WORKSHOP ON ENGINEERED BARRIER PERFORMANCE RELATED TO LOW-LEVEL RADIOACTIVE WASTE, DECOMISSIONING, AND URANIUM MILL TRAILINGS FACILITIES

- - - TRANSCRIPT - - -

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U.S. NRC HEADQUARTERS AUDITORIUM

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Hosted by the U.S. Nuclear Regulatory Commission

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P R O C E E D I N G S

This is a technical, formal workshop with the participants sitting at the tables. The NRC staff along with federal, state regulators and engineers and the public are welcome to attend and observe.

A public comment period has been scheduled at 5:30 eastern daylight savings time today and tomorrow. On Thursday the public comment period is scheduled for 3:30 p.m. And during those scheduled time periods, please use the microphones, we'll provide a handheld one for you to identify yourself and pose your questions and comments, and that's at 5:30 today, tomorrow, and at 3:30 on Thursday.

For those viewing the workshop remotely, a special call-in number is listed in the workshop program for those time periods, so if you have a comment at 5:30 today and tomorrow, at 3:30, please call in at 1-888-566-6344, and the pass code is 15103. And it's in the program, we'll make that announcement at 5:30, that call-in number again.

The workshop program can be viewed on the NRC website under the public meeting announcement.

Restrooms are located in the back of the atrium. There is a ladies' room and men's room. In the event of fire alarm or evacuation, please take all of your possessions with you and exit through the rear of the auditorium, go up the steps as you came in this morning, past the security check in, out the doors, go to the left and we will gather under the trees next to the security booth. And we have to be accountable for everyone, so please stay together. And we'll take our registration list.

You can leave this auditorium and the workshop at any time, but you're only permitted to re-enter through the portal this morning, and you're not allowed to go anywhere else in the NRC except during lunchtime.

At 12:30 we will break for lunch, you will be guided by the NRC security guards to exit at the security portal, go up the steps next to where you came in and they're going to open a door there for us to go to the cafeteria and you'll have limited access to the cafeteria for lunch.

There's no taking of pictures allowed in the auditorium, please turn off your cell phones. No food or beverage other than water are permitted in the auditorium.

Finally, a public meeting feedback form will be provided to you. Please fill in the form and leave it on the registration table or mail it postage free back to the NRC. Back on that table will be those forms for you to fill out.

Well, I'd like to introduce Jim Lyons, our deputy office director, the Office of Nuclear Regulatory Research, who will welcome us this morning.

Jim.

JAMES LYONS: Thank you, Tom.

On behalf of the Office of Nuclear Regulatory Research, I would like to welcome everyone here to the U.S. Regulatory Commission headquarters. I hope you were able to get in here with minimum hassle. It's always hard to get a large number of people into our facility, so I appreciate your patience as you come in.

The focus of this workshop is the evaluation of the performance of engineered barriers, both short term and long term, which includes engineered covers and subsurface liners.

Our primary objective is technology transfer, the significant research and practical experiences in evaluating engineered barrier performance developed over the past ten years.

I'm very pleased to see the wide participation in this workshop from state regulators, the technical communities, Native American tribes, academia and the public. We see significant value in sharing this information with you.

Here at NRC, we are very proud of the research that we sponsored at the U.S. Army Corps of Engineers, the University of Wisconsin through the USGS, and the Agriculture Research Service related to this topic, and I'm pleased that their findings are going to be able to be presented directly to you today.

I want to thank our fellow federal agencies for providing staff and resources to serve on the workshop organizing committee as session chairs, presenters and panelists, and specifically, the U.S. Department of Energy, both their Office of Legacy

Management and the Office of Environmental Management; the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, the U.S. Geological survey and the DOE National Laboratories.

I also want to note that today we're fortunate to have members of the staff of the Canadian Nuclear Safety Commission with us here, and so a partnership that we look forward to continuing on as we move forward.

I'm also pleased, as Tom was saying, that many others that are not able to be here in person are able to take part in this workshop through our Go-To-Meeting webstreaming and video teleconferencing.

So thank you again for your interest and attendance and I wish you success in communicating and discussing these important technical topics today.

So with that, I'd like to turn it over to Larry Camper, who's director of the Waste Management Environmental Protection in FSME, and I'll let him tell you what FSME stands for.

Thank you.

LARRY CAMPER: Thank you, Jim.

Now, you've heard all the things that you can't do. It's okay to breathe, it's okay to relax, it's okay to enjoy yourself.

You made your way through security, so that in itself is a hurdle. We've made some changes recently in our security so it's even more intensive than it has been in the past.

Again, like Jim said, welcome to all of you.

I am Larry Camper, the director of the Division of Waste Management and Environmental Protection within the Office of Federal and State Materials and Environmental Management Programs, FSME.

We do a lot of implementation of research projects that the Office of Research prepares for us. We use it in our decommissioning program. We use it in our Uranium Recovery Title 1 and Title 2 decommissioning programs, so a lot of what you're talking about here today is indeed very timely and of substantial utility.

Jim in his opening remarks cited the various federal agencies, the various state agencies, the university. This is indeed a very interesting and worthwhile gathering of academics and practitioners, both in the federal, state and private sector who really understand this topic. So I think it's an extremely timely conference, I think it's an extremely important topic and, oh, by the way, from my perspective, there is increasing stakeholder interest in this topic as well, so, indeed, very timely.

I won't repeat all the various players. Jim did an excellent job of doing that. I would echo his welcome.

I would rather kind of draw to Thursday, what it is that I hope you accomplish here.

It's going to be, I think, a very interesting discussion at times, perhaps a taxing discussion. I think we'll have some interesting dialogue.

And so what could you do that would really be success for the conference?

First, we think formulating recommendations on assessing engineered barrier performance would be of utility. Highlighting research opportunities to fill in existing information gaps would be valuable, identifying potential improvements to the existing guidance. And finally, recommending follow-up coordination among workshop participants.

So I think if you think about those four things as what does success look like as you carry out your discussion over the next three days, that would be extremely helpful to us.

I would again join in welcoming you and thanking you for the dialogue and the active discussions you're going to have and participation you are going to have and again, draw you to think about what does success look like for the conference.

So welcome and have a good meeting and I'll probably stick my head in from time to time to keep abreast of what's going on.

Thank you. Welcome.

TOM NICHOLSON: Thank you very much.

Our first speaker today is Hans Arlt, he's the co-chair of this workshop. He a senior systems performance analyst with NRC's Division of Waste Management and Environmental Protection.

Hans' past experience included developing groundwater flow models to simulate and optimize groundwater extraction and completing a hydrogeological study of the Nile delta aquifer for his doctorate in natural science at the Technical University of Berlin.

Hans joined the NRC in 1999 where he previously worked on unsaturated and saturated flow issues for the proposed Yucca Mountain repository.

Hans?

Hans will go over the workshop background, agenda, objectives and goals.

HANS ARLT: Hello, my name is Hans Arlt and I'm co-chair with Tom Nicholson of this workshop.

I want to thank you for coming here and thank you for being here the next few days. I'm assuming you'll be here the next few days, and I want to welcome you to this workshop on engineered barrier performance here in the auditorium.

Okay. And before I go into the agenda and objectives I'd like to do a little bit of background, I want to go over some of the events and meetings that have taken place in the past, just to put things sort of in a context and give our workshop a little perspective, because there have been a few other workshops in the past that have been of interest.

So for some of the background, the concept of engineered barriers began to take hold roughly 50 years ago in the United States, but it's only relatively recent that sufficient data has been gathered to assess performance of engineered surface covers and bottom liners.

Research results from various organizations have a lot of better understanding of engineered barrier performance, but have also raised technical questions.

The National Research Council of the National Academy has completed a study and documented its results in a thorough publication titled Assessment of the Performance of Engineered Surface -- Engineered Waste Containment Barriers in 2007. This National Academy report dealt with the shorter time period, or kind of focused on a shorter time period of decades, they weren't really looking at hundreds of thousands of years. However, it is definitely worth mentioning some of the recommendations that it made, and I was just going to go through that real quick.

They included recommending extensive monitoring, including in-place monitoring to assess long-term performance. They also recommended that regulatory agencies should develop guidelines to increase direct monitoring to out barrier systems, that they should also commission and fund assessment of performance on a regular basis.

That they should establish a set of observatories at operational facilities to assess performance at field scale, they support validation, calibration and improvement of models to predict behavior. And finally that EP and NRC should develop performance based guidelines for assessment of containment system performance as an alternative to prescriptive designs. Those were their recommendations at the end of that report.

Additional past activities and studies include DOE sponsoring the alternative landfill cover demonstration project on conventional alternative cover designs.

Also, EPA conducted the alternative cover assessment program, or ACAP, and you will be hearing more about that as presenters give information from that study. They evaluated the performance of alternative landfill covers beginning in 1998.

DOE and NRC held a series of generic technical meetings on issues relating to waste incidental to reprocessing, which included engineered covered performance.

One principle point of technical understanding was a need to document the projected water budget or water balance of the engineered cover over time periods for effective cover operation. That means, you know, that water balance might shift as the years go by, so the water cover -- water budget components would be something like the precipitation evaporation, surface runoff, internal lateral drainage, water storage and finally, the infiltration.

More details on this you can find on the link that you see here on the slide.

In 2008, DOE hosted the landfill workshop involving various DOE organizations, laboratories, NRC, to assess the state of the practice of engineered covers. And this again was a little bit different than what we're doing. They were focused on low-level waste, but yet they did a really good job.

When I went through the results, there were a lot of good insights and a lot of recommendations, and I would hope that participants look back on those recommendations and that we can build on what they did back then.

A follow on technical forum was held in 2009 by DOE to examine long-term monitoring just last year.

For the agenda and objectives, the previous workshops and meetings on engineered surface covers and bottom liners have produced informed recommendations and useful insights. However, there's a need for a broader group of cooperating organizations to focus on longer time periods covering a wider range of environmental conditions, waste forms and field experiments.

So that's us, hopefully that will fill that bill.

We are fortunate to have many organizations and many individuals with extensive experience and expertise participating in the next three days. This is a unique opportunity for organizations and many individuals to present their knowledge and learn what others have discovered in this area.

So just -- I think most of you are familiar with -- there's just a lot going on out there. A lot of people are doing a lot of different studies, and a lot of it is similar to what you're doing. And then, you know, years later, you find out that some organization was doing something very similar to what you were doing, but you had no idea what was going on. Or you have an idea that something's going on, but the information is very difficult to obtain for various reasons.

So this is like one of those opportunities, we've got a lot of different organizations here, a lot of different people. And I even know during the telecons in preparation for this workshop, people were exchanging information because they weren't aware of what the other person had in data.

So, one of the main objectives of this workshop therefore is to facilitate the exchange of information and ideas as it relates to engineered barrier performance.

To provide technical background in context, the first two presentations will provide information on engineered barrier types and related regulatory guidelines. In addition, there will be a series of presentations from the states on their own experiences in this area and a series of talks by federal agencies and laboratories on research activities and findings.

Both of these presentation series will be followed by panel discussions. And the panel discussions are where we have the speakers plus additional organizations or members of additional organizations who will be getting together and be sitting at this table here, and then we'll have a panel discussion with people present.

The remaining sessions are divided into four major topics: Degradation, monitoring, modeling and model support.

This workshop is not focused on finding the perfect cover or liner design, but instead on understanding the significant components of the total system.

That means understanding degradation processes -- which is Session 2 -- which affect performance by means of well thought out monitoring programming -- which is Session 3 -- and realistic numerical modeling -- which is Session 4 -- and also gaining confidence in long-term model results; for example, greater than 100 years, by independent lines of evidence or model support -- which is Session 5.

So model support is basically, you have -- you're looking at the year 500. You can't validate the model in a traditional sense that way, so you need other independence lines of evidence. We will go into that more in Session 5.

Designing the optimum surface cover or bottom liner for a specific site is then left to the builder or operator of the disposal facility using the information mentioned above.

And just going through the sessions real quick, this afternoon's presentation and panel discussion on degradation processes will look for answers and insights to the following questions: What are the most significant degradation processes? How can these processes be minimized? How will ecological changes affect short-term and long-term processes?

Tomorrow's presentation and panel discussion on monitoring systems will look at the following: What areas should be monitored for significant degradation? What type and level of monitoring should be performed and how long? Plus additional topics such as does short-term monitoring give you insight to long-term performance?

Wednesday's afternoon presentation and panel discussion on numerical simulations will look at the following: When should numerical modeling be for, over what time period? What detail is needed? And what codes are recommended?

Thursday morning's panel discussion and presentations on model support will all revolve around this, what information or lines of evidence is needed to have confidence that an engineered surface cover or bottom liner will perform as predicted in the short and especially in the long term?

And our goals, Larry Camper went over some of those, but I'm just going to go through them once again. The first couple are specific. Thursday afternoon's session will summarize recommendations on assessing engineered barrier performance and future research needs and discuss existing related guidance so as to achieve these workshop goals. Identify degradation processes affecting performance. Identify total system monitoring strategies and modeling strategies to evaluate overall performance. Identify strategies to obtain information and evidence needed to support short- and long-term performance model results. And then for everybody would be to highlight research needs and opportunities to fill information gaps, identify potential improvements to existing guidance, and recommend follow-up coordination among workshop participants. Tom and I would like it if somehow something from this would evolve so that it would be like a stopgap approach but that we would continue in this way.

And that concludes my overview.

And thanks for your time and attention.

SPEAKER? Will you introduce Craig?

SPEAKER? Okay.

SPEAKER? Our next speaker is Professor Craig Benson, he's going to talk about the identification and differentiation of engineered barrier types by function design. Professor Benson is a Wisconsin distinguished professor and chair of the geological engineering at the University of Wisconsin at Madison, the Badgers.

Dr. Benson has a BS from Lehigh University and a Master's in engineering and a Ph.D from the University of Texas at Austin. His degrees are in civil engineering with a Master's of engineering and Ph.D specializing in geological engineering, and Dr. Benson is a licensed professional engineer. He has been conducting experimental and analytical research in geo-environmental engineering for 25 years with a primary focus in waste management.

His research has included laboratory studies, large scale field experiments and computer modeling. He was co-principal investigator for the United States Environmental Protection Agency's landmark study on final covers, the Alternative Cover Assessment Program known as ACAP, and is a member of management Board for DOE's Consortium for Risk Evaluation and Stakeholder

Participation, CRESP.

Professor Benson.

CRAIG BENSON: Great to have this good turnout for this meeting. I think we started planning this a little over a year ago. And I'd like to thank Tom and Hans and other folks at NRC for all their hard work putting this together.

Bill Albright, who will be talking a little bit later today was mentioning to me on our run this morning about the wealth of communications that we got on this conference, or this workshop, more than I think ever before, and Bill said he got 170 e-mails from Tom and Hans, so thanks for all your efforts organizing this. It really shows, it's well done.

Well, the purpose of this presentation is really just to kind of set the stage, is to talk about different types of barriers that we will be going over this week and discussing, to provide some nomenclature and then to end up at the end of this with some thought questions as we go forward as a group. And so largely, this is going to be nomenclature and definition to some extent.

When we talk about containment systems, largely we're talking about vessels that are intended to contain waste and separate it from the environment.

And I don't know if this will work if I -- you know, as a university processor, I'm used to walking around as I speak. So I'm not used to speaking at a lectern. I'm not sure if the microphone will stick with me or my pointer will work.

All right, we'll use the mouse. Nifty. That's pretty good.

Beam of radiation coming out of our waste.

Anyhow, we've got some waste in here we want to manage, and the objective is fairly simple in concept, we want to keep it within this vessel and separate it from the external environment.

And to do that, we use a variety of different barrier systems. We use covers, in the low-level waste industry largely we rely on cover systems that have multiple objectives. One is very simply for separation, to separate it from the environment, but also to control the infiltration into the cover, and then there's ingress of percolation of the underlying waste which might generate leakage and ultimately make its way to groundwater, but also to control gas. And a lot of our early covers for mill tailings were largely designed based on radon control where we were looking at emission of radon gas into the environment. So gas control is equally important. We talk about some reactive waste as well, gas control is important for sulphate oxidation processes.

So covers have multiple different roles both for liquid phase and gas phase transport control.

Liner systems we don't use in all applications, but when we do use liners, our primary objective is to use them as a transport barrier both to control the amount of leakage, but also to control the rate at which constituents are discharged from the facility.

So in essence a liner actually acts as a throttle or as a valve at the bottom of our facility where we control the rate or the flux of contaminate discharge that ultimately might make its way to groundwater and then to our compliance point off to the side.

Ideally, we design the system so that it attenuates whatever is within the vessel to such a degree that our impact on the environment is within some health based acceptable criteria.

We look at the elements of our different parts of our containment system, our cover and our liner. I illustrated this here because one of the things that we do often, we use multiple components. We don't necessarily use one component to build a liner or a cover, but multiple. And we may use earthen materials and synthetic materials as well.

Perhaps the age-old material, and the one I cut my teeth on as a Master's student, actually I was thinking Bob Kanoff is here today. Bob and I met 25 years plus ago when I was working on my Master's thesis on clay liners in Houston, Texas.

So this is one of our most, perhaps our greatest experience with, our longest history with clay barriers, and when we construct clay barriers, in some applications are extremely effective as long-term barriers for isolation of waste.

What we like to create is something like this, essentially a material devoid of microscopic pores and at the larger scale we're talking about creating some type of barrier system that looks more like what I showed here on the right.

Clay barriers are wonderful materials in some applications and not such good materials in others, as we'll talk about as we go forward throughout the workshop.

As we step forward in the waste containment business, a lot of synthetic materials and hybrids of synthetic and natural materials have been developed. Geosynthetic clay liners would fit into that hybrid category. We're actually taking a natural material of bentonite clay that's usually in a granular form and sandwiched between a couple of geotextiles, which may be needle punched or bonded together, and when this material wets up, it looks something like we see down below here where we simply have a hydrated layer of very impermeable bentonite between some carrier geotextiles and can form essentially a synthetic earthen material or earthen barrier. And these are deployed much like a -- other geosynthetic materials, almost like carpet, as you can see it being rolled out on a slope over here.

These materials have their own unique issues associated with them, can be very effective barrier materials, but also suffer from ion exchange processes and some of the same problems as we'll talk about with clay barriers as we go forward through the workshop.

So GCLs are often used, or geosynthetic clay liners, as a substitute for natural clay barriers in containment systems.

Geomembranes or polymeric barriers are used as well. The common polymers used today, high density polyethylene and linear low density polyethylene, polypropylene and PVC, these are typically one to two millimeters thick, very tough, rugged plastic sheets which are used as a barrier system either alone or in conjunction with others, as we'll talk about in a minute. Virtually impermeable to water if they're put in without defects, but they do tend to transmit some compounds via diffusion at relatively rapid rates. So understanding their ability to contain different types of contaminants is important.

We do know that some defects are inevitable in geomembranes, and so we do get some transmission of water. They're not leak free. But in fact they can cut leakage rates to very low levels and can control transport to very low levels in some cases.

And in the last couple years there's really been some innovations and really some neat, new polymeric materials that are being proffered for use in geomembranes, and particularly laminated geomembranes, there's several different polymer layers which have the potential to create longer life spans and also greatly reduced the diffusive fluxes through these materials.

And hopefully, we'll get to talk about some of that as we go forward.

The illustration is of some of these materials being placed as a geomembrane in a cell out west, in western US. These materials go in as panels, get welded together, here are some installers using a dual track wedge welder or an extrusion welder, simply bonding the plastic together through thermal processes, and then those welds are tested for their integrity either through pressure testing, as shown here on the right, or through vacuum testing as shown here on the left. There's a little bit of an art as well as a science to checking the integrity of those seams.

Oftentimes we will use these materials either alone or in combination, more so the latter these days, we tend to use combined barrier systems to a greater degree.

If we look at single systems, we might have a single clay liner or a single geomembrane, a single GCL, that was something probably circa 1980s, which is more common.

When we look at barrier systems today, particularly for liners, we would be either using a single composite liner consisting of clay barrier or a GCL combined with a geomembrane creating a composite, a synthetic, natural systems put together to take advantage of their relative merits to create a composite liner.

If we're in Subtitle C or hazardous waste domain, or in some cases for some solid waste domains, we'll use a double composite liner, or we might have two composite barriers separated by a drainage layer between the two. So we might have actually two different liners built and each one being a composite.

So we use multiple composites, single composites, single liners depending on what the application is. And we might use these both, a composite in the liner and we might use it in the cover as we will see in a little bit.

Drainage materials, you saw in that previous slide, I showed some drains. We might use geosynthetic drainage materials like I show here on the right, these are fairly thin, on the order of about five to ten millimeters thick, nets that are typically encased between two felt type geotextiles, very conductive, very thin materials, very effective at conducting flow. Or we might use natural materials as well or gravel materials, both being effective, but using different amounts of air space and have different longevity issues as well and different geochemical issues.

Just an illustration actually where those are being used in tandem. Here's a liner system where there's actually a composite liner beneath this, this black fabric here is actually a geocomposite drain and then it's getting a pea gravel being placed on top of it. This is actually in southern Wisconsin for a municipal solid waste landfill.

And we're also -- more typically if we're dealing with liner systems, I have a whole series of pertinences to these, pumps and sumps to collect liquid if we are going to be collecting them at the base of the facility.

If we look at different types of profiles, what I'd like to do for the remainder of my time is just kind of talk about how these materials are arranged in different types of environments, and I'll start off with a simple kind of solid waste environment and go to Subtitle C, hazardous waste environment, and then talk about some of the applications in the low-level and mixed waste environment.

As I mentioned, these are normally used as a series of layers when we look at barrier systems, with the barrier system itself being a composite, here it's a clay and a geomembrane or perhaps with a clay and a GCL with a geocomposite drainage layer on top creating a series of different elements to create the barrier system and then the waste being placed on top of the multi-layered system.

