just add one more point.

M. L. ZOBACK: Sure.

COLLIER: That it's not brand-new--this sort of kit. So I'm surprised it hasn't been sort of discussed more because it's being--there are geothermal--well, country, that's in New Zealand that I've been to, and they're using it there for a whole host of applications, not just to get things down there or get cement down the hole. They're using it with water-driven drill bits to cut through scale, et cetera. So it should be considered I think.

M. L. ZOBACK: Okay. Good.

Paul and then we'll go to Ernie.

TURINSKY: Yeah. Mary Lou, I'm going to ask the panel to do something. You can say no, that's not appropriate.

M. L. ZOBACK: Okay.

TURINSKY: I would like each member to list the top three items they think that DOE should focus on this program. What are the three major items? And I'm curious to see what the consensus is. And think outside of your particular group you were associated with.

M. L. ZOBACK: Would you guys like a few minutes to think about that, and we can go to Ernie's question? Or do you want to just--

COLLIER: Oh, I've got mine now.

M. ZOBACK: Let us go to Ernie's question.

M. L. ZOBACK: Ernie's question? I think it's fair. I mean, that's a great question. But let's give them a little time.

Ernie, don't ask a question that everyone has to answer. They're thinking. They're working.

HARDIN: Hardin from Sandia. I just want to make few observations about coiled tubing.

M. L. ZOBACK: Oh, okay. Oh, okay. Yes.

HARDIN: And I accepted the panel's recommendation by the way. We will have a look at that and specify our comparison to other methods. So but the--I wanted to point out that first off that we're going to use coiled tubing if we elect the--if we select the wire line method anyway. So there are a number of trips that are built into the process in addition to the one trip per package. So that puts a little bit more emphasis on the fatigue lifetime of the tubing.

And the other thing I was going to point out was that the oil and gas industry, we shouldn't sell them short. They have optimized the configuration of coiled tubing, handling equipment, and so forth. And, you know, some of these units are extremely large. And the question was raised during our discussions about whether we could count on getting them to a remote location. What sort of road do you need to get a truck that weighs 90,000 pounds to your location? Thank you.

M. L. ZOBACK: Just almost as much as the waste weighs;

right? Okay. Any more questions?

Peter, comments?

SWIFT: Yeah. Peter Swift, Sandia. And this is a comment. It's actually an expansion on something that--and I apologize to Bertil. One of our bullets was a little short there on that screen, the one where we said that thermal effects need further consideration. And I just wanted to elaborate a little bit on that. I would have brought it up in my discussion. I felt we ran out of some time there.

The thermal effects are usually considered separately in the seal zone where this is no heat source and in the waste zone where there may be a heat source. And so we see, depending on what kind of waste you have in there, peak temperature rises of say 30 to 40°C in the disposal zone. But very modest rises up in the seal zone. So heat induced damage in the rock is probably not an issue in the seal zone. It may be an issue in the--it will be an issue in the waste disposal zone. And heat induced effects, material degradation, again, they matter in the disposal zone. Probably not so much up in the seal zone. And anyway, that was my comment.

M. L. ZOBACK: Okay. Good. Thank you. Are you guys ready to do your top three? I think Kirk actually gave his top three before he gave his long-term list. Have you changed them? Do you want to--let's start, let's go that way across the table.

NORDSTROM: Yeah, okay. I agree. The first thing that we had down there, and I've expressed it more or less the same way in my notes here, careful planning and coordination. And there's--with respect to two things. It's been brought up that, you know, we need to know what the regulations are in order to have objectives. So there's often two objectives, one are regulatory ones which we need to find out about and get those in place. And the other one is good science because good science is not necessarily embodied in the regulations. If you have the good science, then you'll do a good job and you'll get the kind of justification for characterization that you need.

I would add to that which somebody else mentioned earlier a peer review of the different operations that are going on. Peer review during all phases of the planning and the execution, and monitoring and so forth by independent people, people who don't have a stake in it or don't have any conflict of interest and so forth would be really valuable.

M. L. ZOBACK: Okay. So that's your three?

NORDSTROM: Well, that's what I have right now.

M. L. ZOBACK: Okay. Well, that's fine. I had--before you made your statement you said--these are the three things I had written down--but you said except surprises, expect heterogeneities, and embrace realism. So--

NORDSTROM: Yeah, those--yeah. You can write those down.

M. L. ZOBACK: Okay. I've got them. Thank you. Thank you. Next.

COLLIER: It might not surprise you to hear that my top is we need to have some efficient sealing. Without the borehole being sealed properly, it can't then rely on the geology to ensure that the concept works. That's my top one.

The second one is characterization. We need to know what it's like down the borehole, where you put your waste containers. Groundwater composition, heat, temperature, et cetera, how it's all going to move or change over the thousands of years that we're considering. And just an aside one as well, a third side one, if we're drilling a 17-inch borehole 5 kilometers deep, it would seem obvious to perform some sort of experimentation down there in terms of the sealing assessment.

M. L. ZOBACK: So some sort of monitoring--

COLLIER: Well, no--

M. L. ZOBACK: Actually, experiments.

COLLIER: Yeah. That's right. A program to investigate sealing concepts down the borehole once the actual work that's being scheduled has been done.

M. L. ZOBACK: Okay. Good. Thanks.

Okay. Next, Doug.

MINNEMA: I have to speak for myself here. Obviously, my panel members have not conferred on this question. But I think what I sense and I do come at this from a different approach to many of you in the room, what I sense here I think it perhaps a project that may have bitten off more than what it can chew once we've all sat down and looked at the issues involved in what they're trying to do. There's a lot of--there's a lot of good thoughts here, a lot of things that need to be done, but DOE has already decided how much money they're going to spend and how many years they're going to commit to this effort right now. And I sense that those two goals are incompatible with each other at this point.

That's not to say don't do it. That's not to say don't spend the money. What it is to say is go back and relook at the scope of what you're trying to do here, and make sure that what you can accomplish within the limitations that the project has can move this effort forward in a good approach and a good path. You may not get to the point where you can you say I can go from here to a final facility. But you certainly can move it forward to the point where you can say, oh, now I know what I need to know. And I think that's my sense here. And maybe that's three points rolled into one, but I'll leave it there.

M. L. ZOBACK: Okay. Fine. Thank you.

Mark.

M. ZOBACK: My three points are emplacement, emplacement, and emplacement. You know, the issue of whether the annulus is going to be open or not around the canisters is really complicated. You have 2 kilometers there, and if you leave it open, you can dissipate the gases, but you're also open to pathways that are going to exist. And so there's a real conundrum there. If you seal it then what--you know, how do you accommodate the gas and other things that will happen as the canisters and the casing degrade? So you got to figure that out because you're going to design this hole from the bottom up, and that's happening at the bottom.

The second was mentioned a couple times in that there has to be some sort of decision on time scales. And it's related to the third issue with respect to emplacement which is retrieval. You know, if, in fact, all of the canisters are going to be disposed of over a couple of months according to what we heard from NRC, that means that then you say, yes, you're ready to close, and everything changes from a regulatory concept.

But does anybody--you know, if you're thinking about retrieval, I think most of us are thinking about retrieval over a longer period, and how that can be anticipated and accomplished with a borehole scheme is really challenging. So if it's not an issue, then it's very easy to deal with. But if it is an issue, you have to know it and put it into the plan right from the beginning.

So I think the entire emplacement strategy has some really fundamental questions, some are policy and some are engineering. But they have to be dealt with I think before, you know, you're going to make much progress; not with the pilot project, but certainly with the plan for any borehole repository.

M. L. ZOBACK: Thank you.

Neil.

HYATT: Thank you. So looking outwards from where I kind of usually sit and see the universe, I guess one thing that struck me about the discussion we've had is that the selection of the right drilling approach and the right drilling strategy and understanding this issue of the kind of borehole breakout, the damage to the borehole as you created sort of then sets you up. You know, that sets basically the disposal environment. So I think, you know, effort on that should be a priority.

So and then sort of thinking the next step would be--is looking to have a very well-thought-through strategy to characterize the geochemistry in the disposal zone. That seemed to me to be very challenging, a lot of factors to get a handle on. And then those two things together allow you to make a judgment as to whether engineered barriers are something that should feature heavily in terms of where you put your safety credit. So I think those are the three priorities that I would see.

M. L. ZOBACK: Great. Thank you.

Next, Bertil.

GRUNDFELDT: Yeah. Bertil Grundfeldt. Okay. If it comes to prioritization here, I think we should realize that this is probably not the final research project. We need to prioritize what is being looked for based on safety assessment results. And that's where--those are likely to point out what parameters, what entities are important for--in the investigation programs.

When it comes to design we heard several comments in this meeting that material choice and material has an effect. We need to understand the coupling between choice of material and system performance in a good way.

And finally then, this is a question that has been asked by others. In a continued program I think we need to know which problem we are solving by introducing deep borehole disposal.

M. L. ZOBACK: Okay. Thank you.

Claus.

CHUR: Considering that the characterization hole is--part of this characterization hole is scheduled for September next year which I would say the site characterization is of urgency because it's only ten months left to put every, let's say, geologic information which is available in the USGS and that other agencies put together all that information on the stress field, on heat production, and so to select. And then probably you need also a regulatory approval process to get the drilling allowance by a mining authority or whatever. I mean, alone these approval processes I think--I don't know in this country, but they may take a couple of months.

So yes, site selection characterization is a thing of urgency. Second point as it has been addressed earlier for me, it's sealing, sealing, sealing. There must be--put much more thought, in my view, in the methods of sealing and how it works. And last but not least, how it can be proved. I think that's a very difficult one that's been addressed. And specifically also not only in the hole itself, but also in the near borehole damaged zone.

And last but not least, get clarification on the retrievability issue. If that will be a legal requirement, I think the changes to the program or the challenges of the program--is it required only during the emplacement phase? Or is it really to be required after the borehole has been sealed? I think these are issues which should be clarified as soon as possible.

M. L. ZOBACK: Thank you very much. That was excellent off the top of your head. Even Neil was answering other questions while he was coming up with this. So that was wonderful.

I think--I don't have a watch on. How are we doing on time? I think we probably still have a little more time. Okay. We still have about ten minutes then.

Lee.

PEDDICORD: Lee Peddicord from the Board. Something that's kind of striking that was raised in Panel 1, but I think maybe it blends over to the other issues that were considered in the other panels, maybe beyond. And it's kind of the following. You talked about the opportunities using technology, directional drilling, downhole motors. One can take these holes anywhere you want now and have some confidence in them.

Every pictorial we've seen had these bore holes going straight down 5 kilometers. Why? Are there opportunities by--to other consideration? Are there ways to optimize the performance of this using these technologies? Is straight down the best way? Or you mentioned--somebody mentioned the inclined, the opportunities. But if you are, like, really going to do this, might you want to turn it? Might you want it horizontal? Might you want to go back up? I don't know. But why--why would you want to go straight down 5 kilometers?

CHUR: May I answer the question?

M. L. ZOBACK: Please.

CHUR: I'm glad that you raised the question. That is not a requirement. It was--in the KDB well, it was a requirement to reach extreme depth in that case. It was bent for over 10 kilometers. You get--if you have deviated or let's say crooked boreholes you get extreme torque, and you can't reach the depths. So at that time it was required to drill a perfectly vertical borehole.

With today's drilling technology, of course, you can drill deviated borehole and for let's say for the real depository I could imagine that from one site you drill a couple of wells, and then they, of course, will then be deviated. Then it just requires a careful planning on the deviation, on the build up so that the emplacement process is not hampered in any way, but it can be done. It must not be vertical.

PEDDICORD: So let's speculate. You take this down and you bring it up. You bring it up maybe, I don't know, a thousand meters or something, then your whole issue of seals is very much different. If gas and going to go anyplace it's going to go up. You've got all this basement rock above it and so on.

CHUR: I haven't thought about that. You too.

M. ZOBACK: You know, you could fracture the rock. You could induce slip on preexisting faults. I mean, you've got to plan for--

PEDDICORD: There are ways to optimize this thing. Other parameters.

M. L. ZOBACK: I think Bertil had a comment.

GRUNDFELDT: Yeah. Bertil Grundfeldt. That way when it comes to the disposal holes, we have very clear, at least in the Swedish program, that they should be straight and vertical because of the--not to obstruct the emplacement of the canister circles. But then with the investigation boreholes, that's a different story. There you're much more free.

M. L. ZOBACK: I had thought that the emplacement panel actually suggested that maybe slightly sloping holes might help with the descent rates. Is that right? Yeah.

Do you want to say something?

MINNEMA: I'm not the expert on that, but my panel did suggest that. So I have to--I will try and address it. The issue there is to--with a slight angle on the hole, one could slide the packages down into the hole instead of drop the packages down in the hole. You would have better control of the descent raise, minimize the action of something falling in and crushing. And I think that was when we had heard the discussions about various slanting in the holes. And I think Mark MacGlashan's was thinking about that too. That was the idea there was a slight slant would allow one to emplace easier by reducing descent rates.

M. L. ZOBACK: Bertil.

GRUNDFELDT: I think this is an issue where you should reiterate it with safety assessment also because sliding it down might scratch the canisters and things like that. Depending on the material and thickness of materials and whatnot, the way you--it might have long-term effects from that or not. Thank you.

M. L. ZOBACK: Any other comments related to that issue? No?

Linda.

NOZICK: Linda Nozick, Board. I heard the comment a few times about a translatable test. And I think it's a very important idea. What are the most important things that need to be accomplished in this so that it is translatable?

M. L. ZOBACK: Okay, Bertil.

GRUNDFELDT: Drill at the right site, where you put the waste. That's the site near that needs to be characterized. That's the only way of being translatable I guess. We've heard a lot of heterogeneities and site specificity and about chemistry and hydrology and whatnot. That would be my view.

M. L. ZOBACK: Any other comments on that point, anybody? Okay. Other questions? Other comments from anyone in the audience? You all have participated so you all have a chance to weigh in if you have a comment to make.

Bert--Bret. I'm doing really bad with names now.

LESLIE: Okay. Mary Lou. This is Bret Leslie from the Board staff. And it's really just a quick question for DOE to explain something in the schedule which is how long will you have to determine your site characterization plan that you heard these guys talk about? It's very important. What's the full-time frame of--you have your science objectives. When--how long of a window will you have to actually plan for what you're actually going to characterize downhole? And it might have been in Tim's slide. But I think it--no, it wasn't? Okay. Can you address it at least?

GUNTER: I can take a shot at it. I don't have the schedule in front of me, but basically what--this is Tim Gunter, DOE. One of the first steps when we bring on our contractor is to prepare and finalize our drilling and test plan and roll in all the characterization that we would do. I can't really get into the details of that because we're going to be developing that in partnership with our new contractor. But on the order of four to five months I would say. A lot of it depends on when we actually have the contractor on board and in place. But based on the schedule I show, we're hoping that's early next year. If we have a September drilling start date, we have several months to get it approves.