This would probably today be the simplest liner system that would be used, probably wouldn't be permissible for a mixed waste site, which we'd have to use a hazardous waste liner for. That might look like something like this where we have a double composite system. As I illustrated earlier, we might have a clay layer with a geomembrane, some type of drainage layer between it, another geomembrane and then the waste placed on top of it, or we might have a system that looks like that but made completely out of geosynthetic materials with geomembranes and GCLs used to create the composite barrier systems.

Now, these systems have been shown to work very well. Leakage rate data collected from these double composite barriers have demonstrated that at least in the near term that they're very effective at controlling leakage and transport and states that have used these have illustrated from their monitoring data that we haven't had any engineered or any groundwater compliance issues with these modern engineered barrier systems.

We're looking -- in cover systems we could mimic that. In a conventional cover we might have a an earthen barrier, a clay barrier with a geomembrane or perhaps the GCL and a geomembrane and a drainage layer on top if we built it all out of just synthetic materials. And you'll see these used for low-level waste on the East Coast more.

This is an illustration of where, actually, composite liners and covers have been used in a DOE environment at Fernald, the on-site disposal facility which is a low-level and mixed waste disposal facility at Fernald, and I apologize for this type of CAD drawing, but this is the best one I had in my files.

The base of this facility has a compacted clay liner, a GCL and a geomembrane, so a triple composite at the bottom, a leak detection system, another composite barrier on top of that, a GCL geomembrane combination, the primary leakage collection system, and then the waste would be placed on top.

So that's the bottom. It's got a double composite liner in the bottom. The data that I have looked at this facility, and it's been a while since I've done that, actually indicated that these barrier systems were working extremely well.

On the top, or the cover for the Fernald on-site disposal facility, it's got a compacted clay barrier, a GCL and a geomembrane, a lot like that bottom liner that was on the facility, just placed on top, a drainage layer to conduct flow off the barrier system, an intrusion barrier, and then a vegetative support layer on top. So this is about almost nine feet thick, the entire cover for Fenald. But relying largely on composite barrier systems for hydraulic control.

If we look at mill tailings covers in the UMTRA program, these are largely earthen type covers. These were constructed largely starting in the '80s and were originally designed primarily for radon control and erosion control, and perhaps later for control of percolation into the underlying waste. And these are really entirely earthen systems where we have some type of compacted clay barrier at the bottom, perhaps a protection layer in zones where we have frost, and then a rock layer at the top essentially for long-term erosion control.

And many of these covers have been built throughout the U.S. to contain historic uranium mill tailings piles.

Water balance cover is a different type of design. We're not relying on just synthetics or plastics or clays to any degree, but really relying on a different set of natural principles where we use finer textured soils, not necessarily clays. Probably we'd prefer to have silts and other types of materials where we rely on these lawyers to store water with very little drainage and then release it back to the atmosphere. And in many parts of the western U.S. it's a very effective means to manage the water balance and prevent excessive infiltration into the underlying waste.

It's a natural system. I think the key thing is we're not relying on any barrier to block flow, we're relying on storage and then release of water. And in fact, you'll see, this type of system has been proposed for extensive use at the Hanford site for some of the remedial options out there in an ideal climate and soil resources out there at Hanford.

These -- just to illustrate, these work on essentially a balance of water, water accumulating, this is a water balance graph showing the different water balance elements. But essentially, water accumulates, this is water being stored in the cover, and then deplenishes and depletes throughout the -- deplenishes, kind of sounds like is a Sarah Palin word. I don't know if you followed some of that. I made that one up. No politics there, just thought it was funny.

So it depletes and then it accumulates and depletes, essentially storing and releasing that water into the atmosphere, and periodically releasing some percolation when the storage capacity has been exceeded. You can see that here, this red line's pulses of percolation being admitted into the underlying waste.

And we can design these systems to control these percolation pulses to very small amounts depending on what the risk levels are for that particular site.

We see in many applications in the low-level and mixed waste environments where we'll see actually hybrids of these water balance covers and composite barrier systems. The Monticello mill tailing site is a great example of this. At the bottom of this cover it's got a clay barrier and a geomembrane to form a composite barrier. It has a drainage layer on top of that made out of sand, and then above that is a water balance cover. So it actually has a water balance cover on the top and a composite barrier below that.

This has been a very effective system. Actually, Jody Waugh and Bill and I have been monitoring this for a decade now and we get about a millimeter per year of drainage from the water balance cover part alone from this system. So very effective at controlling percolation into the waste and for radon control as well.

This is another example of one of the proposals, and I apologize, this is a busy slide, but this is at Idaho National Lab for their circular disposal facility at the bottom of this. It's got a composite barrier, a soil bentonite liner and a geomembrane, a drain layer and a biota barrier, and then on top of that it's got essentially a water balance cover. So water balance cover at the top and a composite barrier at the bottom, actually both elements being used in the cover.

This hasn't been built yet. This is conceptual in design, but illustrates for these mixed waste facilities in the west how both types of systems are being proposed.

When we look at these, I thought about as we kind of go forward throughout this workshop and I think about these different materials we're using and some of the challenges we have for design life, when we're talking the mixed waste and low-level waste paradigms, we really have very long periods over which we are designing these facIlities that go far beyond our history and our experience in the engineering community.

So I think there's some really important questions to think about. And to begin with, just at the very beginning is, you know, are these systems going to function as intended, you know, with minimum maintenance for centuries or millennia? Can we engineer that in? What evidence do we have to support that's the case? What is the life span of each of the materials that we consider?

We look at an individual element, we have a geomembrane, we have clay barrier, each element, a composite barrier where we put those two together, and we look at the two different elements together, is the life span different than those two materials considered separately.

And then finally, the systems, when we talk about, for example, a lining system with a drainage, leakage collection system or a complete cover system, that's got both the barriers and the vegetation working in tandem. What is the life span of that system? How will their properties evolve over time, both their hydraulic properties for controlling the movement of water, but also their mechanical properties for long-term stability? And how will issues that we might confront in the future, like climate change, affect the performance of these systems? Will this cause the mechanisms to change, the mechanisms that we're concerned about?

Some other questions that we'll talk about, radionuclide transport, and we make predictions about radionuclide transport frequently in barrier systems. If we start building in liners in low-level systems, can we account for the transport processes in those liners and predict that over centuries or millennia? Is that practical with the tools we have, can we bound it with a reasonable degree of precision with what we know? Can we predict hydrological performance over -- can we do it for a few years, for a few decades, for a few centuries or millennia?

And another important issue is, as engineers, we tend to make things on line and grade, nice straight structures. You know, are those going to persist? Are land form revolution processes going to alter the shape of those facilities over time? I would argue they will. And can we predict that with a degree of realism?

And then finally, given these issues of prediction and long-term effectiveness, you know, what type of monitoring systems do we need to evaluate whether we're meeting our goals and whether the elements, not only the facility itself, but the elements within that facility, are functioning properly?

All right. So hopefully that sets the stage, Tom.

TOM NICHOLSON: It certainly does. Thank you, Craig.

Our next speaker -- actually, it will be two speakers we're going to put this also first we heard from Hans, the background, we heard from Craig, a very excellent presentation on engineered barriers and questions to evaluate the performance.

Next we'll have an overview of engineered barrier performance and regulatory compliance criteria.

Jake Phillip is a civil and geotechnical engineer in the Office of Research, he has been with the NRC for 30 years and in private industry for 13.

In the NRC he has authored safety evaluation reports for the foundation design of several nuclear power plants and the stability of uranium mill tailings dams and environments. For the last several years he manages research on long-term performance and effectiveness of soil and cementitious engineered barriers for waste disposal and offers regulatory guides for the design and construction of nuclear power plants. Jake has a BS and MS in civil engineering and is a licensed professional engineer in the State of Maryland.

At the podium is David Esh, he's the senior systems performance analyst in the Division of Waste Management and Environmental Protection of NRC. He has over 15 years of experience in performance assessment of radioactive waste disposal. Dave has a Ph.D in environmental engineering from the Pennsylvania State University at University Park and he is a modeler.

Dave.

DAVID ESH: Thank you, Tom.

I concur with Craig's comments that I think this is a great opportunity and I think it's the most important thing for us is going to be to follow through. So, after we're done and we get to the last day and we do our synthesis and we put everything together, then we have to take that and do something with it, do some action with it.

And hopefully, that action will be action by people like myself who's responsible for performing reviews and writing guidance and in come cases developing regulations, and also for my counterpart here, Jake, who many times we will get into a review or work on a problem and we'll find, okay, we'd really like some more information about some aspect of the problem, and so we look to our research group to go out and get experts like yourselves and generate that information for us.

So today, I'm going to give you an overview of engineered barrier performance and some of our regulatory compliance criteria. And I hope that we've met the minimum requirement of pictures to keep your attention during my 15 minutes or so.

I'm going to go over a little bit of background and some references, some experiences just very brief because I think many of you in the audience are going to provide detail on experiences that we don't need to double count here.

And then Jake's going point go over some of the recent research in this area that they've performed and our view of the goals for the workshop. Hopefully, they agree with the goals that management described when we started.

A little bit of background. Engineered barriers are used in a variety of our regulated activities from low-level waste facilities to decommissioning sites. We work on independent technical reviews of activities that the Department of Energy performs, they're called incidental waste reviews, which involve secondary waste generated from high level waste processing as well as closure of the tank systems throughout the DOE complex.

Lots of different types of barriers. I know we're focused on covers and caps primarily and liners in this session, but I would note that when I look at engineered barriers and when I work on engineered barriers, waste forms are a very big component of that and a lot of problems. And the types of engineered barriers that you use are going to -- or the problem that you're working on is going to be greatly influenced or should be greatly influenced by the types of barriers that you use.

So if -- and in the radioactive field, we have waste that's sort lived, moderately lived and very long lived. The types of engineered barriers and system designs that you use are going to be different depending on whether you have short lived waste or very long lived waste.

And especially the design of engineered barriers may have different considerations whether you're trying to meet a long-term performance objective or a shorter-term performance objective. So keep that in mind as we go through the workshop.

Our engineered barrier performance can be very important for compliance with regulatory criteria. So in some cases the natural systems don't do it enough themselves, we need engineered barriers to try to meet the criteria.

We do have a variety of guidance sources for staff and licensees to hopefully facilitate this, but we realize that, as Hans indicated, in human timeframe, this is a relatively new endeavor and we're always learning new things, and so we always want to take a step back and say okay, what do we have, what's been learned, how can we change it, how can we do better? And so I think that's part of the purpose why we're here.

Experience with engineered barriers has been mixed. I think sometimes engineers may be a little overconfident with what they can do with engineered barriers and scientists are probably under-confident with what you can do with engineered barriers.

I have a good joke about scientists and engineers, but I'll save it for my talk later in the workshop. That way I won't offend the one group disparately and have their attention negatively focused towards me the rest of the workshop.

Some key guidance documents.

Now, this I indicate is key because we have a lot of guidance documents. These are just some more heavy hitters that provide you a concise source of information if you're looking for it.

NUREG-1757, in September, 2006, that was revised and we added a section on engineered barriers. We tried to cover all engineered barriers relevant to decommissioning. We're looking at a more risk informed approach to the use of barriers there, not a prescriptive approach, which is common in older regulatory approaches.

In NUREG-1854 we developed guidance for incidental waste, and there's a section on there on engineered barriers, 4.32. It covers covers as well as cements and it's also what I would call a risk-informed approach, it's not prescriptive.

And then for uranium mill tailings we have NUREG-1620, it's June, 2003. It covers primarily geotechnical erosion protection, radon mitigation.

Low-level waste, we have a monitoring document, it's a little bit dated now, December, 1989. And then we also have a general document on erosion protection, NUREG-1623, September, 2002, and then NUREG-1573 for low-level waste, that's kind of low-level waste performance assessment methodology. So 2000, you know, that's a decade old now, but we're at the point of, I think, doing a reassessment and I think it's a good point because we have a lot of interesting problems that are coming our way.

So here's a few of my minimum picture requirements, the low-level waste. Early designs did not necessarily perform as expected. A lot of them had this bathtub effect happen. And the original conceptual model was let's put the material in a low permeability setting and then we'll cover it back up and it was low permeability, it should keep all the water out, right? Well, it didn't really work that way.

You can see in the pictures at the bottom, the two in the lower left, there's actually a reflection there because there's water in the bottom of the trench as they're filling it. And the main, I'd say, problem with that design or that approach was they underestimated the impact of man's disturbance on that low permeability environment when they put the system in.

So, those designs though, there was mitigation done and action taken, you'll see on the right the solution. In this case it was to put a geomembrane over the facility and that geomembrane is periodically replaced. But that combined with some slurry walls and a few other things were enough to mitigate the problem that was seen.

This was common to a lot of early low-level waste facilities, primarily at the more humid locations. They used relatively simple designs. So when Craig was showing his pictures of all the engineered facilities up there, think like the very simplest that you saw, they were primarily that type of design. The other ones weren't really in existence at the time.

And field scale experiments were very limited, they just didn't do that sort of evaluations prior to implementation, and very limited NCT monitoring performed also. Performance at arid sites has been pretty good though, all things considered.

For mill tailings, the primary function of the covers at those sites are a couple of different components, provide sufficient protection to limit radioactive material releases, that includes radon, it includes groundwater and also includes something that Craig mentioned, keeping it in place. That's a big thing is you want to keep it where you put it.

So those are designed to provide some form of long-term -- some amount of long-term stability, and also the concept is to allow for -- or to provide -- they shouldn't rely on active monitoring and maintenance, or active maintenance, so minimal maintenance design.

NRC takes that philosophy with waste disposal. We believe that because of the uncertainties associated with the long term in predicting what's going on with society, if you're dealing with these problems today, you should be trying to solve the problem today with a solution that has minimal impact on future generations as best as you can do.

So these tailings are overlain by engineered covers that include radon barriers, as Dr. Benson showed. The radon standard, you have to evaluate that it's met after construction, and at this time we're not aware of subsequent problems. I know Jody Waugh is here and maybe he can talk about that in more detail later in the workshop.

The groundwater performance has been mixed, have noticed some things occurring with groundwater, but it's not necessarily to cover performance. So whenever they're doing mill tailing management, those tailings are pretty wet sometimes and they're disposed of pretty wet, so they have a lot of water associated with them and it has to go somewhere.

So you have a lot of variables in the problem and a lot of things that could be causing something that you see, so you have to be careful where you assign that impact from.

And there's couple of pictures. I think prior to doing the guidance in NUREG-1757 for decommissioning, we had the opportunity to go out and see some of these facilities, in the west primarily, and they are really impressive. I mean if you get a chance to be around one sometime, I'd encourage you to go see them.

You see the picture here on the screen. Some of the pictures Craig had, had a better example of scale, they're really, really massive activities and they're impressive to see in person.

And then, for incidental waste where we don't have regulatory authority and we're kind of an independent technical reviewer, in the most case those designs are yet to be implemented. And I know we have some people here representing the Department of energy. Those designs tend to be more towards those modern complex or more complex, multi-layered designs that Craig had in his presentation.

So I think that's it for me.

And now Jake's going to go over some of the recent research that we've had done.

JACOB PHILLIP: We started out because I had seen some work in the literature, a lot of it was Craig's work looking at the performance of covers and so we went to the U.S. Army Corps of Engineers and asked them to look at the effectiveness of clay soils. And they were basically looking at desiccation of clays and drying of the clays and its effect on the permeability of the clay.

And what they found out from their work, which was conducted between 2005 and 2007 was that cracking in soils is diverse along the surface and it extends downwards. They did not heal with time. I mean once you get a crack, it doesn't heal. Even if you get a big pulse of water, it does not heal and make the crack go away.

Hydraulic models that are existing cannot actually predict those changes in the permeability of these clays that crack. And what the corps did was it did some lab experiments and then did some model simulations to predict cracking as a function of tensile stresses which caused the stresses that caused that cracking.

A little later in 2006 we had a project with the USGS and the USGS then the work was conducted in western Wisconsin and clay -- and Craig was the, Dr. Benson was the project manager.

And what he found in some of the work that he did -- and basically what he was doing was the ACAP study which was done under EPA, and we contracted with the USGS and we just conducted through the University of Wisconsin, was to go back and exhume those covers, those field scale covers and find out what worked, how did it work, what were the properties of the materials. And some of the conclusions are there that (inaudible) properties of clay soils do not retain their as-built properties.

Mostly given the type of equipment you have in the field you can actually compact clay soils to something like ten rich to minus 8, and even (inaudible eight centimeters per second permeability, but we found out that very soon, within the ten years of work that Craig was doing, that they're not retaining those properties and the properties that clay can be, the permeabilities can be much higher than.

And he also looked at the effectiveness of geotextiles, or geosynthetic materials, including geosynthetic clay liners, geosynthetic membranes, and geosynthetic drainage layers.

The performance, like Craig mentioned earlier, that clay liners, some of them worked well under certain conditions.

The drainage layers for the period of the research worked pretty well. And the geomembranes performed, mainly looking at the antioxidant rate, that they performed just as specified by the manufacturers for that particular product, depending upon the product, because geomembranes can be different types.

So based on the manufacturer's specifications for the different products, it seemed to work well.

We have a current U.S. NRC project again with, through the USGS and being conducted at the University of Wisconsin. We are looking at the coupling of erosion protection which is mostly riprap, and the hydrologic performance. Because you can just visualize that if you have riprap, you would feel the infiltration would be going in and there would be less evapotranspiration which would look at this competing attributes and look at a way that we can do -- have a cover which is good from an erosion protection standpoint and also from a hydrological standpoint.

The work started in 2009. We should be getting the first report pretty soon to review and look at them to find pertinent models to predict erosion and hydrological performance of covers.

Then once he looks at those models, he takes a couple of the best models and see how field data can compare with the model predictions, and then later on to look at evaluation of erosion protection strategies.

This is -- I'd like to play that.

This is a project that we had with U.S. Army Corps of Engineers, and what they did was this was a laboratory study on the cracking of clays. And this actually this cracking was first compacted to 100 percent, or close to 100 percent, 90 to 100 percent of (inaudible) density with optimum moisture content. And then, then they dried the clay, dried it in a controlled environment, and over a day you can look at the way that the clay cracked. This is all over one day.

Finally, the goals of this whole research and licensing issue, like Dave Esh talked about, we have to identify relevant research to improve our understanding of the assessment of covers, identify gaps in current understanding of these covers, and identify opportunities with people, researchers in the field for collaboration and synthesis of these experiences. Thank you.

TOM NICHOLSON: And now we'd like to get Session One going and that is with Steve Salamon and Susan Jablonski, and I'll let you introduce each other and any other members that will be coming up.

STEVE SALOMON: Hi, I'm Steve Salomon and I'd like to introduce Susan Jablonski who's the director of the Radioactive Materials Division at the Texas Commission on Environmental Quality. She manages the Texas regulatory programs for various radioactive materials licensing and underground injection control permitting and authorization.

Susan is also a health physicist and a professional engineer. She previously served as a director of the health physicists at the Texas Low-Level Waste Disposal Authority until transferring to the TCEQ.

She received her undergraduate degree in radiological health engineering administered by the Texas A&M Nuclear Engineering Department, and her graduate degree from the University of Texas at Austin in environmental health engineering.

Susan.

SUSAN JABLONSKI: Thank you, Steve.

I also am going to introduce Steve who is cochairing this session with me.

He is a state programs technical analyst in the intergovernmental liaison branch of the Division of Intergovernmental Liaison of Rulemaking. He's currently where he interacts with states on a wide variety of technical issues such as groundwater contamination near nuclear plants, radioactive waste transportation and emergency response.

He has been the agreement state program liaison to the states since the Low-Level Policy Acts were enacted in 1980 and ended in 1985 working on interstate compact formation and alternate disposal technologies.

I'd like to thank Steve for helping me in taking the lead on planning for this session.

My presentation today is going to focus on a planned disposal facility, and the timing of this workshop, I know several folks have mentioned how relevant it is, and it definitely is for us in Texas, being as we're embarking on construction and operation of a new disposal facility.

I want to give a little bit of background. I've been asked, you know, why is Texas in the place that it's in, and I have a couple of slides to kind of go through where we got to to where we are right now with the new planned disposal facility.

There are actually three different state agencies that regulate radioactive materials in our state, which make it a little complicated. But we particularly at the Texas Commission on Environmental Quality focus on the disposal regulations in dealing with waste.

I'm focused in this presentation on low-level waste disposal, although we also are dealing with other kinds of waste, we have Title 2 uranium and tailing impoundments in our State, as well. We also have a dedicated new 11e(2) byproduct material facility and we also deal with norm disposal by deep well injection. So although we are -- there are parts of this workshop, and my colleagues from other states are going to be focusing on some of those other technologies, I'll be focusing on low-level waste disposal in my presentation.

I mentioned the new policy, and in Texas we have been endeavoring to try to fulfill the policy acts that I mentioned in Steve's introduction, since 1980.

And at that time -- he also mentioned I was formerly with the state agency that was charged with a Government run, Government owned facility.

And unsuccessful attempts to site for various reasons occurred in our state over two decades. And in 2003, the State looked at new legislation to privatize low-level waste disposal in our state, which basically brought about a whole new discussion of criteria for disposal. And in Texas there was some unique statutory requirements that have to do with engineered barriers as well as additional barriers that were actually put into law in order to allow for privatization.

There's also other components of it that talk about condemnation of private mineral rights, looking at mixed ways from a federal facility that would be adjacent to a State facility and looking at specific regions within the State that would limit siting to a more arid environment.

Additionally, our legislature looked at consolidation of dealing with radioactive waste management and disposal across the Board, and because of that, in 2007 the Texas Commission on Environmental

Quality expanded its role in looking at uranium and other potential disposal methods that weren't part of our legislative platform until 2007.

I mentioned siting criteria that really focused on a part of state and I've highlighted in yellow the section of the state that was focused on by the legislature for a potential siting, which was a new area for the state. We were typically looking at far west Texas previous to that, there's also areas in south Texas, and this focused on the panhandle region for various reasons.

There were some statutory criteria looking at rainfall, getting away from the Texas-Mexico international border, as well as river segments that impacted the Rio Grande.

And so that put us in the region -- and I put a highlight here where Andrews County is where the planned site is to be located.

It's a unique license that was proposed and issued by my agency in that it looks at two separate and distinct facilities under one license, the compact waste disposal facility which would be owned by the

State and a federal waste disposal facility which would be owned by the Federal Government, by the DOE in particular.

There's further breakdown of what facilities will be on those two facilities. It's a smaller compact waste facility that is supposed to be full service, taking Class A, B and C low-level waste. I mentioned the statutory criteria which looks at steel reinforced concrete canisters, filling with grout and an additional concrete barrier that was required by statute.

And then a larger federal facility which actually has two separate disposal units, one for soil only and the other for containerized waste, which would also need to go into the concrete barrier and an additional concrete canister. And then there's a common area to these two facilities for receiving, laboratory and offices.

The one thing that was unique to our statute, as I said, that these facilities, although they could be under one license, that the State had to be indemnified in order to actually take on this additional facility for federal facility waste, and they had to be separate and distinct. And although there's a fence, there is some redundancies in monitoring as well as modeling and other aspects to these sites that make it unique.

I focus first on the liner, and as I mentioned, we're looking at planned facilities. Because the federal facility can take mixed waste, there is a full compliant RCRA Subtitle C liner system proposed for both the containerized and uncontainerized portion of those facilities.

The concrete barrier concept, although it's being used at other low-level waste facilities, has kind of taken a step further in this design in that the compact waste facility always would be put into a concrete barrier. And this additional concrete barrier is kind of an envelope to the entire cell. So although there's a clay liner, there's an additional shotcrete liner made out of concrete that was judged to be technologically equivalent to reinforced concrete.

One of the aspects of monitoring this plan is neutron probe access tubes which will be installed in the trench, and the ideas are -- adjacent to the trench, is that those neutron runs will be made ahead of time looking at moisture profile and they will be then tracked over time to continue to monitor possible changes in that profile.

The cover, you know, is a hybrid of all of the information that we've received and is kind of what is in the forefront with the new design coming out for the facility. The advantage we have is we have not built Anything Yet.

And so it has -- it's an ET cover, primarily, this is in a more arid part of Texas, and so it's one of those hybrids that we heard about earlier this morning that has both storage and those composite layers as unique parts to it.

These are just some quick drawings which I'm not going into too much detail that are included in here that look at kind of the subtle differences between the compact waste facility and the two federal waste facilities.

As I mentioned, it has both a liner and has some of the same features in the cover that's planned.

For the containerized facility, because it is taking, the plan is for mixed waste, it has that double composite feature to it. And for the soil only, again, same double composite, but not the barrier, the concrete barrier, the shotcrete barrier's required in the soil only cell.

We did a lot of modeling. And because we don't actually have a facility on the ground, much of that was relied upon in order to make decisions about what features were going be acceptable into the design.

And so one of the things that were used is the SAP Code in order to look at the barrier and liner system. We also used @FLAC, which pretty extensively the applicant used both the 2D and 3D version of that to look at seismicity and the overall stability of the site, both while the facility is open and then once the facility is actually closed and the cover is in place.

And so as we as look to those @FLAC models, there was some complicated runs that were done on that to look at the longer behavior of the disposal units and the soil structure interaction. And we were able to look at some of the perspective possible attacks to that system that could be simulated as well in those codes.

Help was relied upon to look at infiltration at the site as well as VSTDI, and these are still things that we're looking at as possibly looking to what monitoring would complement these models as we move forward, and then possibly looking at any changes that might need to be made as we learn more and more about the site as we move forward.

One of the other focuses is erosion.

In this area of Texas it's an important parameter, especially looking at the long terms. I didn't mention, but one of the other aspects in our rules have to do with looking at peak dose, and it's a period of a minimum of 1,000 years up to peak dose. And there was a policy decision, with a lot of input from stakeholders, that we really needed to look at much longer terms associated with low-level waste. And that's probably unique to Texas and some of our other counterpart states, who looked at rulemaking not in this decade and got the kind of input that we did on looking at very long terms.

And so, we utilized SWAT to kind of look over and review the information provided in the application and are still looking at the possibility of how that can be entered in future codes.

The applicant relied on RSSRAD and we did modeling in RSSRAD as well as part of the initial application review. And the license requires a more sophisticated, complex model that can kind of take in all of these other models and take those parameters and really look moving forward at the site. And we have kind of followed the lead of the NRC looking at @Golsin to be a platform to be able to do that.

And so we are currently looking at @Golsin to build a platform for this site in particular and have inputs for the other codes that are able to tie in to an overall assessment of the site moving forward. And we feel like it has the potential for us to be the model that we will use going forward.

As I mentioned, we are using site specific data that we plan on collecting, and in this workshop in particular I'm taking extensive notes and my staff is on line listening to look for what kind of sensors and what other kinds of measurements should be taken in the field as we endeavor the next kind of segment beyond the modeling for our site.

And this kind of just goes a little bit more into the profile information, we have some designation in the licensing of the kinds of sensors and the kind of measurements that we plan for the operator to take at the site, but we plan to keep that informed as we get information and learn more about the state of the art of what will work in the area of west Texas that we're focused on.

So that's the end of my presentation, and we're going to move on to the next presentation.

I would like to introduce Loren Morton who is a senior engineer with the Division of Radiation Control with the State of Utah. He has a Master's degree in geology from Brigham Young, and has been a hydrogeologist with the State of Utah for ten years. He has experience with groundwater hydrology and licensing issues related to the Clive Utah facility. And he's talking about the Clive low-level waste Utah facility this morning.

LOREN MORTON: Okay, thanks.

Well, good morning, ladies and gentlemen. I'm Loren Morton, I work for the Utah Division of Radiation Control. And I've got the challenge today of trying to condense about 20 years of work by our licensee, Energy Solutions, and by State staff in coming up with engineering design for covers and liner system.

So, to kind of get this moving right along.

Today I'll try to outline what I'm going to present. We'll talk a little bit about monitoring technology, short- and long-term types of monitoring, the models we have used to try to evaluate the cover systems and their design. We'll talk about policies that we arrived at in putting all this together, approaches we used, and I'll mention a few of the sensitive inputs and assumptions that kind of came out of the work we did.

This here is an aerial photograph of Clive Utah. It's about one square mile from these dimensions, here to there to there and back up again. It's located about 70 miles west of Salt Lake City, it's on the margin of the Great Salt Flats. Average annual precip there is in the neighborhood of about eight inches per year.

Three of these -- four of these cells receive low-level radioactive waste. They're found in low activity radioactive waste cell or LARW cell, a Class A cell, a Class A @nor cell, and the mixed waste cell here where RCRA hazardous wastes are commingled and codisposed.

The cells here labeled in black is the vitro cell which the State of Utah helped, with DOE funding, move the vitro tailings out of Salt Lake City out to the desert and then Energy Solutions constructed an 11e(2) cell for Title 2 materials. And it's approximately 25 percent constructed at this point.

Okay, I'll going to spend a little bit of time going over the evolution of the cover systems. And not to bore you, but hopefully it will help you, I'll build on some of this discussion later.

Prior to 1998 -- and before I jump into this, let me, the colors here are meaningful, and being a geologist, you know, you learn colors are important.

Engineers -- my bosses are engineers and they've never quite understood the meaning of that, but it's an inside joke anyway.

Here, the orange layer at the top is our riprap layer. And on the top slope the D50 is about an inch and a quarter, thereabouts. And then there's some yellow layers here, and these are graded sandy gravels and the permeability is fairly high. And then I've got some green layers. Here you'll see a sacrificial clay and then the radon barrier had two layers in it and then a clay liner below.

Now, prior to 1998, we were trying to force water that might infiltrate into profile out through type A or the upper filter. And that was going on at this interface right here. And then to try to make sure we had a stable filter underneath, we laid down a geotextile, the company did. When I say "we", I guess we are both implicated in this.

Later in a license renewal process, we identified some opportunities for improvement. One had to do with having very fine materials next to coarser materials. There was a filter stability issue.

And two, the plastic materials that made the geosynthetic woven material could break down in long periods of time. So we needed to replace that material with something natural.

Another complication that came up as we thought through it was because these two materials above are sort of open and porous and very permeable, there could be a lot of desiccation in the sacrificial clay which would increase its permeability and therefore it might not perform like we hoped.

And third, there'd be freeze and frost heave in that layer as well.

And so, we weren't exactly alarmed at the time because we had the redundancy built down here. We had another filter B, and this upper radon barrier, it's permeability as constructed was 5E minus 8 centimeters per second, and the filter B was running at about three, three and a half centimeters per second, so it was a seven-fold or more than a million times permeability contrast.

But, yet, still we needed these filters to be stable in the long run. So in the license renewal process our upgrades were like this.

We replaced this, what was clay over here with a silt loam. And this we would hope, it had a higher moisture retention property, and it could -- we weren't counting on it for internal routing of fluids. So if there was frost damage or desiccation in some degree, it was inconsequential.

The actual diversion we wanted to have would be right down here at the interface between the type B filter and the upper radon barrier. Again, seven order of magnitude permeability contrast.

The sacrificial soil would hold on to water retention that created a thermal buffer so we weren't going to see frost damage of this radon barrier, and it was less likely to have cracking develop in it.

Looks like our meeting is over.

Is it time for a coffee break?

Okay. Now, beginning in about 2004, we carried on some of these same design concepts. Is that arrow showing up there -- okay.

Let's see, but we refined some of our radon modeling, and as you notice here, we had a lower radon barrier layer that was six feet thick. With revisiting our radon models, we could actually thin that down to just one foot. And so that change was made beginning in 2004.

And across all three of these profiles, near the center of the cell, the waste thickness is on the order of about 43 feet. Okay.

Now, in terms of short-term monitoring, I tried to think how to go about what I could discuss and the thought came to me to talk about the pan lysimeters where we do place small basins below the clay liner and we have gravity drainage out to an observation manhole.

Now, these things are qualitative devices in our mind and they're made possible because the depth of the groundwater at this site is 25 feet below surface, and that in turn means it's about 15 feet below the clay liner. So there is room to get in there to build these basins and run the piping we need.

And in cross-section, these devices look like this. So our waste would be constructed on top of the clay liner, small basin lined with high density polyethylene and granular backfill, and then gravity drainage out to a collection manhole.

We look for fluids there occasionally. And we'll talk about that a little later.

Oh, here we go. Oh, well, then, we're going -- we will move forward.

We'll skip the short term and talk -- how much time have I got? Okay.

Our long-term monitoring is mostly on groundwater, which we do with wells.

And we found that the pressure head issues -- the groundwater is very saline, high (inaudible) solids on the order of 50,000 milligrams per liter. So there we had to do measurements with -- convert saline measurements of head into freshwater equivalent.

And -- but we did find out that velocities are about one to two feet per year, so that allows us to do groundwater quality sampling once a year and head monthly.

We've found there's been some complications with some -- how we manage surface water at the site, and that has in some cases created artificial recharge mounds, which has altered groundwater flow directions and velocities.

We also have shallow wells and some deep wells in nested pairs. We look for hydraulic gradients both in the horizontal and the vertical, the site naturally has an upward rising flow from the deeper aquifer, and that's important, but there has been some reversals of gradiant due to some of the storm water mismanagement, and the company is working on trying to reverse some of those problems.

We made a policy decision back in 1991 that we would protect a saline aquifer. Now that sounds odd. But we saw it as a means to an end.

First, we wanted to encourage the best available technology. And we knew that PA, or performance assessment modeling would help us back into a good engineering design that way.

Secondly, we wanted to protect the long-term public health and the environment of our citizens in Utah.

And third, we knew that the added cost of that extra disposal, those extra requirements for containment more rigor would be borne by out-of-state generators. And that would be a way of protecting our citizens.

So we have State groundwater quality standards and we found some contaminants that were natural and we set protection levels on a well-by-well basis. And we looked for some of the key isotopes are mobile, being fission products, and occasionally, we adjust protection levels where warranted. And that's been mostly those that are redox sensitive who appear to be altered by the artificial mounding that we've seen nearby.

The models we used were EPA Help, UNSAT-H, and @Pathway 1-D. They were deterministic in steady state. The domains were one and two dimensional and our period of performance we set at 500 years, we matched that up with NUREG-1199 and 1200 that had guidance on engineering stability or integrity.

And we're done.

SUSAN JABLONSKI: Next, I would like to introduce Susan Jenkins with the South Carolina Department of Health and Environmental Control.

Susan has a BS in ceramic engineering, an MS in bioengineering from Clemons University, -- Clemson, I'm sorry, University, and she began working with the waste program in 1997. And she currently is the manager of infectious and radioactive waste management program.

SUSAN JENKINS: Thank you.

It is good to be here today.

The Barnwell site started operating in 1971 and it's a 280-acre site, it's owned by the State of South Carolina, it's leased to Energy Solutions and run by Chem-Nuclear Systems. Not all of the area is suitable for low-level waste disposal, but 120 acres have been used to date.

The disposal practices have evolved over the years, but currently, we use three types of engineered barriers, we use the trenches, vaults and enhanced caps.

The regulation requires that these engineered barriers be designed with physical and chemical properties to last for the institutional control period, which begins after closure and is expected to last about 100 years is what we currently have it set at.

The trenches are designed to prevent water from accumulating in the waste zone. There's not a synthetic bottom, but we do have a virgin clay bottom which retards percolation. It is a clay sand so we do not experience the bathtub effect and have no need for collecting @leakage and possibly having to treat that.

The bottom elevation of the trenches are sited at least five feet from the highest historical water table elevation.

The use of vaults was incorporated at the site beginning in 1989. This is a time when there was some concern expressed over mechanical creep in high density polyethylene that was used in the high (inaudible) containers at the time. So we began using the vaults then for classes B and C waste. But in 1995, there was a regulation put in place that required the use of these vaults for all classes of waste.

The vaults are designed to last for 500 years, and for Class C waste they also act as an intruder barrier as required by regulation.

We use a fine to medium sand for backfill and that's to reduce void places, and we do expect these vaults to help stabilize the waste zone for the future and to help support the caps that are placed on top.

We do use a conventional cover. It consists of -- we have the bentonite clay layer as well as a geomembrane, and this is just a schematic showing these layers and showing that design.

These are just some photographs taken of some recent cap installation. As you can see, over here, this is the GCL and then on top we have the geomembrane and of course placing the soil on top.

There are 120 acres capped at this site. This completes the phase one closure for site, which ended when the site was closed, and only opened to compact waste. And the caps were constructed in nine phases of construction.

The first phase was constructed, it's down here, in 1991, and the caps -- the idea of the caps came from the fact that in 1991 we saw tritium in a nearby creek in higher concentrations and sooner than expected, because the site had been in operation for 20 years. So tritium started showing up in the creek, so we began installation of these caps at that time.

And the disposal practices -- this cap does cover the very first trenches. The disposal practices at that time were not as advanced as they are today. There were liquids disposed, there were @simulation vials, a lot of tritium, there were organic liquids that were disposed. There was a time when they started using a absorbents such as vermiculite and @diatenatious clay, but they weren't using it solidification practices like we require today.

So we do think that the waste form is a very important piece of the puzzle and we're hoping to see better performance, you know, in some of the later trenches, and we do believe that this southern trenching area is the source of the tritium plume that we see at the site today.

As for monitoring devices and systems, we use salt monitoring, we do visual inspections of the caps after significant rain events and routinely every month the caps are walked on foot looking for variations. There is an extensive groundwater monitoring network. There's 182 monitoring locations that excludes the sumps, that consists of on-site wells, off-site wells, and samples collected in the surface water and surrounding the creek. The samples are taken quarterly and we look for radionuclides and VOCs.

This is just a map illustrating the tritium concentrations that we're seeing in Zone 2 wells.

Just to give you an idea, this is that Phase One cap area that I was talking about earlier. This is where the oldest trenches are located. The highest concentration at the whole site, on site, is currently at this location, WM 110, about 21 million picocuries per liter, and it is adjacent to and directly south of those trenches, and the tritium plume is traveling this way towards the creek.

At the headwaters of the creek we are seeing about a half million picocuries per liter and here at the compliance point, which is where the creek flows off of Chem-Nuclear or Energy Solutions' property on to Savannah River site property, we're seeing about 100,000 picocuries per liter, and that, since this is a tritium driven plume, the hypothetical dose at that location, although there are no consumers there, equates to about 5 millirem per year.

The engineered barriers performance short term, well the trenches seem to be intact, as are the vaults. Most of the trench vaults are dry, so we believe that the caps are working to prevent that infiltration. Tritium levels in the sumps have been background since 2007.

The earlier caps before the enhanced caps were clay caps and I believe there was a synthetic liner, but it wasn't very thick, and I don't know how well it performed, but these enhanced caps were placed over it.

But we did have a lot of problems with settlement in the early days and subsidence over those older trenches especially. Here with the enhanced caps we've had four incidents needing repair dating back, first observed in 1998 and 2007. Those repairs were made in 2005 and 2009.

But in the process of repair, we were able to inspect the condition of the cover, and there were no beaches to the cover, the GCL was intact, as was the geomembrane, so there were no significant failures. It was mainly a settling or a slumping over several maybe 1,000 acres -- excuse me, 1,000 square feet were the locations. And all of these incidents were on the phase one and two caps which have the prefault trenches beneath. But the current data shows the site meets performance objectives of the (inaudible) limit at the compliance point, and again, there are (inaudible) receptors at the compliance point.

Will engineered barriers perform long term? Of course all of these barriers have limited life spans. We, at our site, we are mainly depending on the vaults to support the caps and we're depending on the caps to help mitigate the tritium plume, which we don't expect to be a problem in the very long term since tritium has such a short half life.

But we are using modeling and annual training reports to predict future compliance and currently we're evaluating all of the performance objectives for the site because we've completed phase one closure activities.

This is just showing the trending report, it looks at 27 locations down the center line and the border of the plume, we have about a third of those sites showing an upper trend, a third a downward, and a third are not showing an upward or a downward trend.

This is one example of that. This graph is showing the tritium concentration at the compliance point down at the creek, and it begins in 1998, and you see there's an increasing trend here through about 2001.

2001 marks ten years after the installation of those first caps. And so after that, we have not seen a trend and we are hovering around 100,000 picocuries per liter down in that area.

So, is it conclusive evidence that the caps are working? Maybe not, but it is a good indication that we are getting some support from that.

And actually, let me just go back, one thing I forgot to mention here. The well, WM 110 that showed the highest concentration, it tends to be driven by the water level, so it fluctuate quite a bit. And what we think is happening is beneath those trenches there is like a slug or a mass of tritium and so that water level is coming up and basically flushing it out over time.

Practical insights on monitoring the vaults and free-flowing material we're hoping is going to improve the stability. We think frequent routine maintenance and inspections are key. It is a good idea to leave some monitoring time between discovering maybe some problems with the cap and doing that repair, it gives you time to monitor that and see what's going on, and it's a good idea to reduce penetrations through the cap because the cap does tend to move and those penetrations are often rigid, and so that can be a problem.

Early models predicted 400 years for the water to get from the site to the creek. Later, it was said it was 50. Now, we know, using tritium as a tracer, that it takes about 20 years.

We've used groundwater modeling, (inaudible) and we're currently developing a new model as we speak. We are beginning that process and it will use (inaudible) and MT3DMS.

In summary, we think all the engineered barriers work together to enhance performance, and again, waste form is a very important part of that. We expect our engineered barriers to mitigate but not eliminate the current tritium plume. We're not using direct modeling of the engineered barriers per se, we're just using other indicators of their performance and the groundwater model is showing that the performance objectives will continue to be met.

SUSAN JABLONSKI: Thank you, Susan.

Next, we have Gary Robertson with the State of Washington to talk about their experience with decommissioning evaluation of cover designs for low-level waste in uranium mill tailing facilities.

Gary has 27 years of experience with the Washington State Office of Radiation Protection. Since 2002 he's been the office director and prior he supervised the office's waste management section, that includes both the commercial low-level waste facility and three uranium mills and a major waste processor. Gary is active in the Conference of Radiation Protection Program Directors, and the organization of agreement states.

GARY ROBERTSON: Hello.

Washington state has a unique history with low-level waste and uranium mills.

The first uranium mill was built in 1956, the low-level waste site started operation in 1965, well before the regulations were established.

I'm glad Jacob showed photos of clay barrier potential failure.

One of the first closures we did was at Western Nuclear, it's a facility that was operated by Phelps-Dodge. Their closure plan included a three-foot clay cover that we rejected mainly because the Ponderosa pine, but also with concerns of cracking and bio-intrusion.

We had them go back and look at a thick homogenous cover that would be self-healing, lots of fines, 14 percent clay mixed in it. If root penetration did occur and a tree was toppled over, it would self-heal. We really focused on NUREG-1620 for our evaluations.

Now, I'm going to just take you on a tour of the Western site from beginning to end, and the site has been closed for 13 years.

One of the issues that we first faced was rock durability. And fortunately, I had staff on-site every time there was a sample taken, and we did randomly sample each screening exercise. Later, there was an accusation that there was selective screening and sampling of the rock, and that's just not true.

This is a diversion channel. Western is located in a mountainous area. The channel can take 5500 cfs, it's deep, there's lots of rock in there.

And this is -- the diversion channel is up in this area. This is the tailings impoundment area. The cover is 11 to 16 feet thick.

When we finished the site, I walked around with the tribal elders and they saw a site that looked like this. They weren't happy. I don't blame them.

We had had the company remove all of the debris, rocks, stumps, you name it, and in the end, we had the company bring all that material back so it was more conducive to the animals in the local area.

This is the site as it sets today. You can see up in this area there's animal tracks. They belong to horses, wild horses, buffalo. This is one of our geohydrologists, and this is one of the Ponderosa pines that we had planted on the site. We jump started the climate's plant community in the area.

This is a road into the site and we wanted to keep it as natural as possible. We had a rock barrier to keep ATVs and all terrain vehicles off of the site. Somebody moved the rocks. And this site belongs to DOE now, they are responsible for the site.