M. L. ZOBACK: Could you clarify something for us? We had this discussion in the drilling panel. People have--groups have submitted proposals to you all, and is that a one package thing that they propose the site, the personnel, and the drilling contractor, that's all a package? So whatever site you choose the drilling contractor has already been predetermined. Is that correct or not?

GUNTER: All right. I'm thinking carefully about my response because this is an active procurement. So I can only tell you what has been made publicly available through the RFP.

M. L. ZOBACK: That's all I'm asking.

GUNTER: All right. And so what we asked for, short answer, is yes. It would be a site, a drilling management--site management services, and then also either a driller as a partner or the ability to bring on a drilling company as a subcontractor.

M. L. ZOBACK: Okay. That was the question. I have one question, DOE directed, related to Richard Garwin's talk about plutonium. And I understand that the Deep Borehole Field Test is carried out by NE, Nuclear Energy, within DOE. But--and plutonium is the responsibility of NNSA, National Nuclear Security Administration. Is that part of DOE?

GUNTER: Yes.

M. L. ZOBACK: Oh, so why isn't plutonium being considered for disposal in boreholes?

GRIFFITH: It's not--it's not any--

M. L. ZOBACK: Oh, no. I understand that. But you're all DOE, you're a big umbrella.

GRIFFITH: I don't think that's been considered--

UNIDENTIFIED SPEAKER: Microphone, microphone.

M. L. ZOBACK: Oh, sorry.

GRIFFITH: Andy Griffith, Department of Energy. I don't think it's been considered at the upper levels of the Department of Energy--

M. L. ZOBACK: Okay.

GRIFFITH: --and sufficient for a decision to be made. But it certainly, you know, technically, from a technology standpoint it's feasible.

M. L. ZOBACK: Okay.

GRIFFITH: You know, it's worth considering.

M. L. ZOBACK: Okay. Thank you.

Lee.

PEDDICORD: Lee Peddicord from the Board. About 15 years when we were going the plutonium disposition evaluation, boreholes was one of the options considered at that time. And it may be reconsidered because other issues with MOX fabrication and so on. So it's not necessarily going away.

M. L. ZOBACK: Okay. I just--Richard brought it up, and it was left hanging. And I felt, yeah.

EWING: Just a follow-on comment, more recently than 15 years ago, just a few months ago the Red Team reviewed various options for plutonium disposition. Deep borehole was on the list but not recommended.

M. L. ZOBACK: Who did this? The Red Team? That sounds ominous.

EWING: The Red Team is--if you look in the back of the report you'll see the cast of characters.

M. L. ZOBACK: Red, interesting.

NORDSTROM: Kirk Nordstrom, do you know why?

EWING: I'm just reflecting to--so the analysis really didn't--the recommendation was--from the Red Team was to dilute the plutonium and then put it in WIPP. Okay. So it was very interesting because at least--and there were a number of options, but the two geologic options were deep borehole and WIPP. And I would recommend you have a look at the report because this decision didn't involve any consideration of the geology, geochemistry, or hydrology.

M. L. ZOBACK: Okay. Thanks. Well, I think it's time that we move toward closing of this workshop which will be with a response from DOE. But I really to want thank these brave panel members that stepped forward, but all of the panelists for all of the amazing input we've gotten the last day and a half or so, and DOE for their contributions in setting the stage. So, again, thanks.

Okay. We are now going to hear, as I said, from--back from DOE. I am very pleased that we have to give the final or closing comments Andrew Griffith from--the Associate Deputy Assistant Secretary for Fuel Cycle Technologies within DOE Nuclear Energy Group, and we look forward to his comments.

And after we hear from Andy, we will have a period of public comments as well.

GRIFFITH: Thank you, Mary Lou. And I'd really like to extend the Department's appreciation to the Board for what I would consider an outstanding workshop. I think that the dialogue has been excellent. It's been candid. We've received--had the opportunity to hear people's unvarnished opinions and thoughts on the technology. And that's always welcome in any department R and D program. And just to emphasize, we are talking about the field test here. We're not talking about any future possible placement.

And along those lines, though, I'd like to thank Mary Lou and Bret. I think you were the two, kind of ring leaders in organizing and shepherding this workshop. And I think a workshop like this doesn't happen by accident. So I think your efforts should be recognized. So thank you very much.

The panelists were great. I think Professor

Pusch's enthusiasm last night kind of stole the show. But I think all the panel discussions were, like I said, outstanding. I think that you've given us a lot of food for thought, and I think our initial reaction is not to rebut or defend anything that was initially thought of. I think we need to take the inputs kind of as they were delivered with the best of intents. The, you know, ultimately we believe that if we keep an open mind and we do prioritize properly, we're going to get the most out of this project which we are budget constrained. We are schedule constrained because people are expecting us to deliver some answers sooner not later. It's not a perpetual science project, but we definitely want to get the most out of the investment. And the U.S. taxpayers certainly deserve that.

And I think on top that you assembled world--you know, experts from around the world which, you know, what more can a project ask for. Usually, you know, we get a couple years into a project. We gather our initial thoughts. We kind of start down a path. Then we bring in some experts and say well, what do you think. And they say, well, you should have done this. If you only would have done this. And here you basically presented the opportunity to have all that up front. So I think, you know, overall that's of great benefit to us.

Now, I'm going to deliver a bit of a commercial for the Office of Nuclear Energy, and I think it relates to this project specifically because this is how I basically describe our R and D program. What you see here is--you know, I'm an engineer, so I like flow sheets and chart and so on. But basically it shows a nuclear fuel cycle as an energy system. And it shows in very summary level the interconnected pieces of that nuclear fuel cycle.

Of course, we've got the specific technologies. We have the fuel--Office of Fuel Cycle Technologies which deals with the fuel cycle in the light blue, while the colors aren't really easy to see here--okay. So these light blue boxes here, here, and here, they're working on technologies that are more in the future for a sustainable nuclear fuel cycle in the future. We do have some efforts on advanced accident tolerant fuel for light-water reactors that could be deployed sooner, perhaps. But then we also have the Office of Reactor Technologies which is developing light-water reactor sustainability activities and the advanced reactors of the future. But they're all interconnected. The reactors are the workhorse of a nuclear energy system. That's where the power is produced. That's where potential industry uses could be produced, but they don't exist without a fuel cycle.

And then we have the back end here, and they're kind of shaded in a different shade there because we do have accumulated waste today, and it needs a disposition path.

But also as we go forward and we develop future nuclear fuel cycle systems, they should consider future disposition paths and technologies. So--and of course, they're all tied together with safeguards and security by design throughout because we are dealing with material that needs to be handled safely and protected.

But besides the technologies, they need research capabilities, so we do have a Technology and Operations Office in the Office of Nuclear Energy that's providing the research capabilities. We have Enabling Technologies Office which engages with the universities in the industry in the U.S. which is a tremendous benefit to us. And we have international partners, so there's an office that helps us work with our international partners as well.

So extending that further, so the nuclear fuel cycle works as a system. And I've heard it iterated throughout this workshop, we believe that the borehole technology also has to work as a system. And it's not just the technology post-placement, it's while it's operating, while we're thinking about operating the facility, while we're thinking about the research that needs to go in the field test. All the components do have to communicate and work together. So I think on the larger scale, the fuel cycle interconnects and just translates to all the different components that we've heard about the last two days on borehole technology.