It's probably the only site in the country, I would believe, that was designed to have a pond in the middle of it. It's a seasonal pond, it's probably five acres. It has a nuisance attraction. You can see the tracks. Now that the barrier is open, everybody wants to come in and drive through the mud puddle.

One interesting fact, the animals coming down to get drinks actually leveled this out. We've been watching it with the DOE stewardship program and it ends up being self-healing.

Another area that I wish I would not have left was this building up here. It's another attractive nuisance, all the copper has been removed. All the covers, metal covers have been removed. Folks started taking the roofing material and a 24 year old died, and this isn't Native Americans that are doing this, this is folks in the Spokane area.

Just another shot of the diversion channel.

This is a monitoring well. And one of the interesting facts with Western is that up-gradiant, we have 200 picocuries per liter of uranium, down-gradiant, we have less than six. So, we ended up not looking at uranium to decide if the bottom liner is failing, but sulfate and chloride.

This is a monument. If you notice over here, it did say 500 feet. It's not linear with the rest of it. That's -- I've always wanted to go back and somehow put a number in there, a thousand feet.

This is U.S. Ecology. This is disposal practices in 1972. 2002, these are environmental bags, steel boxes, engineered concrete barriers. This is a Trojan reactor vessel that was buried at U.S. Ecology intact. So we have a wide variety of waste streams, over 622 isotopes are located at the site.

This is just a simple drawing. The importance here is to get the cover on the site as soon as possible, and one of our lessons learned is the next trench, we'll closing it as you go instead of leaving it.

This just shows the drying point. We estimated the cap would fail at 500 years.

This just goes out to 10,000 years and it gives you an idea of the error bar in calculating standards.

This is the tritium plume and out at after cap failure around 800 years, the mobile fractions of uranium. Then Carbon 14 and iodine, and way out there, 100,000 years, uranium and plutonium.

This is just an illustration of the dose distribution for our rural resident. The 95 percentile is at 130 millirem and the upper bound reflects the increased uncertainty at 10,000 years.

Mitigation measures going on at U.S. Ecology.

We have institutional controls for the future. We're only going out 100 years in our forecast, but it's part of the 200 area plateau, and there will be controls long going.

Key takeaways: Early and frequent

stakeholder involvement, transparency, making sure you have technical experts in all the fields, geohydrology, geochemistry, geotechnical engineering, civil engineering.

When I started in the waste program, all we had was health physicists and we were trying to go through an EIS for one of your our closures. It was brutal. Early on I realized health physics is a good field, but, boy, there are others that are vital.

That's it.

SUSAN JABLONSKI: Thank you, Gary.

Next, we have Larry Bruskin with the State of Colorado. Larry is a graduate from Franklin and Marshall College with a BA in geology and the University of Arizona with a BS in geological engineering. He has worked for the Colorado Department of Public Health in Environment and Hazardous Materials and Waste Management division for the last 20 years, currently acting as the division's authority on landfill liner and cover design construction and quality issues.

LARRY BRUSKIN: Thank you very much.

Let' see if I can work this.

I'm Larry Bruskin, I'm an engineer in the hazardous materials waste management division and my associate, Steve Tarlton, who's the radiation program manager, was unable to be here today, so I'm doing this presentation.

As I said, I'm with the State Health Department, Hazardous Materials Waste Management Division, and our division has a lot to do with landfills. We are authorized by the U.S. EPA. They've delegated authority to us for both solid waste, hazardous waste and we are an NRC agreement state.

Colorado's probably one of the most unique states in that we have actually ten finished, completed Title 1 and Title 2 sites, seven being the Title 1 sites. We have three Title 2 sites, and I've also listed a couple hazardous waste sites that I'll eventually talk about.

This is a map, of course, of the State of Colorado. And as you can tell, the majority of our sites are in what we call the western slope, they're the valleys between the intermountain areas. A couple are actually within some of the lower elevations of the mountains and a couple of the hazardous waste sites you can see are in what we call the eastern plains.

Give you a little bit of a tour of what we have in the State of Colorado. This is the Durango site, it's a Title 1 site. What we're seeing here is the transition from the top slope to the side slope. The Durango site was the only site that had a vegetative top, and that was just on the top slope, side slope had rock riprap like the remainder of the other Title 1 and Title 2 sites.

And this is kind of an overall view of the Gunnison site. I don't know, it's about 40 or 50 acres or so, it's clearly a rock top, rock side slope, riprap completed for erosion protection.

This is the Naturita site, very, very similar, it's such a geometrical form, it's really impressive, this is a little bit smaller, I think this is around 40 acres or so.

This is the Rifle site. It also is completed with rock riprap on the top and side slopes, and that's the way they've been done since the 1980's.

We also know that vegetation prominently becomes apparent after several years or maybe even a shorter time period. These are just two small slides of a couple sites, the @Madall Title 1 site and the Gunnison site, and it does not appear to be a big deal now, but letting unwanted vegetation grow, we believe can be detrimental, potentially impacting the radon barrier's ability.

So conclusions that we found in Colorado for Title 1 and Title 2 sites. We have really not seen any evidence with cover failure, nothing like slope instability, no excessive erosion, clearly there's been no radon emanation that has been measured above standards, nothing related to cover failure that we've evaluated.

However, as I mentioned, we know that unwanted vegetation will quickly establish potentially challenging the radon barrier and its ability to limit radon and limit infiltration.

So, what do we have in Colorado? One thing that's fairly unique, we believe is our climate. As you can tell, map of the United States, Colorado in the dark black outline, the precipitation tapers off very rapidly as you proceed from east to the west. In Grand Junction, it's about 12 inches per year, which is over on the western side, in Denver, it's about 16 inches per year precipitation, and that's fairly standard outside of the mountain areas.

Now, I'll take you to another site that we have done under both CERCLA and state hazardous waste programs, and that's the Rocky Mountain Arsenal.

The Arsenal was started in about World War II and ended in about 1982 for production. They manufactured munitions for military use, particularly agents such as Sarin, mustard in the old days, and other vital military materials. During the time, they also leased areas to private companies including Shell Oil, and they manufactured their own chemical products such as Shell No-Pest Strips and all kinds of other stuff that over time were produced for commercial use.

Well, the waste disposal practices were clearly not up to standards, it was literally throw your stuff out the backyard, throw it into unlined trenches, into basins, whatever was the best thing around. And that was just done, that was the state of practice as you all know.

The state and EPA signed a record decision with the Army and their partners to clean up the mess, the ROD was signed in 1996, and it required that large areas of these waste areas be covered with a cover that has performance equivalent to riprap Subtitle C. So, in order to prove this equivalency, the Army elected to go with four test covers to prove that an alternative to a prescribed riprapcy barrier cover would work. The test covers were established over a three year period and then it was followed by one year growth -- one year test period after vegetation was established.

Percolation was measured in 30 by 50-foot pan lysimeters and the results of the test year indicated that all the covers that were designed and constructed would work as meeting the criterion of what was set.

This is a schematic of the test pots that were designed and constructed, pots A and B, the ones on the left- and right-hand side were 42 inches thick soil cover. The difference between those two were the percent finds, which at the time we thought was a very dominating factor. It turned out be it is a factor, but maybe other things come into play as well.

Test covers B and C were similar with the thickness varied out to 48 inches and 60 inches, and the percent finds were the finer type, the greater than 50 percent minus 200.

This is an overview of portions of the Rocky Mountain Arsenal. The original boundary of the Arsenal was 27 square miles, not all of it, of course, was contaminated, but the central portions were actually the pieces that were.

The -- you can see the large land area we're dealing with, the black arrow represents one mile. All the orange areas were covered with what we call rip equivalent or Subtitle C style cover. And it was simply a water balance cover that, essentially, just very simple to put together, prepared subgrade with a biota barrier 18 inches thick. The Arsenal had the luxury of the old Stapleton airport, concrete runways were sized and utilized for the biota barrier followed by a soil layer compacted loosely, 75 to 80 percent standard proctor density and native vegetation on top.

This is probably the key slide in the presentation and pan lysimeters were placed beneath all the rip equivalent covers in October of '09, a year ago, had the most percolation in any of the three covers, and you can see it's still about an order of magnitude, not quite, less than the required percolation criterion, the 1.3 millimeters per year. The trending is clearly down, the establishment of the covers over time we think will provide even better percolation results, and we're not going to even measure it against the criterion number until the year 2013 for this cover.

So, here's a slide of what's happening today, all the covers are now complete. The Shell cover is the lowermost cover, and you can see there's three lysimeters. The green area is all the 20 lysimeters, they're all in place taking measurements on a monthly basis, but Shell has been there for about three years, so we're more confident in that data at this point.

Quickly show you what it looks like today. This is basin F cover during one of the inspections back in May. You can see grass, native vegetation, I think it's western wheatgrass growing clearly up to that fenders f that mule, I mean it's just very impressive, knowing that some of these areas have been vegetated in less than two growing seasons.

Here's just another view, it's not perfect, you can see some tracks, maybe that's a little bit of drainage. You can see some, maybe some unwanted vegetation, which we believe will quickly be replaced by the good vegetation. By the way, that's the Denver skyline in the background. The Rocky Mountain Arsenal is only about ten miles from downtown Denver looking west toward the mountains.

And we also had to put fully lined channels on the cover, they're line channels fully compliant with a composite liner system below.

And just to wrap it up, the conclusions that we found for water balance covers is first of all, it's very premature, we haven't even started the compliance enactment yet, but the initial percolation data at the Rocky Mountain Arsenal is very positive. We believe that the design can be adapted for stabilized tailings in conjunction with the regular radon barrier where applicable.

And finally, based on experience in Colorado, we think that it is very advantageous to restore the natural ecosystem. It's definitely easier to construct than a fully compliant Subtitle C cover, and clearly for the owner costs less, we believe, for initial design, development, construction and post-construction maintenance.

And finally, the end product is what we are all hoping for, and it's this right here. This was taken about a year and a half ago right on the Shell cover.

Thank you very much.

BRIAN ANDRASKI: The next presentation is by Loren Setlow, and he is with for the EPA Office of Radiation Indoor Air. Loren is the program lead for NORM for EPA's Radiation Protection Division and he's also the chairman of the U.S. Government's Norm Subcommittee of the Interagency Steering Committee on Radiation Standards.

And in addition, Loren is also serving as an expert consultant on projects for the International

Atomic Energy Agency and the International Commission on Radiological Protection.

Loren has BS and MS degrees in geology and he's also a certified professional geologist with over 35 years of experience.

Loren.

LOREN SETLOW: Thank you, Brian, and I appreciate the NRC for hosting this and organizers for putting together such a nice and wholesome set of meetings and discussions.

First, I wanted to talk just a little bit about the existing regulations, and then I'm going to talk about the reasons that we're conducting the review, and then the process for what we're doing.

As you've heard, and Rich was talking a little bit about it, the regulations were issued under the authority of UMTRCA, the Uranium Mill Tailings Radiation Control Act, very specifically for EPA, Section 206 of the Act which actually modified the Atomic Energy Act, Section 275 and established the process whereby the EPA was to establish the health and environmental protection standards that were to be utilized by the NRC and its agreement states, as well as the Department of Energy for monitoring and for providing the environmental protections for existing uranium mills, as well as those which would be licensed in the future.

Currently, the regulations, even though they were written for conventional uranium mills, were utilized by the NRC and its agreement states for licensing of inside leach recovery facilities as well as looking towards the heat leach facilities that may be coming on line in the future.

The regulations that cover the Atomic Energy Act Title 1 specifically listed inactive and abandoned mills, tailings with contamination of soil and buildings and also the Title 2 mills, which were those which were in operation in 1978 or might be licensed in the future.

The requirements for us were that the standards had to be consistent with RCRA for non-radiological hazards. And -- but we were provided with some discretion as far as setting the standards for controlling the radiological hazards.

As a means of dealing with that, the standards that we have cross-referenced the hazardous waste facility requirements of EPA, they provide radon emissions standards, limits on the groundwater concentrations of hazardous substances and radionuclides and certainly the remediation standards monitoring corrective action and post closure monitoring, very similar to what you see in many parts of what's found in RCRA.

Now, the reasons for the review, it's been over 25 years since the rules were originally finalized and 15 years since the last update for groundwater protection at the inactive facilities.

The rules, as written, lack explicit provisions for the ISL recovery facilities, which is now a principal means of uranium recovery in the United States, and certainly for the heat leach facilities which are coming on line.

There have been changes in EPA's protective standards for hazardous substances in groundwater and drinking water. Some of the MCLs have changed, for example, for uranium and arsonic, and it's not reflected in the standards as written now because we've provided, actually, it's numerical standards with numerical limits dating way back to early 1980s.

And then, certainly, there have been changes in the economics of extraction and site remediation which will have to be taken into account as we examine our existing standards.

In terms of dose and risk for radiation and radon, the principle scenarios for exposure have been changing. There have been impacts with the subsistence and the cultural lifestyles have affected communities that were not taken into account when the rules were originally written, and their potential impacts on children's health, which have not been evaluated.

And certainly, although the majority of facilities are in the western United States, I guess there was one facility in Pennsylvania which was included in the requirements for review by UMTRCA, but new geographic locations that may need to be considered in the risk assessments that would vary and the kind of scenarios of what we had done in the early 1980s, facilities in Virginia, discussion about sites in

Michigan and elsewhere.

So, the analysis, our review process, we've got a work group and they are going to be conducting analyses of the standards in the regulations. They are going to compare the existing standards with the history of performance of Title 1 and Title 2 facilities, and I greatly appreciate this audience for providing lots of examples for us to use and consider as we do our own review.

We also will be looking at the implementation of the standards by the regulatory agencies where there have been issues with specific facilities. Is it just because of the design or are there certain things that might be improved in terms of the relationship with the federal agencies themselves? What about the impact certainly on the tribes and environmental justice communities, children's health and the general public?

Also, the changes in EPA standards, and we've got new executive orders, new statutes, other national and international protective standards that have to be taken into consideration. So it is a much more complicated world than it was in 1983 when EPA first finalized its standards.

And certainly any new standards would need to balance the environmental compliance costs and benefits. Taking a look at certainly public health and environmental protection and safety benefits, but also the impacts on the implementing agencies, Title 1 facilities, a lot of sunk costs already. What are the national costs and benefits of making any changes to those? How about the impacts on industry, which certainly we need to take into consideration, UMTRCA requires that, as well as the economic and societal impacts of whatever we decide we might want to do, it should be decided to go ahead and revise our existing standards.

In the process we're trying to maximize our efforts to improve and enhance obtaining stakeholder input, federal agency coordination, industry, states, tribes, environmental justice communities, environmental and other NGOs, and certainly the general public.

And participation in workshops such as this provide opportunities to learn of advances in cell and cover designs for limiting radon emissions, resisting erosion and certainly preventing water contamination.

As far as how we are doing all this, in addition to the workshops, we've held some public information meetings, we've held two in May, one in Casper, Wyoming, and another in Denver. We're anticipating holding another in Arizona in September, one in Texas in the near future, and we'll see where we go from there. We have developed a blog, a discussion forum, uranium mill tailings standards, and there's the web address for it.

It's a site for public input on discussion topics for this review, a calendar of events, library of relevant documents, which we're going to be continuing to add to, and we actually have our own dedicated e-mail address for additional public input, pretty easy, uraniumreview@EPA.GOV.

Thank you.

BRIAN ANDRASKI: Next presentation by Joel Hubbell. Joel is a groundwater technologist with the Idaho National Laboratory. Joel has been active in developing tools and techniques for characterizing and monitoring fluid flow in the subsurface. One of these tools, the advanced tensiometer, has been used for monitoring water potentials at waste disposal sites with deep vadose zones.

So with that, Joel.

JOEL HUBBELL: Thanks. You know what, I guess when I wrap up my entire talk, I kind of look at it as, you know, what we're doing here is we're trying to understand the flow and transport from these particular sites, can we design around it, and ultimately, we want to verify that what we predicted from the design characteristics of -- what we predicted is actually going to occur. So we've got short-term and long-term monitoring that come out of that.

And unfortunately, we are stuck with every site seems so be site specific. Everything, you have to design around it. You can't -- one application doesn't work at all sites. So we have to work with the available tools and techniques that we have available to us to then modify that to our particular sites and then verify how well these things work then.

I'm going to talk about a couple of different investigation sites, or investigations that we've done over time. And the first one was kind of a column test. This goes back about 15, 20 years ago, we were concerned about Carbon 14 at our disposal site, and we really needed to understand what was going on.

So we built the column, ran the test, and over the year-long period, what we found, fortunately for us, was that most of the Carbon 14 that had been introduced that was being generated as carbon dioxide, actually ended up going up into the atmosphere and not into the water table. So we could, therefore, put that off to the side, it did not turn out to be one of the contaminates of concern for this particular site.

And so by running an experiment we were able -- laboratory experiment, we were able to determine what was really important at this particular facility at that particular location.

A few years later we did a large scale infiltration test, our site's a 99-acre disposal area, and we were concerned of the potential for flooding. We really wanted to understand what was going on at this particular site.

So we looked at a flooding scenario and we did a large scale infiltration test, 6.6-acres, and put in 2800 gallons a minute into the thing and we watched the water flow. And we have a geologic environment here that is 95 percent salt and 5 percent sediments. And what we found out is that the water moved primarily vertically, about 15 feet a day, until it hit an inner bed. And then when it hit an inner bed, then it would move laterally.

And some investigations that the GS did at a later time indicated that we actually had some water probably moving about 4500 feet laterally from a local water source and it was moving at about 90 feet a day when they ran those tracer experiments.

So, understanding the system is incredibly important.

I remember we did early modeling of this and decided that it was virtually impossible for the water to move laterally at those rates and within the vadose zone. So we learned a little bit on that particular experiment.

And one of the things we learned is we didn't have the tools or the techniques to really figure out what was going on, so we needed to step back a little bit and develop those. And one of the first places we got to do that was we decided let's look near field, short term, let's actually put some monitoring instruments in the waste itself, and this just shows a couple of our active waste pit, and then some instruments that were placed in there. And we put some tensiometers in there, some lysimeters, gas ports and that sort of thing.

What it indicated, and this was about ten years ago or so, that the sediments around the waste during the disposal, actually the actual operations time period, wetted up quite rapidly, we had water moving in there. And so we would expect then once we got the site capped, which is still perhaps a decade off, that we would expect and we should see gravity drying at these particular facilities like this.

So we started looking at, you know, what kind of monitoring instruments we could use for this, and played around with some, I guess, advanced some of the instrumentation, and also the tools and techniques for installing these things. You can put an instrument out there and take measurement, but how long it will live and how long it can provide data is really important. And so you need to have a -- you need to have instruments that will give you the data and with the precision and accuracy that you really need for these particular experiments, or at least investigations.

And you know, when you go out there, we end up with data like this, it's actually valuable data. But, you know, our goal is not to gather data at these particular sites, it's really to use the data to make informed decisions.

And so, this data set here is using unsaturated hydraulic conductivity along with tensiometric measurements over an 11-year time period to look at infiltration pulses in here. And what we see is that over this 11-year time period, we actually had 90 percent of the infiltration over a two year period in '05 through '07. And most of our monitoring had been done, obviously for nine years there we almost got no infiltration whatsoever until these episodic events can really change our conceptual picture of how water is flowing.

Next slide.

Along with that we realized that since we were getting episodic pulses, we needed to do some very -- we needed to do monitoring basically continuously over time at some facility to see what's going on.

So we had a waste disposal site that we monitored out in South Dakota under a liner. And we put in instruments immediately below the cap and then midpoint, and then about 80 feet below the cap.

And what we found out is that immediately below the cap it actually wetted up over time, and this is a hypalon cap, 50 mil, and we -- it indicated that what we expected to happen at this particular site was not necessarily what was happening at the facility. And so we found that it actually, immediately below the cap, we got about nine feet where things actually wetted up and we could see a very slow decline in water potential suggesting gravity drainage. At about 45 feet below the cap we actually saw a drainage over time. At the bottom we saw that there was recharge coming in from the sides and that sort of thing. And so, we didn't really see the gravity drainage at that point.

And one of the interesting things about below this cap is that we saw cycling of air underneath the cap, even though it was 65 acres, we saw airflow going underneath there, and we also saw kind of an effect where the -- it looked like where if you -- when the barometer changed, it would actually compress this cap and kind of squeeze fluids out of the subsurface, which was very, very interesting.

And sometimes even when we want to collect to collect really good data, like water level data, this is underneath the site with the deep vadose zone, and the initial data there, it's a four months time period and it's about eight-tenths of a foot in the vertical direction, and what it indicated was we were trying to take water level measures, something very simple, and what we were seeing was about a foot fluctuation in the water table over time. And so then we worked with this, worked with the data logging system and with the measurement system and came up with that, the long-term real water level which is shown later in the last half of the graph on this side in here.

That was the real water level data here, but this is what the apparent water level was that was really confounding us as to the direction of groundwater flow and that sort of thing at this particular site.

In summary, then, our instruments and placement techniques are really critical for understanding the system. And, you know, first you have to understand the system, and then you have to design around it, but then you have to verify it. And I think that we're working on getting instrumentation and actual measurements, I guess, to verify whether our modeling results really are correct.

Thanks.

BRIAN ANDRASKI: Our next up is Mark Phifer. Mark is a senior fellow engineer with the Savannah River National Lab. Mark has 27 years of environmental and geotechnical experience at SRS. Includes a varied background, but a lot of good work and interesting work. The first ten years included environmental regulatory compliance, civil and environmental design, project engineering.

Subsequent to that at Savannah River, he's been developing, deploying and evaluating waste site closure suction groundwater mediation and radioactive waste disposal technologies. And most recently, Mark has been working on performance assessment and composite analysis related activities again at SRS.

Mark.

MARK PHIFER: I'll be talking to you about just some highlights from subsidence studies that we conducted at SRS.

The subsidence studies that we've conducted, the first few that I'll show you came from RCRA closures at the site, and then the subsequent ones are working with our E area low-level radioactive waste facility which is regulated under the DOE 435.1 waste manage -- radioactive waste management regulations.

So we try from previous work that we've done under one regulatory basis, learn from that and, you know, transition that into other regulatory basis.

Now what I'm showing you are just some highlights because of the time that we have.

This is a picture showing our E area, low-level radioactive waste facility. You know, we do performance assessments, composite analysis, maintenance plans, monitoring plans and so forth associated with this, and all of that information is used to -- operation and design a facility.

At this facility, we have a graded approach in terms of where do the rads go. We have vaults that are concrete vaults for higher level rads, we have grout encased disposal facilities for large pieces of equipment that have higher levels of rads associated with it that can't go in the vaults, and then we have shallow land disposal.

And some of the talks that we've had before have pointed out there is a lot of -- whenever you are disposing of waste, the waste form and what the rads are make a huge difference in where you go with your disposal facilities. And we have a lot of conflicting interest whenever you have a disposal facility.

At this facility, one area to me that is conflicting interest is protection of the people in our operating facilities and protection of the workers at the waste site itself.

So one of the things that we do for a lot of our job control waste, that's protected equipment that people wear, the tools that people are using whenever they're working in a rad area, they're put into these boxes that you see in the picture here. These are metal boxes. Okay? But the waste that's put in these metal boxes is low density waste. And it's done like this because these boxes can be handled as non-rad once the waste is inside, because the outside is clean. And that provides a lot of worker protection.

But then whenever you get to the disposal facility, you have a lot of inherent subsidence potential associated with it. And in this case, these boxes are typically stacked four high, and we have on the order of 13 feet of subsidence potential associated with these boxes when they eventually collapse.

So we've had to do a lot of studies on how do we stabilize this waste, you know, once we receive it in our low-level rad facility? And I'm going to show you just highlights of several studies that have been done.

This first study was just looking at how would we perform dynamic compaction. Dynamic compaction here was taking a 20 ton weight, dropping it 42 feet on to a footprint of the trenches that we had at the time and trying to compact the waste. And this test was performed on noncontainerized waste. We didn't really start using containerized waste until 1985.

So dynamic compaction on uncontainerized waste worked very well for stabilization and then subsequently building a closure cap on top.

We performed another dynamic compaction test after we had initially performed dynamic -- or closed the facility. We had another facility immediately adjacent, okay, to a closed facility and we had to take a look at did the seismic effects from dynamic compaction adversely affect the closure cap that we had immediately adjacent to where we were doing the new work.

And so we had some studies where we actually went out and built one of our trenches, put in these boxes, had all the geophones and stuff, and were doing testing both for seismic, but also for effectiveness.

And what we found whenever we went back and dug up, and this is a picture of where we dug up, and were able to look at the amount of compaction that we were able to get, wherever you put these boxes in and they're in a fairly intact condition, we can only get rid of about 25 percent of the subsidence potential because the boxes collapse on one another and give themselves a lot of structural strength. And even whenever you do excessive dynamic compaction, you can't get rid of all the subsidence potential.

These two pictures are just showing where we actually did perform dynamic compaction out on the site. We have data associated with both of these. One of them was conducted in 1989 and the other one in 1998, and you can actually see the cranes associated with that compaction.

But from these earlier studies, you know, what we've learned was that we can probably only get rid of about 23 percent of the subsidence potential whenever the boxes are fairly fresh. Okay? And so you build a closure cap on that, you know, we're still having nine feet of subsidence potential.

Now -- and that's nine feet of differential subsidence potential, because you're disposing of bulk waste next to containerized waste. So there aren't too many caps that can handle that type of differential subsidence.

So from that, you know, in order to increase the effectiveness of dynamic compassion -- and we also look at static surcharging and some other methods, but dynamic compaction was the best, we either have to increase the corrosion associated with the boxes after disposal to make dynamic compaction effective, or we have to increase the compactive effort.

However, increasing our compactive effort, we have other facilities around that we have to be protective of from the seismic event caused by the dynamic compaction. So we're limited in what energy we can apply.

Because of -- now, here's where -- and we're getting into the DOE 435.1 system which includes, in my mind, a fairly robust maintenance system of you don't just go out and put a closure cap in, operate your facility, but you have to do maintenance over time. What new technology is coming out? What have you learned in the field? And so we're taking this information and going, well, okay, we have these boxes, we know we can't get rid of the subsidence potential immediately to be able to put a closure cap, a final closure cap on, what do we do?

Well, here, we made the decision that we would have interim run-off covers, essentially exposed georing covers that we could easily maintain until the boxes corroded enough so that we could have effective subsidence potential.

And going along with this, we're performing studies, sort of two sets of studies, one is corrosion of the containers that are used, and these are just examples, this is a B-25 box that we dug up after eight years, and we still have other boxes that we have available to dig up, and we'll do that on a periodic basis. And then also the second areas are just coupons from @seanland containers and the B-25 boxes that we have that we can do corrosion evaluations.

We've also conducted modeling looking at how long does it take for corrosion to occur before the dynamic compaction or static surcharging is effective? And this is just some of the grids that you see here after application of the energy from the modeling that we've conducted.

So, you know, in conclusion, we've got about 20 years of work that we've done on subsidence potential. And in my mind if you have a substantial subsidence potential, particularly differential, that probably is the major thing that you have to be concerned about before you even get to a cap degradation through other means because it's, you know, a catastrophic type failure.

We have quantified subsidence potential associated with our facilities, we've looked at the effectiveness of various subsidence treatments, have quantified those to an extent, and we have changed our closure plans so that we have an interim cover to give us time for corrosion to occur so that our subsidence treatments would be effective. And that time may be, you know, in terms of a hundred years before we have a final cover. We're not looking at a final cover immediately. We're looking at an evolving cover system because of the subsidence potential that we have associated with it.

And, you know, this is being conducted in context of DOE 435.1 that requires us to maintain our closure systems over time. We just don't close it and walk away. We have to continue to prove that the system will work effectively.

That's it.

BRIAN ANDRASKI: The final presentation is going to be by Roger Seitz, he's filling in for Marty @Laturno who is unable to participate in the workshop.

Roger has more than 25 years experience on performance assessment for waste disposal and environmental restoration. He's worked at Hanford in Idaho and the International Atomic Agency and is currently an advisory scientist at Savannah River. His work involves all disposal sites in the DOE system and he has also worked on radioactive waste management in more than ten countries.

ROGER SEITZ: Thank you very much.

Marty has been recovering from an accident and he was really hoping to be back at work this week, but it just didn't work out, there were some complications yesterday, so I'll do my best to fill in for him.

This is a high level view, it would be a little difficult to talk about all the details for each of those questions for all of our different facilities in DOE, so I'm trying to give some perspective of the regulatory view and DOE expectations in the context of the questions that were asked.

Briefly, I will introduce DOE order 435.1 and how we're using feedback and experience over the last ten years to do an update for the DOE order. Talk about the performance assessment maintenance concept and I think Mark's presentation and Joel both referred to some specific examples of how that process is implemented. Monitoring requirements within the DOE system, and also, I'll touch a little bit on efforts that are underway for information sharing.

As background, you'll recognize the photo, that's the E area that Mark was just talking about. And the situation we have within DOE is our disposal facilities are located on DOE sites, and so we don't have so much of the siting, choosing suitable location. We find locations within the sites that we have.

In the DOE regulated low-level waste facilities, you'll find the designs are based on a systematic approach. We look at all the different barriers that are there, covers, liners, waste forms, containers, and it can be a fairly complicated mix of considerations as you're determining what the optimum solution is for disposal of any given waste. And the E area in the photo is an example of that, where we have multiple different facilities that are performance driven in terms of the waste that can be disposed there.

Mixed waste facilities on DOE sites tend to be the more traditional, RCRA liner, leachate collection with a RCRA-based cover, so it's more of a design based concept.

This is a rather busy picture, but I think it's nice overview of the regulatory framework. DOE order 435.1 is the DOE regulation for radioactive waste management. And you'll see in the upper boxes we have performance assessment, composite analysis requirements. The composite analysis is an assessment that considers all potential sources that could contribute to a dose.

There's a relatively rigorous review process. And I think people -- we're becoming more and more transparent in the process. And as people become exposed to the reviews that are undertaken, they're gaining appreciation for just how rigorous they are.

Two things I want to emphasize in this presentation are with the red highlights there, the monitoring plan and the maintenance plan. Those are two key documents that support -- once a license is granted for disposal facility, those are two key documents for continued operation of that facility.

And another thing that we have within compliance with DOE order 435 is the idea of annual reviews. Each year there's a summary that's prepared of operations at the facility, monitoring results from the facility, any maintenance activities that have gone on at the facility, so it gives you a nice summary of everything that's happened over the course of that year, and then it's placed in context of what that says about continued compliance for the disposal facility.

We are in the midst of an update, we're trying to take advantage of lessons that have been learned. The original order was issued in 1999, last year, ten years after issuance of the order, a process was began to update the order. And that update is looking into what kind of changes have occurred in the regulatory environment, what have we learned from operations of disposal facilities.

And it's put in the context that @wheel on the side, for those of you familiar with the DOE system, that's the ISMS process, the integrated safety management. What you'll find, the first three parts leading up to development of controls, is where we were in 1999.

Now, we're in the feedback part of that loop trying to gain from the experiences over the past ten years, and we're in the midst of looking at an update to the requirement.

We just completed a complex-wide review which included input from every single DOE facility in the

United States. And it was a very large effort, a lot input, a lot of useful input that will be considered as part of the update.

Two key areas from the perspective of this workshop that we're looking at are probabilistic sensitivity and uncertainty analysis, how will we better use that in our assessment of facilities and link it to monitoring and other considerations, and that leads to this concept of performance monitoring which we will hear a lot about this week. How are we going to use all this new information that we can collect to help build confidence in what's being done for our performance model?

PA maintenance. And the whole maintenance concept evolved from the idea that we work within an iterative process, we look at performance assessment as a learning process, so we're trying to continuously improve our understanding of the system, and improve covers and improve technology for barriers.

Nevertheless, we have to make decisions. We have to be able to make decisions to support safe disposal of waste as that learning process is going on.

And what the maintenance idea does, it gives you the opportunity to look into some of these specific considerations. There were concerns about subsidence at Savannah River, what types of things can we do to continue to build confidence that we can continue the safe disposal of waste?

A key thing is when we think about maintenance, we want to identify those things that are most important. So you use things -- I'll use the term "importance analysis" which is really sensitivity analysis, uncertainty analysis, to try to identify those factors that are most important for the performance of this system. Then, you focus the maintenance on those activities.

Similarly, maintenance often comes up as a result of comments that we receive. So we may get specific concerns from stakeholders that can lead to specific maintenance activities.

Just some quick examples of maintenance activities, monitoring is considering a part of maintenance, but we also have laboratory and field experiments. The bottom picture is the one that Joel showed you from Idaho, a specific column experiment was done at Idaho to help support assumptions in the performance assessment.

The top picture is an example of collecting as-built samples from a waste form of something, and in this case they were looking primarily for chemical properties, I think. But there's any number of different things that you can do to build confidence.

Monitoring. Monitoring is something else. These are required. Maintenance is required, monitoring is also required.

Within DOE 435, you need to prioritize your monitoring based on what you see in your performance assessment.

So we want to focus monitoring on those issues that are going to be most relevant towards our conclusions regarding compliance.

Action levels. One thing that we're running into, when we use monitoring results for within the iterative process and we begin to start trying to compare, okay, what are we seeing in monitoring to what we've got in the PA, it gets to be very challenging.

And this will be something, I have a presentation tomorrow where I will go into more detail.

Within the DOE order, we look at action levels, we want to establish some sort of point of comparison that we can use from the modeling where we can also collect monitoring data. And that can be very challenging, and I have a caution that I'll reinforce tomorrow, that Mother Nature can be very confounding sometimes. Be careful what you promise.

So within the idea of performance monitoring, in the update to the order, we are trying to better define effective approaches for performance monitoring.

My last slide, I'll just talk briefly about some things that are going on with sharing of information. I think we found that working with stakeholders more and more transparently has been very positive with the DOE performance assessments.

And you can find the tank closure performance assessments on the DOE website, they're available for anyone to download.

Other performance assessments and technical support information is often available on the DOE information bridge. I haven't gone out and confirmed that everything is out there, but there's a lot of information, both PAs and supporting information for PAs on the information bridge.

More recently within DOE we've established what's called a performance assessment community of practice, and this is -- we're intending this to be a very inclusive group of anyone involved with performance assessments. We've encouraged regulators to be involved, practitioners, oversight personnel, and I welcome anyone who's interested, contact me or let me know. We've had -- we had people from -- regulators from Nevada and Washington State at our last community practice workshop that was held in Richland.

Another thing, the performance assessment assistance teams. This is something that's given the opportunity for DOE to send out assistance to sites as they are developing PAs, sharing experience, to supplement this review that occurs at the end. We figure you have a better chance of building in improvements if you do it early rather then late.

The last thing I'll mention is scoping

process. This is actively involving stakeholders and regulators at individual sites. This has been very effective in helping them appreciate what goes into developing a PA and making sure the PA reflects their concerns.

Thank you.

BRIAN ANDRASKI: Now, we're going to move into the panel discussion and I'd like to invite David Esh back up. David spoke earlier and he's going to be serving as a panelist with this group.

Again, a little background, David is with U.S. NRC and is a senior systems performance analyst with over 15 years of experience in performance assessments, and his interests include engineered barrier performance, including waste forms and his terminal degree or Ph.D is from Penn State.

DAVID ESH: For the balance of the session, I'm suggesting, because we don't have too much time, we just confine it to two questions which I had which is part of the objectives we have for this session, and that is immediate performance assessments. At NRC a few years ago, one of the things we found out was, and the problems we had was putting in the properties of the cover materials in the performance assessment.

We talked about looking at the literature, we looked at that, we had a distribution of the properties, the materials. But the properties and materials of the cover were very important in finding out how much water infiltrates the cover.

So my question for the panel is: What are the types of laboratory, and particularly field testing that you are having in your facilities that can give us a better handle on the properties of the cover materials for the performance assessment, to verify some of the performance assessment findings? And limit it only to soil and composite covers and not look at the concrete barriers.

PANEL MEMBER: On the one slide I had there that kind of listed the geotechnical properties, you know, that I look at when we do our site investigations try and identify borrow sources just in particular like grading size and (inaudible) limits and laboratory tests for hydraulic conductivities for densities and all, and look at all that, and try to come up with representative parameters to put into the model and then incorporate that into the plans and specifications for construction.

PANEL MEMBER: With the synthetic material, they have a host of parameters too that we also look at and include also.

PANEL MEMBER: Roger, do you want --

ROGER SEITZ: Well, a lot of the soils materials, we, you know, are utilizing materials from the site, so we do a lot of shelby tube type testing, you know, taking shelby tubes and having laboratory tests.

We have had in the past, some large scale testing where we were building barriers and doing sealed double ring infiltrometers and things that in association with taking shelby tubes for smaller size samples. So, you know, we have a variety of means that we've used, both field and lab for measuring parameters.

Now, the harder thing, though, is if you're trying to get a distribution, you know, the number of samples that you've taken, and if you're trying to do like sealed double ring infiltrometers to get a distribution about the hydraulic conductivity, that's a lot of money.

And so to me the hard thing is not necessarily getting what you think is an average value, at least as-built, but it's getting the distribution and then taking a look at the long-term properties over time.

We've done more of that -- you didn't want to discuss, but we've done more of that with the cementitious materials of looking at, you know, the type of degradation over time and we've relied more heavily on things like have been done in other labs for HDPE and things of that nature.

PANEL MEMBER: At @Thianel for the large scale properties, we've been actually looking at kind of monitoring (inaudible) or underneath the waste, like with a tensiometer or heat dissipation unit, depending on what the range of water potentials is underneath the site, and looking at the long-term trends then to see -- you know, once you cap a site, you should see a drying trend basically. And so if you have some direct measurement instruments, then you can actually see whether it is drying out over time or whether it's staying steady or whether it's actually wetting up. And so that's looking at the larger scale.

And so what we've tried to do is put instruments underneath the active zone evapotranspiration and do monitoring there as a verification step in this process, and then supplement it by the analytical, the laboratory tests, that sort of thing.

PANEL MEMBER: I'll just give a little bit of a regulator's perspective.

Well, first, this session was obviously designed by engineers and implemented by engineers with one minute precision on the timing and 33 percent over on the overall budget.

But in terms of samples and measurements, what I like to see is different types of measurements that complement each other and can confirm or verify each other.

But especially the field measurements or scale measurements, measurements that get the issue of scale and the actual conditions of expected facility. Because I think those things, there can be a big jump between the lab and the field, whether it occurs due to implementation and quality assurance or something complicated happening in the field that you may not have anticipated.

If you get that information in the field or get that information in a lysimeter test, it really gets you closer to being confident in the ultimate assessment.

PANEL MEMBER: Just real quick. Kind of a philosophical thought on data. One thing we tried to emphasize is use the results of your assessment to identify where you need that improved precision. So that's an important part of it.

I -- one example, I remember one thing from Idaho there was an effort to collect some theta psi information for materials we were going to use for the cover there. So there is some pressure plate results.

DAVID ESH: And the last question, I mean this is on monitoring. And one of the things that has come up in new nuclear power plants based on the regulation that we have, 20.1406, which basically says that for new nuclear facilities you have to minimize the production of radioactive waste and minimize contamination. And so one of the things that our group actually worked on was a regulatory guide 4.21 which talks about minimization of radioactive waste at nuclear power plants. And one of the things that we actually proposed in our regulatory guide was we need monitoring closer to the facility, closer to the parts of the facility which are actually emanating or discharging of radioactive fluids or gases.

So in that context, I would like to know from your experience, what are those types of instrumentation are you using and do you think whether it is useful rather than depending on groundwater monitoring away from the site so that you know there is an impending failure or a problem with your facility.

PANEL MEMBER: Well, at our E area we're kind of, along with what Susan was talking about, tritium, you know, is a very good tracer, so we do do vadose zone monitoring below our facilities to look at, you know, tritium, because it's going to be the first thing that comes out.

So that's one of the big ones that we do. And that goes into the performance monitoring that Roger was talking about, because what we do is we have action levels within the vadose zone, and if it gets above action level, that keys us that we have to do some more investigation to determine is that going to be a problem at the compliance point or not, and if it is, what do we do about it.

PANEL MEMBER: So it seems like we can rely on tracers to some degree for both gas and fluids to actually see what's out there.

The sampling methods for the vadose zone are pretty well limited to suction lysimeters and pan lysimeters, and so you have to have it fairly wet in order for a suction lysimeter to work, and their lifetime is unknown at this particular point, probably over 20 years maybe, in some places, but they usually plug up and seem to die over time, I guess.

Then, we'd like to have other measurements of water potential or water content. You've got neutron access tubes that give you a direct measurement and then you've got instruments like the tensiometers or heat dissipation sensors, there lives, I guess, alr also unknown at this particular point. Probably the neutron access probe has the best longevity because it is an instrument that is just a tube in the ground and you measure, you know, lateral distribution or vertical distribution along a stand pipe.

And, you know, I think that's something that needs some active development on is the instrumentation and how long these things can last to give you measurements. And anything that heads towards a direct measurement is the most valuable, obviously, because you can actually trust it then rather than an indirect that may be heating or using heat or some other measurement to indirectly measure.

PANEL MEMBER: Brian?

BRIAN ANDRASKI: You can also use tritium as a tracer for low-level radioactive waste site. We're working adjacent to the site near Beatty, Nevada. And due to the dry conditions where suction cup, porous cup lysimeter would not work to actually collect a soil water sample, we used, we sampled soil water vapor, and that's done by -- we basically pull the vapor from the soil through a cold trap and we collect the ice, and we freeze it out, and then that ice is melted and that's the sample that we submit for analysis.

So that's one way. Again, it's minimally invasive once you have -- you're essentially doing a soil gas type of sampling protocol.

It does take time, but it's something that we've used quite a bit for maybe the last ten or fifteen years that sort of thing and it's worked well for us.

And we do that both in the shallow unsaturated zone, upper two meters, but our site, we're working with a thick unsaturated zone, similar to Joel's, where it's 110 meters to water. And we have deep bore holes that are instumented to collect these types of samples as well

DAVID ESH: Well, I'm not going to keep you from lunch any more. I'm sure you must be dieing to go have something to eat and drink. And so I'd like to take this opportunity to thank the panelists and we had a good interchange and good information from some of the activities at their sites.

Thank you once again.

UNIDENTIFIED SPEAKER: Just make sure you go up the back stairs, the guards will escort you upstairs, you can either eat in the cafeteria or there is a sandwich shop in the other building. Okay? And we will meet back here at about 1:25. Thank you.

(A lunch break was taken)

>>MR. NICHOLSON: If everybody would take their seats, please. This afternoon, we're going to have a special session on degradation processes and the co-chairs for it are Craig Benson and Jody Waugh. Craig.

>>MR. BENSON: Thanks, Tom. This afternoon we're going to talk about degradation processes and how they can affect the properties of cover materials. And Jody and I are the chairs for this session. We're also going to be speakers, so we're going to do a little tag-team here on introducing each other. And Jody is going to be our first speaker, Jody Waugh. I think everybody here knows Jody. When you think of

cover ecology, you think of -- equals Jody Waugh. Jody's the lead ecologist for S.M. Stoller Corporation and for years has been in this role working in the long-term stewardship of DOE sites through the legacy management program.

Jody's got his Ph.D. from the University of Wyoming in ecology. And I will turn it over to you.

>>MR. WAUGH: Thanks Craig.

I know at the beginning Hans had mentioned that some of these presentations would be research and some would be practical experience.

I think, really, this presentation has more to do with practical experience, observations of the U.S. Department of Energy Office of Legacy management.

Before I get started, I want to make just a couple of comments on the term "degradation." Hopefully, this will clarify some misconceptions. Degradation, we're talking covered degradation.