So next I'm going to go through the agenda chronologically, and I'll just touch base on a couple of activities there. And I'll return back to the--enough of my commercial. I'll return back to the Board's logo, so it's not distracting from the contents of the workshop.

Dr. Orr I thought gave a great overview of what our--what we envision for an integrated waste management system going forward. I'll touch base on just the consent-based siting portion of his talk because I think it's really important to reemphasize. We believe that the way forward is to develop a consent-based siting process and that such a process is not black and white by any means. I think there are many ways to develop or implement such a process, and different communities might see it looking many different ways. And so part of our quest is to find out, okay, what will work in our situation for one of the facilities or any of the facilities within an integrated waste management system.

Now, for the field test, the consent-based siting process was very, very simple. Basically, we put out a request for bids. And people came, responded to that request with a site. So it was really simple. But, of course, the constraints were pretty simple as well. There's no expectation that any radioactive waste would ever be placed in that field test. In fact, we said that it would not be part of the fuel test; however, going forward, it doesn't necessarily preclude it. It's just that, clearly, as we move to projects that are dealing with actual radioactive waste, the bar gets a little higher. And that consent-based siting process is going to be more robust than what we did for the comparatively simple field test. And we do have work to do within the Department as we continue to develop what a consent-based siting process would look like as well as, you know, clearly, any start of a process like that would include an extensive outreach and input from the public as well as other interested parties.

So next, Tim Gunter, David Sassani, and Ernie Hardin did, I think, a very nice job of providing an overview of our initial plans and what we thought was important for the field test. And I think it really set the stage for the discussion. But I think part of that--I'd just like to pull out one comment that was made.

Susan, I think it was from you, and that was that language is important.

Words are important. And really, the suggestion that we're confirming, preexisting thoughts or opinions that I don't think that's really the case. Really, we need to determine the feasibility of the technology. And if it takes, you know, our existing cost estimate and our existing schedule or it takes more, that's something we're going to have to consider in the future. Like I said, we're operating with budget constraints. We're operating with schedule constraints. So really, the objective is to deliver the best information as soon as possible within the available funds.

You know, and it really is a balance between the research urgency and the quest for sufficient knowledge because, you know, I think in, you know, we may never be satisfied with knowing everything about the feasibility of geology for this, but the question is do we know enough? Do we know enough to go forward? And that's kind of the ultimate test I think.

And then, yeah, let me talk a little bit about engagement with our regulators: Environmental Protection Agency and the Nuclear Regulatory Commission. We have not yet formally engaged with them. I think based on Dan's comments earlier today, they're aware of what we're doing. We're aware that they're aware of what we're doing. We're not quite ready to engage with them in a meaningful way, in our minds at least. Clearly, if they have questions they know how to reach us. But clearly, the intent is that we start that dialogue. And as soon as we are comfortable with having enough information that would make worth their time, we are going to definitely reach out and ask them to weigh in.

And I know there's also been some communication at the higher levels of our agencies as well. We're all in resource-constrained environments, and, you know, we want to make sure that we're all using the best--we're making the best use of all of our time and resources.

Then yesterday, the lunch talk, Dr. Gibb, you gave a great overview of the international activities. I really appreciate that from, you know, a great historical perspective as well. And again, I think that really added to set the stage as well identify new--or technology that wasn't addressed previously such as the hollow tube methods.

The panels, I guess, the one general comment I have is each panel had the most important thing to tell us which, you know, that's cool. I certainly appreciate the passion because otherwise, why are we here.

The Drilling Panel, you know, that offered the best line with--suggesting that we're selling the hide before we shoot the bear. Clearly, that's not the case. I would never do that. But I think one thing it did kind of open our eyes because it was even mentioned here at the panel wrap-up, we are not looking to develop technology for drilling purposes. We're looking to basically take advantage of the advances that have been made in the oil and gas industry to bring the technology as far as it has come today. And clearly, it's much farther than it was when this technology or this application of the technology was considered decades ago in the U.S.

So really, we think that basically taking advantage of the existing technology, but as pointed out, we need to be mindful it has to be done in a quality way with the best of industry standards today. That's going to be really important to us. So it really did, I think in my mind, it kind of raised our--it heightened our sensitivity and awareness of that.

The Emplacement Panel was excellent. Safety culture, I can't agree with you more. If you're--even when you're going through a mock operation such as receiving dummy waste packages, handling them, and emplacing them in a field test borehole, you have to do that in a way that reflects high standard of conduct of operations. You have to do it as though you're doing it for real. When you're drilling the characterization hole, when you're drilling the field test hole, it has to be in accordance with the highest standards of industrial safety. We can't afford any kind of safety issues associated with this because we'll only distract from the important scientific and engineering mission of the project. So, you know, I can't--I embrace that message wholeheartedly.

A lot of practical advice on balancing the science and engineering, it is a very important balancing consideration going forward because there are practical constraints as I mentioned as well scientific objectives. And I guess along those lines, let me also comment that there is a key part of the team--well, in addition to not having the drilling organization identified in part of the team yet, another key part of the team, and it kind of goes into the operational considerations going forward, we have brought on AREVA as the engineering services contractor. They're going to be doing the preconceptual design work for the waste package receipt, handling, emplacement operations. And they clearly bring a strong nuclear operational culture with them, or experience. And so we expect those operational--those important operational considerations to be included in their work as they deliver for the team.

Going to the third panel dealing with seals, again, excellent discussion. We do need to explore whether the seal testing can be done as part of the field test just recognizing that when we seal that field test that it inhibits the access to the field test borehole. One of the considerations with the organizations that are bidding on the drilling contract is that there are some organizations that will be interested in using that borehole for their own scientific research when we're done with it.

So these are--this is, again, a trade-off where we balance what are our near-term needs. Are there other ways of testing borehole--or sealing technology in an actual borehole without it being this one? I don't know. But certainly it's something worth considering going forward.

This morning we opened up with Dan Schultheisz. Again, I think it was great to hear his perspective presented to the group. And we look forward to working with EPA going forward on establishing those important standards that need to be in place when--by the time we actually plan to deploy this type of technology if we ever reach a decision to deploy this technology.

Panel Number 4, the Hydrogeology at Depth Panel, great conversation, multiple characterization holes. Right now that's really brought into our initial plans as, no, we don't expect perfect geology. We're trying to pick the least heterogeneous geology. Did I get that right? Okay. I'm looking at my technical guys there.

We know we're going to be surprised. And if the characterization hole discovers portions of that geology that are not suitable for the field test borehole, then we might--we're going to have to reconsider, look for maybe another area within that site, and do another characterization hole. Is that going to be successful in identifying a suitable place to drill, a field test borehole? My crystal ball is not perfect on that, but I think the going-in assumption is that we're going to see some things we didn't hope for certainly, but maybe we aren't going to be surprised with. The idea here is, is it going to be good enough. And again, the question is we're trying to advance the application of this technology further than it's ever been advanced before. So clearly, we're trying to get as much knowledge out of this field test as we can within the time we've planned.

Are we going to make adjustments between now and over the next five years? Probably. The question is, you know, what are those adjustments and are they still going to deliver on that objective. We'll have to wait and see how that goes. But, you know, clearly, again, another theme that's come up, adaptability. I fully expect we're going to have to adapt.

All right. Other items that came up during Panel 4, embrace reality. There you go. It's probably not going to be as good as we predict. Understood. Message received. I think Ernie, during the comment period, question period, I think Ernie Hardin brought up a very good point that we are looking at a different paradigm from the type of hydrogeology of Yucca Mountain, and so we're also going to keep that in mind. But again, we need to be adaptive.

Panel Number 5, Geochemistry of Fluids at Depth, it was really interesting, the graphic that showed the Kola Borehole because it was anything but straight. Once it hit the crystalline rock it really snaked around. And I would find it really uncomfortable to be tasked with the mission of putting waste packages down that borehole. It's just asking for trouble. So that was, I think, a very telling graphic, the picture of--the nature of that borehole at least. And I think we're going into the chemistry aspect of borehole disposal with very open eyes. And I think all the challenges that we're going to be facing were discussed really well during that panel.

Panel Number 6, Multiple Barriers, the layers and defensive strategies that were employed in Yucca Mountain, I love the stacking doll visual display. It was--it really does capture the layered approach. And is that the approach we need to employ here? Should we go in with the expectation that we're going to be putting any kind of waste package in some survivable for more than decades outer packing, outer barrier? We need to consider that soon and kind of keep that as one of those adaptive strategies going forward, perhaps.

And the last panel, unfortunately, I did have to step out. Just because I'm away from the office, it doesn't mean they leave me alone. But from what I did catch of it, the--I think that one of the key points from that panel was that we need to look at, with the efficacy approach to this technology, that we really do have to look borehole disposal approach from a system's aspect because all the components do have to work together. Because really, we are looking for something that will isolate this as a system for a very, very long time scale.

So with that, that's a really quick, high flyover of our impression, of my impression primarily of the discussions over the last two days. I thought the summation panels were excellent. I've got the slides for that, so that's definitely a template for things to check off to make sure that we're, you know, taking into account as we go forward.

Kind of going back to the questions on the agenda. What does DOE need to make this field test a success? I think that's pretty straight forward. I've already mentioned it. I think we're really trying to get as much information. We're trying to advance the technology, the application of this technology as far as it has gone--farther than it's gone before over the next five years. And we want to identify the highest priority questions to answer, the tests to run, the information to gather. We want to make that information available to academia as well as the regulators. We want to do it in a transparent way that when we make decisions and go forward that we're able to share those with people outside DOE. And we provide opportunity for the receipt of feedback because, clearly, we don't want to just stick our head down and go on a straight path. We expect to come into--to encounter things that we hadn't expected. And that the more great minds that we're able to engage with, probably the better off we'll be.

We might not agree with all the opinions. You know, I think it kind of goes without saying, but having not heard someone else's thoughts on a particular challenge that we face, probably not--I don't think that's going to spell success for us.

What external factors in current waste site factors could impact the time frame? And the examples given in the question were regulator standards; I think I've already addressed that clearly. Before we make a decision to actually dispose of any waste that we're considering for this technology, we need to have a very good handle on the standards. And if they're not in place, they need to be pretty nearly in place because there's no time for surprises in the regulatory world as you're getting ready to actually do.

Funding appropriations are going to be a big external consideration. I mean, certainly we submit budget requests each year, and this will be a key part of those budget requests going forward for the duration of this project. Hopefully, Congress appreciates that and is willing to support us in our plans. But they have other priorities. There are other priorities within the Department. So there's always things that can occur that we'll have to deal with. But again, that's not a technical adaptation process. That's kind of the reality of work in the government as many folks out there have ever had that joy and experience can attest.

The example of packaging the waste at the DOE origination sites, that's just--I see that kind of an engineering issue that we'll deal with when we get down the path. I don't think there's any show stoppers there. I think there's opportunities to do it better rather than worse. And so when--as we head down the path, and I think there were some good points made about the disposal of cesium/strontium capsules, you know, maybe those aren't the best initial concept to consider for this application. That's not my decision.

However, if there's challenges with that, certainly it's our obligation to identify those challenges. If there's other waste forms that would be better suited for any kind of initial use of this technology, we need to identify that. And the sooner we identify it, the sooner we kind of factor that into our plans going forward, the better. Because recognizing that the wastes are under the responsibility of the Office of Environmental Management, they have their own set of budget priorities. But they also have a very active set of site stakeholders who would like to see their waste disposition sooner rather than later. So there are a host of policy and program dynamics there that we need to wrestle with.

And moving onto the last question, what other activities must DOE complete to determine whether the deep borehole disposal is a viable option? Well, we do need to award the drilling contract because that's going to provide the key site and member, drilling member of our team. That's essential going forward. And other than that, I think we've talked about a lot of considerations today. I think in two years we'll be a lot more knowledgeable about what the best next steps will be.

So that wraps up my reaction, my raw reflection. And I'm happy to answer any questions. I'd also like my lifeline to come up here. Bill Boyle, if you could join me, because if there's any really hard questions, I'm going to have to punt to Bill. But with that, I'll open it up to questions for whatever time we have.

M. L. ZOBACK: Okay. Thank you. We actually have about 15 minutes left. So really, thanks for the awesome summary.

Anybody want to have a word? Oh, sorry. This is Mary Lou Zoback from the Board. Thank you very much. Those were--that was a very nice summary and reaction and some thoughtful responses. And we have scheduled about 15 minutes. This is everyone's opportunity to talk directly to the boss.

So Gerry--

GRIFFITH: Now, wait a minute. I'm not the boss.

M. L. ZOBACK: Well, you're somebody's boss.

GRIFFITH: Rod is the boss. This is his meeting.

M. L. ZOBACK: No, no, no, DOE.

GRIFFITH: Okay.

M. L. ZOBACK: To speak directly to DOE.

Sorry, Steve, we'll let Gerry go first. I didn't see you.

FRANKEL: Thanks. Gerry Frankel on the Board. I wanted to just get back to consent-based siting issues. So, you know, I asked Dr. Orr about it, and he indicated, yeah, we're all for it. We don't really know what it means yet, but, you know, we want to do it. That's sort of was his response. But, you know, I think--well, I appreciate your comments and also, you know, from what we heard at our last meeting from Melissa Bates about some activities and discussions with John Kotek, I mean, it's very encouraging.

But it seems to me that consent-based siting is not just achieving the consent of the local community that's going to, you know, host the field test or hole or repository. Right? So it means a lot more than that. And, you know, I think it has--there has to be transparent decision making. You talked a little about that. But this process has been more or less a top-down directive. Right?

And so I would encourage you to have this open, educational process for the whole community of stakeholders. Right? And this community is a really important one, obviously. Right? So, I mean, there was--there were comments about the need for peer review at different stages. And I think DOE tends to have peer reviews but then they're closed. You know, they're not open to the extent, for instance, that our meetings are.

So I think there's still a, you know, a culture change, maybe it's underway, but that will be required to really achieve the kinds of consent-based siting that we've seen as a Board in other countries where they, you know, they really--like Sweden, for instance, where they've taken it--they've taken this very seriously to educate the public, you know, allow input from the public. So I just, you know, again, I appreciate what you guys are saying, and I encourage you to really move forward.

GRIFFITH: Andy Griffith, DOE. I agree with everything you said except for one thing, that it seems to be a top-down approach so far. Just to be clear, we haven't started the approach yet. We're basically doing the planning for it. But I agree with you totally that when the decision is made to go, that it has to go with open-ended questions on what communities, what states, what regional governments, tribes, what they envision for a consent-based siting approach. And that's more the starting point that has led to success in other countries, and we hope that it will lead to success for us.