That isn't synonymous with remedy performance. In fact, some of the work that we've done in LM, even when the cover isn't working, in many cases we're still --

we've proven we're still protected -- we're still protected, okay.

And it's our position that our sites, under the UMTRCA framework, are currently protected.

Nothing about degradation is that maybe, as you'll see in this presentation, hopefully, one cover design's degradation processes may be another cover design's renovation processes.

So the term "degradation" can mean different things to different people on different covers. So I wanted to emphasize that at the beginning here.

This is the slide that Rich had put up earlier.

Office of Legacy Management manages sites, cold war, waste legacy sites all across the country.

Most of these remedies are cover disposal cells for uranium mill tailings at this point in time. And as you can see from the map, they represent a broad range of climates and soils and ecology.

I put together some topics here to address -- ultimately to address questions that were posed for our session.

You can look in the program if you want to review those questions.

First I'll talk about uranium mill tailings, cover degradation processes for different climates and ecology. I'll talk about evolution or historical improvements in mill tailings, covers to minimize degradation.

Rich introduced the idea of cover innovation. I will talk a little bit about that. The whole idea there is to prove the sustainability by accommodating degradation processes. And then I'll have a summary of responses to the question, Session 2 questions.

So first we'll just talk about degradation processes. Our experience, our observations over the years that cover degradation processes for different climates and ecology.

I'll go through this and talk about several different sites, from cool, dry pacific northwest to warm, dry southwest and even back into humid, cool Pennsylvania. And most of what I'm talking about, as far as degradation processes, I will be talking about what we might call the earlier or conventional cover designs

that we had for uranium mill tailings.
I think Craig went over this earlier. There's a compacted soil layer here, high clay content, originally just focused on radon attenuation. It's actually kind of sort of retrospective design that this would also be a low permeability layer. A bedding layer or a drainage layer with a high conductivity. And then rock riprap, which is for erosion protection for the long-term, durable rock.
So this is the earlier conventional cover I'll really be talking about. And I'm going to present these in just kind of a series of lessons from observations. And one is -- has do with unforeseen ecological consequences of these designs that maybe the folks that designed these things didn't consider when they were built. First is that rock covers can increase water storage capacity, even in the desert, and really create a habitat for some deep-rooted woody plants. And this happens over a broad range of ecologies and climates.

You see an accumulation of water in the bedding layer and the low permeability layer, and this seems to favor the germination establishment of shrubs, whether you're 40 inches plus precipitation back in Burrell, Pennsylvania, where we're dealing with Sycamores and tree of heaven and an invasive species called Japanese knotweed or, on the other end of the spectrum, in Shiprock, New Mexico, 7 inches of precipitation where we see as woody plants, saltbush and rabbitbrush, even tamarisk, and several annuals, like Russian thistle and kochia. Another example, Grand Junction, around, actually at this particular site, around 8 inches of precip, again, desert shrubs, fourwing saltbush, shadscale, spiny hopsage, and an invasive species called halogeton.

And then up to Lakeview, Oregon, it's sagebrush and rabbitbrush and bitterbrush. These plants are rooting down into the low permeable layer.

And that's really the lesson two, is these plants get established and the roots of these woody plants can penetrate this compacted soil layer overlying the tailings.

We and our predecessors have excavated a lot of plants to see where the roots are going, to determine routing depths. Basically, the primary roots are extending vertically down through the rock and bedding layer and then, usually, branch laterally at the compacted soil layer or radon barrier surface.

And then we see secondary and tertiary roots extending vertically into the radon barrier, typically as mats of fine roots in planes of weakness within that layer; planes of structural weakness maybe where we're getting preferential flow in those layers.

Here's some examples: Lakeview Oregon, again, sagebrush. It was excavated, primary roots going down laterally, in this case, into a soil layer.

Lakeview -- I don't have a picture of it there, I'll show you a better -- Lakeview's different in that there is a thin layer of soil we put on top of that rock riprap layer, and this is where the shrubs are getting established.

And then roots going down into the radon barrier, which is down near the bottom of this. Here's the drainage layer, the rock layer, with a soil layer on the surface. And then the sagebrush roots, again, following these lateral planes of weakness, you can see even some of the dye from some of the tests following those fractures in the soil structure of that radon barrier.

Very similar fourwing saltbush at Grand Junction, Colorado. Excavated root going down, in this case, going through a protective layer that overlies and radon barrier and then down into the radon barrier.

Again, we see these mats of roots forming along the structural planes in the radon barrier soil, a structure that was formed in those soils.

Similar thing, back east again, more humid site, Japanese knotweed. In this case, an invasive species that's got a very woody root that roots down into the radon barrier.

A third lesson, a third observation, is that semiarid sites in the west, we see windblown dust beginning to fill the voids in the rock and sand layers. And in the east, organic soils, as plant litter decays down into the rock and the drainage layer materials.

This type of soil development in the rock enhances plant habitat, helps drives plant succession.

Soil development in this layer may limit lateral shedding precipitation, something we've never measured but as fine fills the void space in the sand and rock, you can see how that might happen.

Here's just an example. The Grand Junction disposal cell, Bill Albright, outstanding in his field, I guess, and you can see the fines filling the rock layer, just as an example.

Lesson four, the root intrusion, soil development tend to increase the saturated conductivity of the CSL.

Now, I want to remind you that most of these early covers weren't built for groundwater protection, they were built for radon attenuation. So, in some cases, there were calculations to say, okay, we already built this thing, how good of a layer is it for percolation?

In general, the target saturated conductivity is less than -- I've got these under meters per second; Craig's got me on this. I changed everything from centimeters to meters per second.

And we measured this at several sites with a device called an air-entry permeameter. And I won't go into air-entry permeameter, but this particular one was designed, and we purchased these from DB Stephens down in Albuquerque, which is a soil physics firm.

So, again, going back to Burrell, Pennsylvania, the humid site. This is actually the cover out here.

In this case we measured in this low permeable radon -- the low permiability radon barrier with entry permeameters at Lakeview. Lakeview is a little bit different in that it has the soil layer on the top, where we're measuring down in this low permiability layer. We measured it at two different depths within the layer. We measured where there were roots going through it and where there weren't roots.

Shiprock. Shiprock's a little bit different. You question how representative these measurements are because they're really only in the top part of this very thick compacted soil layer or low permeability radon barrier.

We did several measurements in the -- at least in the surface, in the first 2 to 3 feet of that layer looking at saturated conductivity.

I don't have pictures of Tuba City. Saying that's Tuba

City, Arizona. Grand Junction site, we dug through the protective layer in this case, down into the low permeability layer, and took measurements with air-entry permeameters and these are in situ saturated conductivity measurements.

And, in general, the data tends to come out between 10 to the minus 6, 10 to the minus 7 meters per second saturated conductivity. Again, the target, anyway, that we would like to see is something closer to 10 to the minus 9.

So these data aren't unique. So I threw in some data from ACAP sites kind of just for comparison.

They're all kind of within that range. So you'll hear a lot more about the ACAP sites later. These are ACAP sites where we tested a low permeability or resistive type cover, compacted soil layer.

So again, everything is sort of between 10 to the minus 6, 10 to the minus 7. Some bump up above 10 to the minus 6 at the ACAP sites.

And these are just mean values. There is high variability in this data. I have to go through the references and extended abstract to get more information there.

Lesson five. Different types of soil development processes seem to be going on, depending on where you are climatically, that may be causing preferential flow in these higher-than-expected saturated conductivity values.

Seems that maybe the soil structure is developing faster than we would think. At least, you know, if you've taken a soil genesis and morphology class, these things take a long period of time, while we're see some structural development over a shorter period of time.

Plant roots, perhaps burrowing animals -- we have excavated burrowing critters on our site, they have at other sites.

Freeze-thaw cracking and dessication. And perhaps there's some evidence, from what we're doing is the borrow source, had very well-developed structure. You dig this up, you don't break up that structure, but then you place this over the tailings and recompact it. It retains some of those structural planes, perhaps. Okay. There's some evidence of that. Particularly when we see these roots following those structural planes early on in the process here.

Lesson six. And this isn't so much of a lesson as a test. We've been testing a device, water flux meter a colleague of mine, years ago, developed at the pacific northwest laboratory. And testing on the cover, we did this at Lakeview with these water flux meters installed below the compacted soil layer. And most of them, after five years, have stopped working. So talk about design life -- somebody was talking about that earlier, these haven't lasted as long as we would like to see.

But in testing that, we have measured percolation flux. This particular site seemed to respond to precipitation events and fairly high percentage of precipitation at the locations where we measured it. Not necessarily representative of the cover, but as a test of device.

Lesson seven. And this, I think, goes beyond -- may be a lesson that goes beyond UMTRA sites and to other sites, especially as we get into these alternative covers, these ET covers.

We put a lot of emphasis on soil physics and soil hydraulic properties and the engineering of the cover, but a very important component of an ET cover is the ET, you know. We have to understand the soil edaphic properties, the fertility of these soils, soil properties that influence plant growth, as well as the hydraulic and physical properties. And so my lesson here is that inadequate revegetation and poor soil edaphic properties -- you know, you dig up a subsoil and you put it up and you think something's going to grow on it, you may be mistaken.

Here's just an example of one of our sites. These were seeded at the same time, all of this was seeded at the same time. This is over the cover where there was just a thin soil layer.

The idea was to get grass established. But in that thin soil layer you can't hold enough water to create the habitat that those grasses need to persist. And so the water is moving through that thin soil layer into the rock and eventually created their habitat for deeper rooted plants.

So just kind of a lesson is we need to

understand soil edaphics, soil fertility and have adequate revegetation planning as we go towards the ET type covers.

I wanted to just say something about the questions -- there were questions related to this, but the effect of degradation processes on radon attenuation and bio-uptake.

We in the LM program haven't directly measured effects of root intrusion and soil development on bio-uptake or radon attenuations. We have looked some bio-uptake of plants that are rooted into the groundwater, which may or may not be indicative of whether plants are taking up -- could take up contaminants that are rooted into the disposal cell.

However, DOE has -- I think Rich talked about this earlier. DOE has monitored ambient radon in the atmosphere above disposal cells and on the parameter of disposal cells. In these limited sites where we've done this, Shiprock, Lakeview, Grand Junction, they're all sites where the radon was below the standard.

And that's all I'll say about radon at this point in time.

Now, I want to kind of shift gears just a little bit and address the question of how little we've learned, essentially, from the degradation processes in improving covers to minimize degradation.

I'll go through this kind of briefly here. But again, the early covers, the one I've been mainly talking about, conventional designs -- this is back in 1987 at Burrell, compacted soil or bedding layer or riprap over the top of that.

By the time the Grand Junction site was developed, a protective layer was being placed over compacted layers, primarily for frost protection.

So that frost wouldn't move -- you wouldn't get frost from desiccation cracking in the radon barrier. So we have a protective player and this thickness was often based on the depth of frost for that particular site.

Moving up in 1992, at the Durango site. It's kind of a hybrid, where we were -- the UMTRA program was starting to look at incorporating soils to establish vegetation.

Durango was just on the top slope for

erosion protection. At least on the top slope it went away from the large riprap for erosion protection, which is essentially a soil-gravel mixture, so that vegetation would grow in that.

The soil was intended to be a better rooting medium than materials used in the past, they included a biointrusion -- biointrusion layer, to keep burrowing critters from getting down to the GCL, which was new.

And then you still have the low permeability radon barrier. Much more involved system.

Much more recently, at Monticello, Utah -- and I want to point out, Monticello was kind of a Cadillac design.

One reason for that, it wasn't an UMTRA design, it was a Superfund design.

So, with a little more emphasis on being complaint with RCRA designs. And I think Craig mentioned that Monticello design earlier. Essentially, it's an ET cover over the composite; in this case, HDPE and the low permeable radon barrier below that.

But the concepts for this was water balance or ET type covers must try to accommodate some of these degradation processes and rather than fighting the degradation processes, is try to preserve some of those favorable soil edaphic properties so we can get vegetation to grow.

In the background here is actually the cover for this. Reestablished the sagebrush steppe vegetation, which is -- could be argued as potential natural vegetation for that area, native plants in that area. The revegetation target, in fact, was the native plant community -- characterized the native plant community to come up with criteria for revegetation.

Water storage layer was designed thick enough, hopefully, to accommodate potential climate changes at that site.

Looked at different climate changes -- and we'll talk more about this on Thursday, both paleoclimate information and climate modeling information.

It has an animal intrusion layer. It's intended to keep burrowing critters from getting down into the capillary barrier here, which could actually increase the storage capacity of this sponge in an ET layer.

And then, the RCRA C compliant has an

HDPE. And then after we took advantage of that HDPE in here and created perhaps the world's largest lysimeter, a 7-hector lysimeter. We were capturing any percolation that comes through that comes through this ET cover. And it's working very well after ten years.

At Monticello we looked at degradation processes on the low permeability type of covers. Those earlier covers where we did similar studies a couple of years ago, Craig Benson and bill Albright teamed up with us to look at soil development and root growth in this water balance type cover.

So we trenched into that soil layer, we characterized the soil morphology, we characterized where the roots were going in this layer. We looked at the soil hydraulic properties of different scales from these two-stage borehole infiltrometers.

The soil blocks monoliths up to sealed double ring infiltrometers. Work that was done through Craig Benson's geotech engineering lab.

Just some highlights from those studies is that we did see greater-than-expected soil structure development eight years after construction. And this soil structure development was related to some increase in saturated conductivity, even in that sponge layer, but also, apparently, an increase in water storage capacity of that layer.

As water's moving a little bit deeper in that profile, passed the roots of those grasses, it improves the habitat for these shrubs, the sagebrush to establish. In sagebrush, you're removing that water from a greater depth. So it kind of altered plant community, it altered habitat conditions for the plant community.

We also saw an increase in leaf area index, which can be used as an index of transpiration rate, how much water these plants will remove from that soil profile.

But, overall, the root and soil development has little influence on requirements of the water balance of this cover, as we measured in that 3-hector lysimeter. Perforation didn't change.

Now I'm going to talk a little bit about a comment I think I made earlier, when I said one cover design's degradation process is maybe another design's renovation processes.

Talk a little bit about some work -- I think Rich mentioned this earlier -- but, really, cover renovation is improving the sustainability by accommodating degradation processes.

In an LM program, our focus is in two areas; we want to improve sustainability because we want to reduce long-term maintenance costs. In other words, we want to be closer and closer to a maintenance-free type of system. And we want to make sure, over the long term, that we don't increase risk. So the cover renovation kind of addresses both of those.

Again, I want to emphasize, under UMTRA framework, we're in compliance. So this is something, again, we're looking at in the long term as something we may be able to address in the future if it becomes necessary.

So the whole idea is, we've been talking about shrub encroachment and soil development. Well, maybe this is the solution and not the problem, at least with respect to the water balance of these systems.

Without intervention, in other words, if we didn't maintain these sites, natural degradation processes may eventually transform these low permeability type covers into ET type covers.

Saturated conductivity is increasing. Actually, the bulk density is starting to decrease a little bit. We have vegetation that comes onto the site. In essence, Mother Nature is trying to convert these conventional covers into ET type covers.

So the question for long-term surveillance of these sites and maintenance of these sites, do we continue to control the plant growth, as we have to do on many of our sites at this time? Can't we just let Mother Nature take over and not do anything? Or do we, perhaps, even want to try to enhance and improve on the soil development and ecological succession and these sites?

And that's the whole idea of cover renovation. It's not rebuilding the cover, it's using what we have and our understanding of the natural processes that are acting on those covers.

So the goal is to transform conventional covers into ET covers. Reduce the soil compaction, the soil bulk density, increase the water storage capacity of that layer, so we're storing the water.

The surface blend the soil and rock together, which really kind of imitates the natural analogs in that area of stable surfaces. And I'll talk about that more in session five on Thursday. And then enhance the establishment of favorable vegetation to remove that stored water.

What we've done is constructed a pair of large drainage lysimeters, swimming pool sized lysimeters, after the design of the ACAP lysimeters. And you're familiar with those. In those lysimeters we built the cover identical to an actual cover. This was done at the Grand Junction site. And we'll be comparing the water balance of the existing conventional cover with a renovated cover.

Renovation concept of this -- at this point is really pretty simple, we just mixed the soil and rock at the surface, as we see on stable surfaces nearby and natural surfaces nearby, and transplant native shrubs into those -- into the ripraps.

We built -- these lysimeters is what they look like. Again, here's the Grand Junction cover that's built into these. There's two of them, one would be a control, the other one will receive the renovation treatment.

And then, just recently, we wanted to practice a little bit with our renovation treatment and rip our lysimeters, which are pretty expensive to install with lots of instrumentation. So we built a test pad and in the spring we'll go out and we'll look at different ways of ripping that test pad and planting, so there will be different vegetation and ripping type treatments in that test pad.

And I want to finish up here with a summary of some responses to those session two questions. I don't repeat the questions, but the summary addresses those questions with regard to degradation of coverage.

Rock covers can increase soil water storage and create habitat for woody plants. And this categorizes an unforeseen ecological condition. You need to understand the ecology of our sites as we design these facilities.

Root intrusion and soil development can increase the saturated conductivity of these low permeability radon barriers. It's a different soil development process that may be causing this increase in saturated conductivity and potentially preferential flow pads. The soil structure developing faster than expected, root intrusion, freeze-thaw cracking desiccation and perhaps retention of some of the borrow soil structure. We see higher-than-expected saturated conductivity, and this may cause percolation. And this may or may not matter at a site.

When you look at the whole, I want to emphasize what Kent Bostick and Rich were saying earlier is we need to -- we need to look at the whole system of these. We've evaluated covers, for example, at the Burrell, Pennsylvania site, and the roots have grown through, the water growing through. But, essentially, that site, it doesn't matter, okay, we're not seeing any increase in leachate as a result of it. Water may be just passing through, it's not mobilizing. So we have to look at the whole system as you evaluate performance.

Another is that inadequate vegetation planning, poor soil edaphic properties. So utility properties can compromise cover performance in the short term. You build it, you plant it and then, after a few years, the vegetation just doesn't look as good as you would want it to.

Root growth and soil development had little effect on the performance of the water balance coverage at Monticello. Cover designs have evolved in response to and understanding of the evidence of degradation processes on these covers.

Degradation can be minimized by designing covers to accommodate these things. That was the idea behind the water balance cover at Monticello. DOE is currently investigating cover renovation, which is the enhancing of natural transformation -- conventional low permeability covers and ET covers.

We have not directly measured the effect of degradation on radon flux. However, we have measured ambient radon on and surrounding disposal cells and they are in compliance in that regard.

Plant establishment, whether naturally encroaching on the site or intentionally by renovation, could dry cover soils and potentially increase radon flux. There's another one of those tradeoffs we were talking about in addressing degradation processes.

And so anything we do in the future would cover -- excuse me -- cover renovation, our research will address not just the water balance, but also radon attenuation bio-uptake, erosion of the site, as well percolation of the site.

That about right?

Craig will get us back on time.

>>MR. BENSON: Okay. We're going to have two presentations. Might be the second one and then we're going to take a little break and then we're going to have three more after that.

I think one of the things that Jody talked about, about, I guess, nomenclature, we might call it, is an important one. One of the words I try to avoid is the word "fail." Fail has a negative connotation to it, so that's a word I try to avoid.

I thought about, even, things like degradation and do we have a negative connotation.

And sometimes I think it's very important that things that change over time aren't necessarily degrading, they may be improving.

So as I thought about my presentation, rather than calling it a degradation of processes or mechanisms or degradation of behavior and materials, I just called it changes.

And it is important to understand how the properties of materials, engineered materials, change. Because when you're doing performance assessments, like we've talked about some this morning, the properties that we put into those performance assessments drive what comes out of it. Understanding how those properties change is really important to creating a realistic performance assessment. And so understanding changes is important, whether they tend to improve performance or diminish it over time.

I think one of the tenets to changes, at least in earthen type of materials that we put in covers, I guess, actually, two tenets, one whether we're an environment which is near the surface, like a cover, will have a variety of different stresses which affect earthen materials and other types of barrier materials from low stress, cyclic interactions with the environment due to wetting and drying, freezing and thawing, those tend to be very aggressive processes which can impact the performance and engineering properties of cover materials.

Contrast, if we're in a deep setting, in a liner, it's a very different scenario. We're not exposed to the environment, we've got high stress, we've got moist conditions, very different set of situations in which the barrier is exposed. Normally, the conditions near the surface are the aggressive ones. That's where we get large alterations and properties. And, in contrast, at depth, under high levels of stress, we actually get barriers that behave very well for very long periods of time, or I should say that their properties tend to improve over time. I'm going to focus on the behavior of near surface systems for covers, largely because that's what we've been working on. But I would like to kind of come back and talk a little bit about liners and sprinkle that in as we go through.

So we talked about this particular session and I wanted to think about processes that alter -- and again, I use alter rather than degrade -- hydraulic properties and earthen barrier materials.

And really, what changes the hydraulic properties and their ability to transmit field flow is the change in the network of pores. So anything that changes the pore structure will alter the hydraulic properties of the soil and alter the rate at which water is either retained or transmitted. We might get growth in pores, essentially increases in pore size, creation of macropores from cell processes. We could also get processes like precipitation and consolidation and pore fillings, so things that would alter the behavior and make something more impermeable.

What we normally find, at least near the near surface, is that at least for fine-textured soils, we tend to see formation of macropores, things that tend to increase structure and increase the -- essentially the size and the frequency of larger pores within the soil.

And for course-textured soil, we almost see the contrast that we see pore filling. And in a way this kind of mimics what nature is often trying to do. As we engineer a system and then nature tries to put it back into an equilibrium state with the environment. That's really what's happening all the time.

And so when we think about barrier systems, the closer they are to the equilibrium state we put them in, the less likely they are to change. The great the difference is from the equilibrium state, the more likely it will be to change. And we'll see that as we go through this presentation.

So let's talk about what types of things cause the formation of larger pores in fine-textured soils that we would normally use for covers.

Well, there's really three major factors that cause formation of larger pores. The one is drying processes, which is the wetting and drying causes volume change in the soil, causes it to shrink and then swell, shrink and then swell. The pencil stresses that developed upon shrinkage cause cracking and those cracks then become large pores.

Those cracks and those -- the larger pores due to the cracks are essentially permanent. They may swell shut to some degree, but they never completely heal. They tend to be a permanent structure within the soil.

We might get bending or other types of processes that could create pencil cracks as well. And we might get holes from biota intrusion as well, wormholes or other types of plant -- wormholes, root holes, and I notice there's one other key factor I forgot to put in my list here.

Well, actually, the pencil cracks captures it. When we're dealing with soils that freeze, we actually expand the soil may have ice lenses that form, that actually increases the pencil failure with the soil, it causes a pencil crack and creates a macroscopic structure.

What are the impacts? Well, in a property sense, it increases in saturated hydraulic conductivity, so it's going to be more permeable. And, in some cases, they will get a decrease in water retention. Certainly, if we have larger pores in the soil, the capillary stresses tend to be lower and we can't retain water as effectively and water will flow through those larger pores more readily.

The impact that these formation of macropores has on the soil properties depends on a couple of different factors as well.

First of all, where do we start. If we start with a soil that's got a lot of large pores in it to begin with, we actually don't get very much change, in terms of the hydraulic properties.

On the other hand, if we start with something very impermeable, very dense -- to simply characterize -- with micropores, we'll end up with something that can change dramatically. And I'll show that here on the slide.

The other factor that's important is the propensity for volume change in any particular soil. Some soils, they change volume more readily, some tend to change volume, to a smaller extent, when they undergo wetting and drying and freezing and thawing.

I think this slide illustrates the idea of why adding a micropore -- or, excuse me -- a macropore is important.

On the left is a specimen of compacted clay. This essentially only has micropores. Really dense. It's nearly impermeable, highly plastic compacted clay on the left. It has a hydraulic conductivity of about 10 to minus 11 meters per second or 10 to the minus 9 centimeters per second. That's really impervious stuff. There aren't any large pores conducting flow. On the right is the same clay, just compacted a different way. Same density, even, but has a very different pore structure. It has lots of large pores and they tend to be much more permeable; four orders of magnitude more permeable, in fact.

And you could imagine the one on the left, if I put a few large pores in it, it would go from 10 to the minus 9 to 10 to the minus 5. Those large pores would be like pipes conducting the water through.

It would have a dramatic effect on the hydraulic properties. On the other hand, if I pick the one on the right and I add a couple more big pores to it -- well, it's already got a whole bunch of big pores, so it doesn't make a difference.

So the impact of the formation of

structure in soil and the formation of pores and the impact on the engineering property depends on where you start. If you start off with something very impermeable, it tends to have a dramatic impact. If we start off with something that's got a lot of structure to begin with, adding a little more structure isn't so important.

And that's what we've seen in our data consistently. I've just given you an example of this -- you know, find this nifty little pointer again. I'm going to find that radioactive pointer in here.

Nate, could you help me find the ball of fire pointer?

I don't care if it's a ball of fire.

That's high radiation.

So I just -- I think this graph is just a little busy, but I think it illustrates this point very well.

We start off -- this specimen is compacted clay that we prepared initially at different compaction water content, create different initial -- we compacted it dry, it created a very permeable, very structured soil. We compacted it wet, it created a structureless soil just consisting of micropores, so it was very impervious.

Two very different initial conditions. So over here, if you look at the red dots by the red triangles, those are the initial conditions. So very permeable over here and, on the other hand, we get the wetter specimens, very impermeable, almost 10 to the minus 9 centimeters per second hydraulic conductivity.

Then we took these same specimens and we just subjected them to wetting and drying processes. So we got it wet, dry, wet, dry. And, periodically, we would remeasure the hydraulic conductivity.

So it's wetting and drying and while it's wetting and drying, it's shrinking and swelling, and that shrinking and swelling is inducing pencil and ultimately causing cracking to form within the clay specimen.

So what we see over here on this wet side, where we start off at N equals zero, this N is the number of wet/dry cycles. So this is the initial condition down here.

If we just dry it in one cycle -- we took a very impermeable material, put it through one wet/dry cycle and, through that process, would cause cracks to form.

And we had something -- we had, essentially, all micropores, very impervious, put just a couple of cracks in it.

What happens to the hydraulic conductivity?

Well, it jumps way back up. It has a dramatic impact. It's something without a structure and add a structure to it, that has a large effect.

And then as we put some more cycles on it, we developed some more structures, but the impact of that is much more subtle, because we've already added half structure and we're just adding a little bit more.

And over here, on the left side, so if we start off with something that's fairly pervious to begin with and then we put it through some cycling, it doesn't change very much. In fact, this one actually diminished, hydraulic conductivity dropped.

And this one here went up a little bit, but it didn't change much, because there was already a lot of structure in the soil, these dry permeable specimens, to begin with, we put them through cycles of wetting and drying and we don't get much change in structure.

The other interesting thing is that over time, things become similar. All right. They may be very different to begin with and the initial -- as we vary the initial condition, we can create things, engineer things that tend to be very different to begin with.

But, over time, nature tends to balance them out. And you see these properties, regardless of where they started, are essentially the same at the end, as we went through this process.

So the formation of macropores within the soil, this impact on hydraulic properties, depends a lot on where you start. If you start off without structure, we have tremendous effects. If we start with structure, we have much more modest effects or no effect whatsoever. And I think there's some lessons to be learned from that, for creating barrier systems at the near surface that we can take away, as we'll get to a little bit later.

As I indicated, the other thing that's important, too, is to the mineralogical composition of the soil. We tend to see that some soils will shrink and swell to a greater degree and then undergo larger volume changes and, therefore, larger changes in structure.

And I just illustrate that with these four specimens that I rotate through. This is lodgement till from the Indiana area, it's a very -- it's essentially almost a silt. Changes in volume very little. We kind of cycle around, do a low plasticity clay, a moderately plastic clay from the Denver area, and then a highly plastic Gulf Coast clay.

From Houston we see very different propensity for volume change. As they get more plastic they tend to be -- undergo larger changes in volume. You can see the larger cracks that form in the specimens due to the great amount of volume change. And we see corresponding larger changes in hydraulic connectivity. This is a ratio, essentially, conductivity after wetting and drying, to the initial conditions. So a large number of the greater increase has a function of a number of drying cycles.

And we see the really plastic CH soil has nearly a three order of magnitude increase in conductivity, whereas the CLM tends to have a much

more modest increase in conductivity. So the propensity for volume change is important as well.
One of the other things that we think about, we think about cracks, desiccation of soil, we tend to think of these large kind of gaping cracks. I think it's the kind of way we often think about desiccation cracks forming in barrier systems.

But I would argue that this is less the rule than what we actually see. This is more -- this is kind of the sensational slide, it's a great one to show. But, really, this isn't what we see most of the time. Usually what we see are these type of structures that form, these types of vertical cracks that create -- they're very closely-spaced, fairly high-frequency cracks that form in soils that create a very dense network of pores as well.
So the structure that we see often tends to be kind of like a scale of your hands, sometimes larger. But the very large cracks that we often think about forming are less common.
But this is the type of cracking that we see very

commonly. And, actually, Bill and Jody and I have dug up so many of these right now, I think we've seen just about all the different things you might find.
We see some similar things by freezing, and we look at how freezing and thawing affects soil. Freezing and thawing and wetting and drying, they're thermodynamic, like very similar. I hate to even say that right after lunch, but the word "thermodynamic," it brings back bad memories for some people.

But, thermodynamically, they're very similar. Their base change is different, but the effects on volume change and structure of the soil are very similar.
This is actually a frozen specimen of clay. So, actually, it was frozen and then we thin sectioned it, put some super cooled water and glued it on to a glass slide and shown a light up through the back so you can see these ice lenses in it where the light is shining through.

What we find when soils freeze, we get these cracks due to the formation of lens that cause pencil cracking. At the some time we see formation of vertical cracks due to desiccation that occurs as the water moves up to the freezing front, it actually dries the soil below and that drying actually causes desiccation.

So you'll actually get a coupling of both desiccation cracks and pencil cracks from ice lenses forming.

And this is a very dense network of cracks as well, as it illustrates here in this slide. Here's a scale up here. Some old English units up here. I apologize. Inches -- as Jody knows, I'm an SI guy. I still have some old slides in my files.

But you can see the cracks here. They are tiny little cracks, right? And if you've done any agriculture in the freezing part of northern tier of the U.S., you've seen this structure in your surface soil all the time. Very dense network of cracks that form, and these cracks conduct the flow.

And like we saw with wetting and drying, freezing and thawing has similar effects on hydraulic conductivity, at least a factor of ten and, on occasionally, a factor of up to 10,000.

I just illustrate here some data from a clay barrier over in Michigan that we monitored back in the middle 90's with both laboratory experiments and the field data as well.

We saw the same thing in the lab and the field, that we do get structure forming and that structure causes alterations in the hydraulic properties. In this case, causing the saturated hydraulic conductivity to increase.

The other aspects of this, at least in the near term, these formations of these pores tend to be permanent. They don't tend to heal over time. You might think over a very long period of time, you might get some precipitation processes or other types of chemical processes that might fill some of these pores, but what we see, at least in -- and what our data tells us is that these -- the structure that develops is relatively permanent. These things wet back up after they've been drying or dried, the structure tends to stay.

The only magic bullet we have for remedying the impacts of structure is to squeeze it, put stress on it, where you can remedy the effects of structure.

But barring increases in stress, these macropores that form tend to be permanent and they conduct flow on a permanent basis, at least in the near term.

Other things. Freezing and thawing, wetting and drying are physical processes, how about some biological processes. Just took a couple of slides from some of the ACAP sites that Bill and I exhumed up in Montana. We had a couple of sites up there.

This was from one in Polson, Montana. Some friendly ants forming a nice macropore. And then, actually, this pore here -- the mechanism that actually -- you can see these two vertical sides to it here were it formed, perhaps by a worm. It had to be a pretty straight worm. We're not quite sure what formed it, but this is, essentially, a root mass that filled right down through that pore. Right down through the pore.

And, actually, we were able to pull that out. It's like the size of a pen. So you pull it right out of the hole. There was that root mass filled within that pore and kept it open. So we get effects of biota as well.

We get those -- I guess the other aspect we see with the effects of biota is that the biota tends to -- they cause the cracking or cause the formation of pores. It also tends to follow the pores. If we get pores formed by physical processes, like wetting and drying and freezing and thawing, those pores will conduct water and they will then become, essentially, pathways for roots to follow.

And that's what this slide shows. You can just see these kind of cracks that exist in this silty barrier material.

You can see some here. I'm just kind of following them around. These here are kind of all, again, the size of my hand or so. And you can just see these layers of roots that have been laying along those cracks, because that's where the water is and the roots grow.

We see this at depth sometimes. This is actually a sample. Our commercial lab tested this summer for a site in -- somewhere in the southeast. I'm not quite sure where it was. It was a Superfund site, top secret, they didn't want to tell us the details.

But they were looking at -- doing a performance assessment. It wasn't for a radway site or for a chemical waste site. They were looking at how the closure of this site would affect long-term transport to groundwater and they needed to understand the hydraulic properties of this clay layer beneath it, about 10 meters below grade.
So they exhumed these large samples. These were 500-pound samples and brought them back to our lab.
And then we did saturated hydraulic conductivity test on them. We never expected them to be this permeable.

They had hydraulic conductivities up here in the 10 to minus 4 range. They were very permeable, even at relatively high stresses. And those were due to these historic root holes that existed through these clay specimens.
Actually, we were able to go into these holes and actually pull out some of the organic matter that still existed in the roots.
What time period those roots were present isn't clear.
So they clearly were former root holes and they were

conducting the flow, as you can see by this blue dye.

Relatively insensitive to stress, which is the first time I had ever seen this, which is kind of a cylindrical root hole which might have some root stresses that would prevent it from closing upon the application of stress.

So biotas can also cause formation of macropores to develop in a hydraulic property.

So what does this mean in terms of our hydraulic properties that we use for design? Well, as Jake alluded to this morning, we had this project funded by NRC and, actually, a whole bunch of folks at National Science Foundation, Department of Energy, EPA. As the potpourri of partners. What Bill Albright and I did, we went around -- and with Jody as well -- to our sites throughout the United States and exhumed samples from these sites. We had a whole series of tests, and Jody mentioned a number of these, I think I'll pass quick through them.

We did a large and small scale field test. Some of these are the same photos you had in yours, Jody, some from out at your site there in Monticello.

But, yeah, there are some important lessons that we learned from this. The first thing I think that -- as you have alluded to, Jody, we did see a lot of structure whenever we had systems in the field.

We saw a lot of structure. And when we get structure, we know that our hydraulic properties are a function of scale. And I think Dave talked about this this morning of really understanding the appropriate scale for the problem we want to analyze.

And if we looked at larger scale tests, we got a pretty accurate depiction of what was going on at field-scale conditions. Things seem to level off if we've got a large enough scale test.

When we looked at our large-scale data and we looked at our hydraulic properties, what we found, for the most part, is that -- remember if I showed you that first slide from the laboratory test where we had very different initial conditions, but, over time, became essentially the same. We got the same hydraulic conductivity after a number of wetting and drying cycles.

We saw the same thing in the field. This is a graph. Some of you may have seen this graph before. This is our in-service field conductivity in the Y. This is after between four and eight years of service. And on the X is the as-built saturated conductivity.

And if there was no change, the data would scatter right along this one-to-one line. And the increase in conductivity over time means that the hydraulic conductivity should be above this one-to-one line.

And what we see is our data following this band essentially at the end, it's independent of where we started from.

The hydraulic conductivity falls within about 10 the minus 5 or 10 to the minus 3 centimeters per second, on average. That's close to 10 to the minus 4 being the mean. Not a hole lot different from what our laboratory tests show, not a whole lot different from that large block sample that we exhumed from ten years below grade. Everything seems to go to a similar number, in terms of saturated conductivity.

We found that to be true with independent climate. We tend to think of these effects being really dramatic in dry climates, where we get a lot of wetting and drying. Well, they happen in wet climates, too.

We found similar alterations in conductivity in our humid and sub-humid climates, as well as our arid and semiarid climates. And, in fact, if you talk to any farmer in the eastern part of the U.S., they'll tell you, this structure forms all the time. These properties get altered -- actually, in the upper midwest we count on those properties to make sure our agricultural field drains well over time.

It certainly affects the soil composition. If we looked at compositional factors, as I alluded to earlier, factors that tend to cause soil to change volume to a greater degree cause larger increases in conductivity. So soils with lower plate fraction tended to be more resilient. Soils where the fines were more silty tended to be more resilient as well.

But things that tended to have less volume change, those soils also had that higher initial conductivity to begin with.

Same with placement conditions. If we place soils in conditions that eliminate structure, well, that structure comes back over time and we get larger changes in property.

On the other hand, if we use placement conditions that induce a lot of structure to begin with, we get much smaller changes. So if we're looking at near surface conditions, placing soils with lower densities and drier water content, it's going to create structure to begin with and get us closer to the long-term effect -- long-term condition from the get-go.

Another important issue is that these processes are not just limited to just the very near surface. They tend to go down 2 or 3 meters. So in fairly thick covers we'll see this.

If we look at this graph carefully, you will see that we saw changes on the order of a few orders of magnitude -- depths of on the order of two and a half meters.

And I always like to show this slide, because it's one of those eye-grabber slides. This is one of those -- from a radon barrier from a case on lysimeter that Jody had constructed out at Monticello, Utah.

And this was down at depths of nearly 2 meters. And we can see this radon barrier had large cracks in it and roots in the cracks where the water had been flowing. So these alterations do occur at depth.

So anything that's at the near surface is likely to undergo these changes over time if it's exposed to the atmosphere and wetting and drying and freezing and thawing processes.

I talked largely about saturated hydraulic conductivity, because that's an easy one, or one that's intuitive.

But we see the same things in the water retention characteristics. We see that the air-entry pressure tends to diminish over time due to formation of large pores. Or in terms of -- if you're more comfortable with the parameter tends to go up, as we've illustrated in this graph.

It's increasing on the order of a factor of 10 up to an order of about 15, at most, with larger changes in alpha corresponding to soils that tend to be denser and more structureless to begin with. The end parameter tends to be far less sensitive.

So we see similar changes in the soil water characteric here as well. And so I guess the take home message, at least for natural fine-textured soils used for either barrier layers or storage layers and water balance covers, is that the farther they are removed from the natural or structured condition, the more they're going to change. So we would be wise to try to get things -- create things in a condition that's closer to the equilibrium state to begin with so that we can understand the performance and that performance will be more typical or more characteristic or steady over time.

One question might come up about some of these other types of barriers and we'll just have to take a couple of minutes to talk about synthetic clay liners because these materials have a lot of the same issues. The same ideas that apply to compacted clay liners and storage layers made of natural fine-textured soils apply to synthetic clay liners as well.

We know that these materials, like this natural sodium bentonite down here, can be very impermeable when they're constructed. Just like a natural clay can be very impermeable as well.

One of the reasons that bentonite -- if anybody's used bentonite, you know it tends to swell a great deal when it's placed in water. That's due to the sodium cations that are bound to the monovalent surface. If we exchange that to some type of divalent like calcium, we end up with something that doesn't swell very much at all. This is a sodium bentonite and this a calcium bentonite. They're the same amount of solids; one swells a lot, one swells very little.
We went in our ACAP sites and pulled out samples of our ECLs and examined them to look at their hydraulic properties.

One of the things we looked at was the -- potentially, the swelling potential of the bentonite. If the bentonite loses its ability to swell when it's wetted, it won't -- and it shrinks and swells in response to the wetting and drying, it won't heal up and seal and form a low kind conductivity barrier.

What we found is that the ability of bentonites to swell tends to diminish pretty rapidly. This green component up here is the swelling of a new sodium bentonite. Up here we measure it in terms of these kind of funny units of milliliters per 2 grams. It's an index test we use.

And up here, 25 to 30 is the range for a new product. And what we found is all of our materials we exhumed tended to have a much lower propensity for swelling when rewetted, and many of them, essentially, were like a calcium bentonite with virtually little -- very little swell at all. And we found that that was largely due to the sodium being replaced by other cations in the environment, calcium and magnesium, which tend to be much more prevalent.

Let's go to this slide.

What we found when we looked at GCLs, like we saw with natural earthen barrier materials is that under some conditions they tended to maintain very low hydraulic conductivity and other conditions, particularly those where they didn't hydrate to begin with or they were exposed to wetting and drying, particularly those which weren't covered by a geomembrane tended to have large increases in conductivity.

And one of the factors that we found that influenced that is some of the construction conditions. We talked about construction conditions earlier today. The moisture coming from the subgrade was kind of a key factor factors in that.

So if I want to just kind of wrap up on our lessons learned here in my last couple of minutes, that we have for earthen barriers, any time we have an earthen barrier on the surface, where it's exposed to a fairly aggressive condition, nature will alter the engineering properties in a relatively short period of time. Dense soils tend to become looser, unstructured soils gain structure. That's the norm, that's what we can expect.

If we don't prevent wetting and drying, freezing and thawing, we can't expect that to occur. If we're -- for some reason we can prevent that from occurring, then we can expect the structure not to develop.

We do see the hydraulic properties in the fine-textured soils tend to become more similar over time.

So really using the longer-term properties that we've observed, at least in a sense -- from a performance assessment point of view, seems to make sense. That's where things are going to evolve to, and fairly rapidly. And we should look at using those in performance assessments.

I would argue that since we know that these changes are going to occur, rather than trying to force fit an engineered design into a system that -- where it's not likely to persist, it would make more sense to create an engineered system that replicates nature more closely. Mimic the longer-term condition in our design as opposed to creating something that's inconsistent with nature.

When you think about designing something for hundreds of thousands of years, trying to replicate nature seems to be a logical thing to do from my perspective.

Choosing soils that tend to have less volume change, lower clay content is more -- is a good recommendation as well. If possible. It's not always practical. A lot of sites you have to live with the soils you have, custom making or purchasing soil can be very expensive.

Some analogs for GCLs can become very permeable, just like we see for natural clay materials. If they undergo wet/dry cycles, cations can become very permeable.

So we do know that, from our experience, that if we put them underneath geomembranes, you hydrate them properly, you keep them from wetting and drying, that they can maintain their very low conductivity.

So they can be very effective but have to be hydrated rapidly, and then we have to protect them from wetting and drying by using some other type of barrier on top, like a geomembrane.

And we found at least the best way to get them adequately hydrated is to use a subgrade that's compacted opt -- the weight of optimum water.

So, lessons learned, things change, right?

All right. We got a little break. We're scheduled for -- we start five minutes later. So you wanted to take ten minutes, Tom? I think we need ten minutes. We'll start up again, according to my watch, at 2:45.

All right?

>>MR. BENSON: Okay, we'll get started. We have three presentations in the second half of the presentation part of this, and then we'll move to a panel session afterwards.

I'm very pleased that we asked Professor Garry Willgoose to come and that he agreed to join us.

Garry, if you don't know, is Mr. Siberia, all right.

SIBERIA is a landform evolution model and it's something that Garry has worked on for many years, and it's one of the codes that people use frequently to look at landform evolution over long periods of time.

Garry is the Australian Professorial Fellow in Environmental Engineering. And if you're familiar with the Professorial Fellow program in Australia, it's a very prestigious accomplishment.

He's also director for the Center for Climate Impact Management at the University of Newcastle, Newcastle being a little bit north of Sydney.

And Garry grew up in Australia, but he does have some American roots to him as well, getting his Ph.D. with Rafael Bras at MIT a number of years ago.

So, welcome, Garry.

>>PROFESSOR WILLGOOSE: Thanks.