BOYLE: Yeah. And this is William Boyle with DOE. And I'd like to give some tangible evidence that DOE at the highest level, their heart is in the right place to not have a top-down approach. And I want to commend Mark Zoback, particularly this afternoon in his slides for making clear the distinction between the test and the disposal which Andy did also when he came up, and Dr. Orr did earlier.

And I want to--again, what you might do for consent-based siting for actual disposal might be different from consent-based siting for the test itself. But using the test as an example to show the DOE's heart is not in top-down, believe me, there were many discussions of how we could have picked the site all by ourselves, government property, DOE property; and that was specifically decided not to do but to give communities a chance if they wanted to volunteer because they might get benefit as Andy mentioned just a bit ago. When the hole is done, they might get benefit out of it. So it was to show the DOE's heart is in the right spot using the test as the example. Even though we're not to full, consent-based siting, we did go with an option that involved a volunteer site, not the government saying we already own this property and we'll do what we want.

M. L. ZOBACK: If I could just--Mary Lou Zoback, Board, just follow up on that. And, Bill, thanks for that comment. But things like peer review panels getting set up immediately, you've got to get a drilling plan constructed in an extraordinarily short time. And a lot of the expertise to do that, I know you have an excellent drilling consultant, but that's one person. And there's a wealth of knowledge. And we've seen a wealth of international knowledge. And getting these review panels set up early because you may task them on very short time frames I think would be a very visible sign that you are really seeking and benefiting from outside input.

GRIFFITH: Thank you. No, I agree. But I should note that we do have the Nuclear Energy Advisory Committee already established.

M. L. ZOBACK: I would argue that doesn't have the expertise in some of these specialized areas.

GRIFFITH: Okay. And well, and I agree with you. Going forward I think there's some more expertise that could be added to the subcommittee.

M. L. ZOBACK: Good. Thanks.

Jean.

BAHR: Jean Bahr from the Board. Just sort of following up on that in terms of the--both the chemical sampling and the hydrologic testing, how much of the responsibility for deciding how to do that is going to be with the contractor that you choose through this RFP process? And how much of that is going to be done by DOE or national lab personnel? And what mechanisms do you have in place for seeking additional expertise as input to those? Because we heard, in particular, how critical the timing and the coordination and actually the sampling methods are going to be for the geochemistry.

GRIFFITH: Right. And I think the initial test plan was part of the--it was made available to those bidding on the work. So they're aware of our initial plans. And I think the expectation of Tim, please--

Andy Griffith, Department of Energy.

Tim Gunter might be able to add to that. But I think there's the built-in expectation as they're finalizing the contract, negotiating the contract, and putting it in place, that there is intended scope to be part of that finalization process so that the scientist from Sandia can talk to the drilling entity and come to an initial arrangement.

And, you know, backing up to what I said earlier. I think the feedback or the input that we heard during this two-day workshop will probably make us think about some of those conversations.

Tim, do you want to--

GUNTER: Yeah. Tim Gunter, DOE. So, right, that's correct. We issued a number of documents ahead of time that lay out some of the preliminary thoughts and plans for testing and characterization. And as I mentioned, once we get a contractor on board, the final testing plan will be developed in conjunction with Sandia. And, of course, DOE will be involved in it also. Sandia, as I mentioned, we've designated them as kind of our lead project lab for this. And so they'll be, in terms of percentage, they'll be equally or greater involved as with the contractor.

M. L. ZOBACK: Rod.

EWING: Just to follow up on Gerry's comment about the consent-based process, so it's, I think, clear the difference between the field test and a test with radioactive materials. And the field test will not involve the use or emplacement of radioactive materials. But I also understand, and I may be wrong in my understanding, that you don't preclude the possibility of that site becoming a place where you would have disposal; is that correct?

GRIFFITH: I don't know of any intent to preclude it. I wouldn't preclude it. I think if the site is suitable and the community and the state want to participate in a borehole disposal project that is actually going to emplace radioactive waste, it makes good sense that they--that opportunity should be available to them.

EWING: That's one side of the coin, but as we've observed the consent-based process around the world, it seems that very early engagement rather than showing up, doing the test that's not with radioactive materials, and then suddenly surrounding communities or the state find oh, this site is being considered. That's a different feeling I think for the public than if they're engaged, even in the earliest stages of doing a field test. That's practice for everyone.

BOYLE: William Boyle. I actually, in conversations for months and months now, when we decided to put in the statement that there would be no radioactive materials, I think it got back to the point that Bertil made here at the end that the best place to do the test is at a place where you really to want dispose of it which is I think in line maybe with your suggestion.

But the way I brought it up in discussions with respect to the Department's statement that, look, we're not putting anything radioactive in here, I think that wherever we end up drilling the hole there will be people in that state or in the surrounding area who will try to view the world rationally and say, so let me get this straight. If this test works out, who's at the top of the list? It would be the only site in the whole world that had ever been characterized for disposal. And, therefore, I think they will get engaged because they will--notwithstanding the statements of the government that we do not intend to put anything radioactive in this hole, they will realize they will be--in the vicinity of that hole will be the best characterized place on the planet if it all works out well.

And so I think people will get engaged because they realize there is a possibility that their neighbors might volunteer and say, yeah, we would like it. So I think they will get engaged.

GRIFFITH: Andy Griffith, DOE. Let me just be clear, though, that a lot of people might be threatened while we're doing a field test with the prospect that, you know, the camel's nose is in the tent.

If we decide for actual--to move forward with actual, deep borehole radioactive facility, the process would start from scratch where interested communities would have to step forward, bottoms up. We would share information on what our interest is and what our intentions are. And they would volunteer to be considered. And so just because the test is being done in one location, we have no expectations that that community is going to volunteer for the actual waste.

We do not want to do this in a threatening way. We want to understand the science. We want to understand the practicality of the placement engineering. Those are the kinds of things that are important to us, and we want to do it in a benign way, however, with the ultimate objective of, you know, how would this actually work when it's actually done. And that actual part of process would start from scratch from a site--from a consent-based site process.

M. L. ZOBACK: Sue, were you looking to say something? No? Yes?

BRANTLEY: Only with a, you know, thought bubble over my head.

M. L. ZOBACK: I can't read the bubbles.

So Dan Ogg and then Steve Hickman. Steve has been waiting patiently.

OGG: Hi. This is Dan Ogg from the Board staff. And I had a question for clarification from the Department. In his opening statement, Lynn Orr made a statement that spent nuclear fuel would not be considered for disposal in a borehole. But I noticed in Tim Gunter's presentation he listed a number of waste types that could go in a borehole including spent nuclear fuel. And so my question is to DOE, can you clarify the Department's position on spent fuel in boreholes?

GRIFFITH: Sure. Andy Griffith, DOE. Hi, Dan. Yeah, the commercial spent fuel is not being considered for this application largely because of the size. Tim's slides included DOE-managed spent nuclear fuel is usually, typically research development or legacy reactors which are smaller in dimension. It could be considered whether a population of that is actually decided to be disposed of in the borehole or not. Yet to be determined. But the distinction is between commercial and DOE managed.

OGG: Okay. Thank you.

GRIFFITH: Sure.

M. L. ZOBACK: Can I just have--Mary Lou Zoback, Board--a brief follow-on question? Not knowing this DOE managed spent fuel, but will any of those fuel assemblies have to be disassembled to put in a borehole? Or are you looking at things that could fit in a borehole?

GRIFFITH: Andy Griffith, DOE. No. We're looking for dimensionally small, you know, similar to the cesium/strontium capsules or some kind of universal canister that would hold calcine waste, something of smaller dimension.

M. L. ZOBACK: Okay. Good. Steve.

HICKMAN: Steve Hickman, USGS. I've been really impressed at this workshop, the intellectual firepower that's been brought to bear and the thoughtful consideration people have given to the challenges you will be faced if you decide to dispose of waste in a borehole. And I would just encourage you to keep that process going. To me the idea of continued engagement of the international and national community on issues like site characterization, fractured rock hydrology, geochemistry, rock mechanics, drilling, downhole measurement, surface geophysics.

There's a list and I think it's really important to think, yes, this is a field test borehole. You'll probably not put waste down there. Maybe you will. But imagine you were going to put waste down that hole. What would you want to know about it to give you the confidence to proceed? And that's how I would focus the science.

We heard a lot about seals. People are worried about seals. I think we're all worried about seals. Ask yourselves and get an expert panel to ask what is it you need to know about those seals following on the discussion here and the damage zone around the hole that give you confidence that in an eventual waste disposal hole you could have a seal system that worked under the right stress conditions, the right depth, the right rock type.

So I really encourage you, even though you're not thinking of disposing in this well, to think about it as if you were and say what would you need to have the calmness to go ahead. You don't want the $26 million to be--have to be spent again, all over again, because you didn't ask or didn't answer the right questions.

So I've just--you know, look at the seal problem seriously *in situ*. I would feel more comfortable if you did seal testing with a heater or something like that. Look at the hydrogen bubble migration problem. Just think about this outside the box. What are the problems you've heard about here? Continue to engage the same people and more. And try and answer as many of those questions as you possibly can in the field test hole to help give you and the world the confidence to go ahead with the disposal site. And to me a lot of that is having advisory committees of people who are not part of the project who feel free to speak their mind. And people here do.

And I just wanted to say, you know, keep that process going as much as you can. Advisory committees on things like seal integrity, site characterization, hydrogeochemistry, those kind of things are going to be critical to keep the external input coming into the system so you don't get closed off from the outside. Thanks.

GRIFFITH: Thank you.

M. L. ZOBACK: Okay. I think that's a nice note to end on unless someone wants to have the final, final word. So thank you, Andy, and thank you, Bill, for--

GRIFFITH: Thank you. This has been great.

M. L. ZOBACK: --the lifeline. Okay. We now have reached the point of the meeting for public comment. And I believe we have one person signed up, and that's Kevin Kamps. So Kevin. And since we're web casting, if you can remind everybody, your name and affiliation.

KAMPS: Thank you. Yeah, my name is Kevin Kamps.

Radioactive Waste Specialist at Beyond Nuclear. And thanks for the public comment opportunity. I'll try to keep it brief given the late hour and the two long days.

I just wanted to tie some loose ends up from yesterday because I suffered a loss of institutional control. I didn't fully explain why I brought up the loss to humankind of the knowledge about Roman concrete for a millennium, and it had to deal with loss of institutional control. So it was very fortunate that a handful of copies of the Roman architect--Vitruvius' Treatise on Architecture it was entitled-- survived in a monastery here--a monastery there and reached the Renaissance and then led to modern concrete applications in the early 1700s. So my point is that any institutional control being assumed on deep borehole disposal is really inappropriate.

And I think another, you know, voice that bolsters that opinion would be Dr. Allison Macfarlane who was NRC chairman during the nuclear waste confidence vote at the NRC commission, filed the only dissenting opinion, and that had to do with loss of institutional control. Because, unfortunately, the NRC staff and the majority of the NRC commissioners seems okay with just simply assuming ongoing institutional control forevermore into the future which is, of course, absurd. So that was that one.

I wanted to tie off the loose end on the Canadian

Deep Geologic Repository that I brought up yesterday and also today a speaker, Dr. Novakowski, brought up the Bruce Nuclear Generating Station Deep Geologic Repository as they call it in Kincardine, Ontario. And I think the first thing I should point out is that it's not deep. It's 680 meters. They call it a deep geologic repository.

And I had said that there was bipartisan opposition in the Michigan congressional delegation, and that's true. But there are some exceptions that I should point out. And that would be Congressman Upton, for one who's Chair of Energy and Commerce. So it's quite ironic because he's long claimed to be a defender of the Great Lakes.

But in addition to that example I wanted to point out that there are resolutions, 170 resolutions across the basin in both the U.S. and Canada. You add up the populations represented, it's 23 million people represented by these resolutions and opposition. And the reason I brought that up was the public backlash against a rushed process. And I'll say some more about that in my comments of today's session.

But during Dr. Novakowski's presentation I was going to ask a question about this, but I'll just turn it into a comment, he was discussing very, very low permeability geologic formations having a diffusion driven process. And the reason I wanted to address this is that Ontario Power

Generation has used that kind of language in defending its deep geologic repository. But to the best that I can understand their position, they're referring to the geology as it is, absent the shaft going down to it and the seals that haven't even been designed yet. So their confidence that the future DGR will simply be exactly the same as the current limestone geology formation is I think wrongheaded. But the public is left with that confusion.

So turning to today. Actually, I did have one thing about quality assurance I had mentioned yesterday. So I just wanted to read a quote from Admiral Hyman Rickover. I think it makes the point about quality assurance better than I can. And this is the quote from Admiral Rickover. "Responsibility is a unique concept. You may share it with others, but your portion is not diminished. You may delegate it, but it is still with you. If responsibility is rightfully yours, no evasion or ignorance or passing the blame can shift the burden to someone else. Unless you can point your finger at the man who is responsible when something goes wrong, then you have never had anyone really responsible." And I just point back to our experience with the Holtec containers for high-level radioactive waste that are deployed across the United States right now as a case study, a warning, a cautionary tale because it's out of control out there.

So for today's session, I think Secretary Griffith's presentation just now has--and the Chairman brought this up, that disposal in a deep borehole that began as a fuel test does not preclude it in the future is a huge red flag. And certainly public engagement can be expected. Beyond Nuclear is a member organization of the Alliance for Nuclear Accountability. And I think it's fair to say that the ANA will be fully engaged in this going forward.

But having said that, I for one feel blindsided by the pace, the rush. We object to the political subversion of science. I mean, the Blue Ribbon Commission process which lasted for two years that we took part in, in good faith, at every opportunity seems to be at risk here. So I mentioned it yesterday, but the Department of Energy's Office of Nuclear Energy being an explicitly promotional--the mandate is nuclear power's promotion, at least one of its mandates--creates a real conflict of interest in these regards. And again, the Blue Ribbon Commission advised that, for example, a federal corporation independent of the Department of Energy be established to deal with high-level radioactive waste management.

So an article that just appeared yesterday in Energy and Environment Daily by Hannah Northey entitled "DOE Team Crafting Strategy for Moving/Storing Radioactive Waste." Again, it's ironic and hard to understand how the Department of Energy Office of Nuclear Energy which also hosted the Blue Ribbon Commission for that matter, is creating the independent agency, is really hard to fathom. And more from that article was that there seems to be a very explicit lobbying component to this to try to get to centralized interim storage for commercial waste, perhaps as early as 2021. So the rush is very concerning.

So again, the trumping of science by politics. And this is already manifesting itself in congressional legislation. So, for example, Senate Bill 854, and it raises that red flag again where in this current legislation that's supposed to fulfill the Blue Ribbon Commission's vision, you read language about the Department of Energy or this new agency that it is creating can go to a proposed centralized interim storage site, can characterize the site, can declare it suitable, and then can check in with the community and ask permission, and then can check in with the governor and ask permission. That's how I read the language in this legislation. So that's very concerning in this regard too with deep borehole disposal.

And, you know, the impression that I'm left with is given the rush, it seems to be like throwing everything against the wall to see what's going to stick. And the timing is very interesting too given the end of the Obama administration in about the same time frame that we're talking about here.

And I guess, yeah, I'll just reemphasize the position. Someone mentioned today, the Scottish operating philosophy of keep it close to the site. I can't find the exact language. We have similar environmental consensus across this country that dates back decades. Store radioactive waste as close to the point of origin as possible as safely as possible. More recently for the past decade, and this was brought to the attention of the Blue Ribbon Commission at every opportunity, hardened on-site storage. And this applies not only to commercial, high-level radioactive waste and irradiated nuclear fuel, but to other categories as well.

I guess, let's see, one other area I wanted to just respond to was a statement by a spokesman from Sandia today during Panel Number 6 about operational mishaps. At least it would be during operational phase and so it would be quickly, you know, known. Something along the lines of people would be drinking bottled water, and it would be a bad thing. But the dose consequences would be insignificant. And so in the context of any number of drinking water disasters in just the last few years--I'm from Kalamazoo, Michigan. We suffered the biggest inland oil spill in U.S. history in 2010. Toledo's drinking water supply shut off last summer for toxic algae, West Virginia chemical spill, the Animas River. But more to the point, I would say Braidwood Nuclear Power Plant and massive releases of tritium into the groundwater which people in Godley Park, Illinois, were drinking and bathing in and cooking with for a decade.

And so I guess what my point is, is that the trust is broken with the nuclear establishment. And I think that was the driving force behind the Blue Ribbon Commission's advice, recommendation that an independent agency needs to be established because DOE has broken the public's trust. And so I'm afraid that this rush is along the same lines of past behavior patterns. And so it's deeply concerning.

And I'll just close by saying, you know, we will be engaged. And thank you.

M. L. ZOBACK: Thank you. Nobody else with public comments? Okay? He didn't sign up. Is it okay? Okay.

MILES: Just brief.

M. L. ZOBACK: Brief.

MILES: This is Rob Miles and, again, I'm just here to give my own personal opinion not respective to WAI or anything else.

I just want to mention the real risk here is not doing anything. We've been waiting for 70 years for a waste disposition path forward. To say that to keep it where it is, is the safest way to do it, I'd say no, that's not true. I was the engineer that discovered the uranyl nitrate problems at Rocky Flats and plutonium in 371. I understand those. There is--you know, there is all kinds of things that happen just by having the waste around. The best solution is for a group of technical individuals who think through all the consideration, figure out what is the best proposal path forward for dealing with the overall nuclear waste problem. It's not that we don't believe that there is a problem. We know that there is. It's time to solve it. And so that's my statement, and appreciate the time. And I appreciate being able to participate. Thanks.

M. L. ZOBACK: Thank you. Okay. Well, just a few brief remarks in closing, it's been a long two days starting at 8:00 a.m., particularly for someone from the West Coast. But I just want to say a few words of thanks once again and begin by thanking everyone who's participated. It's amazing that the room is still so full. I really appreciate that. I particularly want to thank the panelist. A lot of people traveled a long way to come here.

I also really to want thank the moderators who were all Board members who all really contributed to the design of the workshop, the questions that should be asked. Sue, Gerry, Jean, Rod--Rod and I had many discussions at Stanford beforehand, and Allen as well. They did a lot of work on the workshop. But this would not have happened without Bret Leslie's help, guidance, direction, and doing an awful lot of the work.

So, Bret, I really to want thank you for all the hard work and the groundwork and following through on everything.

Board members are all part-time, very part-time. The responsibility falls to the staff. And there was so much responsibility that Bret was very ably assisted by Bobby Pabalan.

Bobby, where are you? Hiding in the back there.

Many of you got--he's Roberto in e-mail. But many of you, the panelist I know corresponded with Bobby.

So Bobby, thank you. I know you had a lot of other things to do, and I appreciate you stepping up so willingly.

Those of you that were assisted in travel know that our administrative director, Debra Dickson, helped out an awful lot with travel as did Linda Coultry, our travel arranger extraordinaire. So thanks to both of the two of you.

And I really to want acknowledge and thank the AV and IT staff. Julian has been rushing around grabbing people, miking them up, unmiking them while they're hardly aware they're being unmiked. And thank you for making that all so smooth.

Scott for the reporting as usually. Amazing. We are going to get a full transcript of everything. And once again, I'll be embarrassed to see what I actually said. But it's going to be there available on the web.

And Jason, you made all the presentations go. There were no glitches. That was amazing. And, I'm sorry, I don't know the video team's names, but thank you. It's clearly been a really professional job, and I really appreciate that. Who did I leave out? I think that's everybody. And the rest--everybody. Everybody participated. I feel like people were really engaged. And I really appreciate that.

And I just want to in my closing two cents, very short, is that the deep borehole test program is proceeding. We know that. We know a lot more about it after these two days I think. And I really appreciate that in all the DOE comments and interactions it really seems to me that DOE has sat here, interacted with all of you, accepted input, accepted criticism, but have done that in the very positive and constructive way it's intended. I think all of us as citizens and taxpayers want to see the very best outcomes of this program, this test program. And I know that we all want to be engaged in any away that we can assist.

So I really to want thank DOE for being so gracious about listening to a lot of nattering on and on and on. So thank you for that. And again, thanks to everyone. And now, I'm going to leave it to Rod to be our final word.

EWING: Okay. So Mary Lou thanked everyone. And I think this is the moment when we should thank Mary Lou. She's been pushing and shoving us along the way for quite some time but all to the good, and so I'd like to recognize you, Mary Lou. So Mary Lou may think that this package, this obvious present is for her, but actually it isn't. So I'm sorry for that.

So Scott, could you stop working for a moment and come up?

FORD: I'm sorry. I'm listening to Led Zeppelin.

EWING: So--yeah, stand close. So Scott, this is his last time with us. And he has worked transcribing for the Board for 27 years. So think about--think about what that must do to someone's mind, 27 years of listening to us.

FORD: Look what it did to my hair.

EWING: Yes. And so Scott, we're sad to lose you, but we understand that there's probably a limit to what any sane person can stand. And so the Board, we have a small gift for you, a remembrance of the NWTRB, and we'll certainly remember you. And thank you very much for everything that you've done for us.

FORD: Thank you.

EWING: So that brings us to a close. I'll just mention that you can all stop by the free wine and beer, and I hope that discussions continue for just a bit longer.

Is there anything else, Mary Lou? I think we're done. Right?

M. L. ZOBACK: I forgot--

EWING: Okay. Sorry.

M. L. ZOBACK: Mary Lou Zoback, Board. I forgot to say that all the slides presented at the workshop are going to be posted on the Board's website and the webcast.

And, Scott, if you'd stop listening to Led Zeppelin, maybe we'll get the full transcript up.

But they'll all eventually be available on the website. So again, thank you.

EWING: Okay. And thank you all.

(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_________________

Federal Reporting Service, Inc.
17454 East Asbury Place
Aurora, Colorado 80013
(303) 751-2777