What I'm going to give you is a bit of an overview of the sort of work we've been doing in Australia. And a few people will know about this, so -- and it's primarily been focused on uranium mill tailings at a particular site, but we've also applied it at a number of other sites.

And what I want to do is give you a bit of a background to land evolution models, because they really go back to some of the original work we did at MIT 25 years ago now.

But the practical applications really date from the 90's and you will see some movies I'll show you of simulations that we did in the early 90's for Ranger uranium, and that was primarily to do with uranium mill tailings.

What we've basically pioneered is the application of these models, which were really designed for sites to understand why landforms look the way they do, how it interacts with plate tectonics, why hills look the way they do, and tailor them to look at much shorter time scales.

So from the point of view of landform evolution models, these are short time scales, whereas -- the introspective, you know, 100 to 1,000 years is a long time scale.

So, from that point of view, some of the science works were really pretty undeveloped, as far as practical applications and the sort of applications you're talking about here, which is cover design. And that the tools really need some optimization as engineering tools as opposed to science tools.

And one of the things that we found is that there are some really interesting subtle issues to do with regulatory things here.

We are pioneering a lot of new types of approaches that the regulations in Australia and I suspect, from what Craig says, here as well. Really haven't quite got to it at this stage. So there are some real challenges as far as actually, hey, you actually use this information.

Okay. So what I'm going to do is talk to you a little bit about some simulation work we did the nearly 20 years ago now. But the reason I like this is, first of all, it's suitable for this talk because it's all about uranium mine site. It's not just mill tailings, it's below-grade ore and it's waste rock.

It's the sort of structure that, actually, we found shows almost all of the bad features that that can come out of landform evolution modeling, in terms of the way things fail.

And it's interesting, as well, that from the Australian context -- for those of you unaware, Ranger is one of only two uranium mines operational in Australia. It's one of the larger uranium mines in the world. It's quite a large mine by standards.

The picture on the right is a picture of what the mine looked like in 1992. And what we've got here is the new facilities here. We have some below grade oil here. Just off the corner here you can see the tailings facility, which is about a kilometer square.

The whole rehab, which is shown here in this -- in the first image of the movie I'm just about to show you, the scale is almost about 2 miles by about 1 mile.

And the rehabilitation area is this area here. The tailings repository is in the back corner here. The front part here is a pit that only opened up in the last five years. In this region just off to the left of the photo, but obviously is not here. Okay. So what I want to do is show you the movies now. Just -- and we look at this one.

Okay. So we'll just stop this movie here. Okay, so what this is now, this is a simulation using the landform evolution model of a thousand years of erosion at this mine site, using the properties of the hydrology, the runoff properties and the erosion properties as they are currently today, as we measured in field experiments today. So what you'll see is you'll see the development in this region here of a whole bunch of gullies. Here -- one thing I might say about this, the design of this as it was proposed then was it would have a 2-meter deep erosion layer on top, essentially, riprap protection.

So the idea was that they had done erosion calculations using USLE, but they said that the erosion was going to be about 300 meet millimeters over a thousand years, 2 meters. That's a factor of six fact -- I think that should be thick enough.

That was more or less the thought behind this.

What you'll see here is -- you'll see here is a large number of gullies up here. You might actually see gullies forming around the barriers around the inch here as well.

Okay. So just run this. And we'll probably end up running this a few times.

What you can see is you can see the gullies here.

Now -- woops. Let's get back to the end there again so you can see right at the end.

Okay, so what we've got here is we still got 300 millimeters of erosion. Okay, this is one of the key pieces of findings out. Is we -- using the erosion data at this site, we actually get exactly the same mean average erosion of a thousand years that you get from USLE. And we've also looked at wet subsequently to this work.

So it's exactly the same average erosion, but what we find that, in fact, we have areas of very deep erosion interspersed with areas of almost no erosion whatsoever.

And to put this in perspective -- this is very, very exaggerated -- it's about 2 kilometers across here, and this is about 35 meters high.

So what you'll find here is that, in fact, there are gullies in here that are nearly 12 meters deep, okay, interspersed with areas where there's virtually no erosion.

Now, the interesting thing about this was that this basically says that the cover is filed. As it turns out, when you run the landform evolution model, it covers very quickly. Exceedingly quickly in simulations.

So the key finding out of this is that we can actually get exactly the same erosion as you would get from a traditional erosion model, but you get a special distribution that is very different from a traditional erosion model because a landform actually evolves in response to the erosion developing valleys of hills that we see in the natural landforms.

So that's -- we can run through that again so you can just see it, because you can see it here. You see it here. There's some gullies actually out on the batters, as well as here. But it turns out, from the particular angle we're looking at here -- at the particular angle we're looking at here, you can't see it, but where the tailings facility is, there's actually gullies of up to 12 meters deep over there as well and actually penetrating the repository wall and releasing the tailings in this particular simulation.

So when we did this, this caused a bit of angst, as you can well imagine, because this was done for the Regulatory Authority, this wasn't done for the mining company, so the mining company were not terribly happy about this, as you might imagine.

But, anyway, this is the alternative way of looking at this. This is showing you how the spatial distribution of erosion and the deposition.

The blue is where deposition is occurring in any year. And the red is where the erosion is occurring in any year. Okay, and we can just run -- first of all, just looking at this, this is in the first year.

So one of the first things to note here is that, in fact, even in the first year, erosion is not uniform on this structure. It starts to the gully and concentrates low, where it concentrates erosion and deposition very, very quickly.

In terms of this -- and you can see it here. At the top of the barrier it goes up -- sorry, from the cap onto the batter, and there's erosion going on and there's deposition going on on the base of those, it goes out under the natural landform.

And the same here. You can see here, down here, even in the area here the red is a little bit light, so the erosions are so fast. There's patches of erosion and deposition all the way down here.

So, we just run that through again. And you can see there's quite some variability where the deposition is occurring. But the interesting thing about this and one of the highlights of doing these simulation was that it showed where the erosion was occurring and how the failure mechanism occurred.

In addition to it being as a result of that. So we can see -- if we can -- F5. F5? Oh, okay.

So there were two insights that came out of the landform evolution model that weren't possible from traditional erosion models. So, first of all, we demonstrated that we get the same results as you get from traditional erosion models if you view the data in exactly the same way.

The first of them is erosion over the long-term is concentrated in the gullies and it's not uniformly spread.

So that's the first obvious one. And the pink erosion dip is what the term is cover failure. So it's no good to say that the erosion over 1,000 years is point three, on average, if the deepest erosion is going to be 12 or 13 or 14 or 15 meters. Kind of Where the two meters is achieved within a matter of a decade or more.

And this was a really important one that took us a little while to figure this one out. Is if the gullies don't actually uniformly erode over their length either, so it's not like just having a gully instantaneously penetrate up into the landform and they uniformly lower it over time.

What actually happens is at the stake caps, you get a penetration going into the landform horizontally. So the erosion is almost penetrating it horizontally into the landform, what's known as a knickpoint in river mechanics.

This picture here sort of really shows -- in the top here is an original constructed landform with a cover. It was originally designed to 2 meters down here as well, sitting on top of natural topography.

This would be what you might think at first instance of how a gully would occur, would start out, along its full length and gradually, over time, deepen. This is a bit of a depositional fan out here. But this is -- what the key criteria here is how deep the cover is on the surface here on the cap.

What actually happens that, in fact, the penetration goes this way and the erosion propagates in horizontally.

So the key is in fact how thick the cover is on the batter, not on the cap, and that the penetration of tailings facility actually occurred laterally rather than sort of coming down vertically.

So what's evidence for this type of gully? I must say, when we did these simulations, these were -- they're obviously pretty novel, as far as this is concerned. And there was some concern that, oh, well, this is just a model, you know, nobody's ever used this before, the results were rubbish, blah, blah, blah. You can see how it probably went.

So we basically did a whole bunch of things. And one of them was we went out to a whole bunch of degraded mine sites in Australia -- and I can show you there are plenty of those -- and looking for the mechanisms of failure of rehabilitation.

And almost every rehabilitation that we found failure on, failed by exactly that mechanism.

The pictures on the left here, one is looking down from -- let me get the mouse back. Here we go.

One's looking from the bottom up at a gully on an above-ground structure almost identical to Ranger. A little bit smaller. So you can see this gully here, walking up the gully, and this is the gully looking down.

So what you can see here is that a gully is actually penetrating the top of the cap here. It's actually cutting through the batter here. This happened in about eight or nine months, so the top scales are sort of right as well. We were suggesting that Ranger potentially would file in about 10 or 20 years, not a thousand years, as I was originally hoping for.

This one here is an interesting one. This was another mine site, and we're standing now on a similar sort of place up here. It's a different mine site, but we're standing up here at the top, on the road, as it turns out, looking down over the natural landform here. Okay. And we've got this enormous gully that's actually about 200 meters wide going down. And the picture is not very clear, but, actually, the alluvial depositional fan goes out into the forest out here.

To put this in some scale, this rock here is about the size of a large car. So we're talking about being able to move very, very significant riprap. If you want to think of it that way. In this case, it's not actually riprap, it's just the rock that happened to be put there from the mining operation.

Okay, so in all the cases, these failures occurred within 12 months because we would know we now are guaranteed to be okay.

Okay, so the question is, well, what do you do about that? And the obvious -- the obvious question would be, despite the affected -- you know, the last one I showed you had rocks that were moving that were the size of cars, is you might simply armor these gullies, okay, and leave everything else. You armor the area where it's going to erode them. And sort of, where it doesn't erode them now, well, you're not going to do anything.

The problem is that the gully location can be really sensitive to very small changes in the abstract flow geometry, things like roads, bulldozer tracks, settlement. Just about anything can change the exact position of where the flow is, and that would change what that gully's position is.

You can't predict those and the construction difficulties. So what you find is that small changes in elevation for any number of, you know, good reasons, meaning that the gullies are not deterministically predictable. You can't deterministically predict where the gullies can occur. You can't, as a result, armor where the gullies are going to be in the model.

Okay. So what you need to do is you need to do probabilistic risk assessment on this.

So that leads you to doing something like this. This is a slightly different rehabilitation proposal that we looked at soon after this. And on the top here we've got one particular realization of landform, where we put on 1 mil of random elevation change in space on this landform. It's a little bit smaller than the other one. And then what we did is we ran a bunch of Monte-Carlo simulations with different random and elevations, and ran the simulations a number of times.

You take the average of the erosion for all of those simulations, okay. And this is what you get here. This is showing -- the vertical is average erosion and deposition is, in fact, below the plant surface here. And what you can see is that the average erosion here, is all concentrated around the tops of the barriers. It's relatively uniform. And what that's saying across all Monte-Carlo simulations, yes, you should get a gully in each of those, because gullies are moving all over the place in each simulation to simulation.

And the numbers here -- I've always got to read this. The number here, the average erosion, the peak here, is about 4 meters. So this is a lot more than the 2 meters.

Even here, when you look at average, when you've got to distribute it over the landform, clearly there are some spots there that have got very low erosion, some spots that have got very high erosion, even on the average across all realizations.

Then you can do some other things, like looking at envelope curves and say, well, what's the maximum possible erosion which typically occurs when you have a gully at that point?

This is now 12 meters, 13 meters. So that gives you a bit of an idea of just how deep the gullies potentially can be, around, about. The form of it actually is not a whole lot different, you can sort of see the same sort of pattern low erosion right here, high erosion right here, a bit of erosion of deposition going on in the center here. It's just the scale is a bit bigger.

This one is the most interesting one. And this is the one that basically sent the shock through the -- through the mining company. Is that then you can actually look at the cover and say, okay, if penetration of the 2-meter cover is failure of the cover, not failure of the facility, what's the probability that any point in the cover will fail?

So this is, if you look at all the realizations that anyone noted and you said what percentages of those realizations have erosion greater than 2 meters, so it's a probability of failure, and then you map it.

The scale here, .85. Because -- so what, basically, it's showing is that there are some points in the landform where it's almost certain to fail after a thousand years.

There are other spots around here, okay, and it's on the edge of a about a -- here. We're talking about whether the probability of failure of the cover is actually pretty small.

So you can then start to concentrate and say, well, actually, clearly, the places that we want to armor protection, we can sort of map out, roughly speaking, where we need to put more cover protection in, because we can look at the probability of failure as high.

So we can actually localize it, but it's not localized to the gullies, it's localized to where the risk of gullies occurring is highest.

So all of this stuffs was done in the 90's, okay. It was -- as I said, it was pretty revolutionary at the time. We managed to run into a few potholes and bumps along the way in all of this and we shook a whole lot of bugs out of SIBERIA along the way, as well, with this.

But we have now been involved in doing something like this ourselves, about 20 or 30 of these sorts of assessments for mines around the world.

We are also involved at Las Alamos with low-level repository doing the same sort of thing here. We have been advising the consultants -- one of the consultants is looking at West Valley low-level repository as well, doing more of these sort of things.

So what I want to do is -- that's the capability that you can do.

And that's -- the sort of simulation I showed in the movie takes about eight minutes on my laptop, so it's not computationally intensive. When we started doing these sort of simulations back when I was doing my Ph.D., I ran on the Pittsburgh City Computer Center. We never had enough computer time, but that's no longer an issue.

Okay. So I want to just concentrate here on what some of the research issues are here.

Obviously, we spent a lot of time during the 90's -- and my science colleagues -- my science colleages are always amused about this, essentially doing a lot of validation of the codes, specifically for sorts of landforms that come up in those sort of sites.

They don't look natural. They have different types of erosion patterns that you would normally see.

So the sort of things we do, we spend a lot of time comparing the erosion results from RUSLE and WEPP and SIBERIA. And when you looked at them exactly the same way, they all got the same erosion. So that gave us confidence that we're not doing anything dramatically different from what -- you know, we know the physics are the same, particularly as far as WEPP's concerned. WEPP and SIBERIA are very similar internally. We know we're not doing anything dramatically bad there.

We also have, just in recent years, the last five years, have been comparing a couple of landform evolution models, is my model, SIBERIA and CAESAR, which is written by of Tom Coulthard.

They give almost identical to similar predictions, in terms of the sorts of erosion we see here. The main difference is dramatic CPU differences. One of my colleagues has done this and he's told me that, whereas SIBERIA might take an hour to do a simulation site, CAESAR would take maybe a week or two weeks to do exactly the same calculation. So it's differences in terms of numerics.

We've also done a lot of stuff on field validation or what I refer to as mine landforms. Not natural landforms, but the landforms that look like mine sites, that look like repositories, that have those sorts of characteristics I showed in the movie. So things like, there was a 40-year-old integrated uranium mine mine waste dumps that we looked at, and we got a very good prediction of what the 40-year erosion looked like.

We also the looked at 10-year-old sites on the Ranger uranium mine, as well, with the batter -- triggered gullies along the batter on Ranger and parts of the gaps and been able to predict quite well with SIBERIA what comes to the end. We've also done plenty of natural catchments as well.

We've got confidence that we can go out 40 years in the model. And given that most of the sort of behavior we see seems to occur in the first 40 years, and we're pretty confident about the results.

The one major issue that we spent a lot of time in the last ten years working on is that the surface conditions, the actual erodibility of surface, condition of the surface, changes almost as fast, if not more faster for these mine sites than the actually landform itself.

Essentially, what you get is you get is you get the preferential removable fines from the surface, that create a harder surface, so you end up with coarse material covering the surface. But then, depending on what the weathering resistence of this rock is, that rock breaks down and that may become transportable erosion.

So you have over the long term -- and I'm talking 50 to a 100 years -- a balance between an erosion process that makes the surface less erodable, starts to protect it, but a weathering process that's breaking that protection down.

And, in fact, it's actually a quite difficult process to do. Computationally, we struggled with it quite a bit until recently. The evidence for this sort of behavior is here. You can see it. This is the surface, the erosion through here. It's all armored up with coarse material. Here's another one where you can see the coarse material. Or what happens is that all the fine material has been eroded away and all the coarse material just drops to the bottom and then you've got a complete cover of coarse material, like when that gully would stop excavating hopefully.

So this is some of the results from the work that we started doing in the early part of the decade.

Looking at how the -- in the absence of weathering, has the armor on the surface changed over a period of 100 years. We go from about 3 millimeters up to about 12 millimeters. And that's accompanied by a very dramatic reduction in the erosion, erodibility of material from potentially up to about an order magnitude drop in the erosion. So this is just simply the armor in effect.

If you look at this in time scales of about 100 years, you can slice and dice this problem in a number of different ways, and you see, essentially, it takes about 100 years for this armor to actually develop. And this is where it gets simulating the rainfall climate conditions at Ranger, which is tropical monsoon.

Okay, so one of the key questions that we've been talking about is what to do in terms of how to armor a surface to reduce the erosion. The sledgehammer approach would be to cover the whole facility with rock. Well, first of all, that's really expensive, as anybody that's been involved would know. It also impinges on your cover design, because, essentially, you've got something that's got to sit on whatever cover you want just to protect that cover.

Occasionally, you cover the sensitive sites, but then you need to know what those sites are to actually put it there.

One of the things we've been experimenting with and which Las Alamos is looking at was actually using strips along the batters to constrain the dip of erosion.

This is something that traditional erosion models just simply can't model. The idea is that if you look at this on the surface here, if this were just land to road, it would probably go down to this -- something that looks like this concave orange line here.

If you put an armor strip about halfway down, this basically stops the erosion from occurring on that. What you got is you get something that looks like it's draped over that.

Now, we've done a lot of simulations, and even if you just put one strip on a slope like this, this reduces the maximum depth from the gully by about a factor of four.

That's not covering the whole slope with armor. So that means that the risk of the slope can have whatever cover you like. You can do whatever you like with that.

The question, I guess, is, yeah, what's the long-term stability of the strips? There's a whole bunch of interesting science issues with that.

Now, I guess the -- since the question of vegetation is certainly one that a lot of people talk about, we struggled a lot with this because you need to be able to simulate the evolution of soils to be able to simulate the evolution of vegetation on these surfaces.

And we've only just in the last year or two broken the bank on and been able to computationally simulate the evolution of soil profiles so that the breakdown of materials so that we actually develop the soil profile.

We think we may have got a computational way to do that, the work, so that we can couple that with landform evolution. We haven't been able to relegate that at this stage, we've only just got it working. And that -- so I think we are at the stage now we can start to couple that vegetation and ecosystems model with that fairly soon.

So just to talk a -- just very, very quickly about some of the practical issues. One thing is that all the current landform evolution models in SIBERIA is, to some extent, guilty of this, as all of them, primarily that had very incomplete testing on engineered landforms, on the shapes of engineered landforms which had unnatural shapes and they have unnatural surface material gradings.

They're not easy to use. They're typically poorly documented. If somebody's doing a documentation to get their Ph.D. and then leave it. They're typically not very well integrated, whereby tools like AutoCAD or ArcGIS and that sort of thing.

Almost all of them have no capability of the sort of things you need for design. SIBERIA has the capability for putting multi-layer caps and differential erodibility, which we put in for for Ranger. And there's been little quantitative testing in the field, except for the sort of work we've done with SIBERIA in the 90's.

So there's uncertainty in the design lifetimes that comes out of these models as a result. As far as radio -- the sort of dramas we've had landform evolution models have a new repository design on the untested -- they are not standard, off-the-shelf rules that say, hey, use them.

Essentially, at Ranger, for instance, the rules say that thou shall have a repository that doesn't fail within a thousand years however you interpret that. And we struggled with that for a long time.

And the question is, how do you satisfactorily demonstrate performance in a thousand years if you only have a few decades of monitoring to go on?

So that's -- we struggled with that one as well. And can you -- one of the philosophical points is can you get a guaranteed safety along with the model or is it just that you want a guaranteed better performance?

I think we are in the position where we can guarantee a better performance, but we can't guarantee safety to a standard, because we're not sure exact performance of the model.

Essentially, the key point here is the -- the forepoint here is that we've been focusing on where do the LEMs, the landform revolution models, give different predictions to the traditional erosion models that everybody's comfortable with.

And if we can focus the monitoring on those areas where the short-term performance is different from traditional erosion models, gully development, things like that, then that gives us a bit more confidence that the landform evolution models will give different results or additional results than the normal erosion models, actually give something that actually makes sense.

Okay. So we may actually have something we can go to the regulators and say, guys, SIBERIA gives different results and the results -- we're sort of saying that's sort of the end of monitoring. And we've got a good basis of data in that regard.

Okay, so final thought, the landform evolution -- landform evolution models are emerging as design tools for repositories. We can get to about 50 years, I think, with some degree of confidence.

I'm still -- you know, we haven't done any demonstrations beyond 50 years at this point, but I'm confident that we probably will be able to if we can get our heads around how the surface evolves, so how the erodibility of the two evolves.

I've been asked to make them part of long-term performance modeling, including ecosystems, geochemistry hydrology. We'd need backup support to do that. Most of the land groups around the world are currently funded for science advances, not engineering advances.

I've probably been more successful than any of the other groups, in terms of getting money from the Australian mining community and field demonstration sites.

That's it.

>>MR. BENSON: Our next speaker is Steven Link. Steve has a Ph.D. in Botany from Arizona State University. He worked at PNNL, Pacific Northwest National Laboratory from 1985 to 1996. Actually, we worked together there for a few years and at Washington State University in 1986 to 2009. He currently works for the Confederated Tribes of the Umatilla Indian Reservation and specializes in restoration ecology.

>>MR. LINK: Thank you.

I'm going to speak about ecological processes and changes in the performance of covers. And I'm going to track the questions posed for the speakers for this conference, but I'm going to spend a fair bit of my efforts discussing the Hanford Prototype Barrier, which has been in place for a long time now.

So, initiating this discussion on types of -- some of the questions. The first main question was: For all types of covers, what are the most significant, short-term, the long-term ecological degradation processes causing increases in radon release, water percolation, erosion and bio-uptake? And from the biological point of view -- and that's really all I'm going to talk about -- are -- and these have been discussed here already. But as the root growth and intrusion, of course, are concerns.

Root intrusion can result in radon release, percolation, bio-uptake, especially if root barriers are not perfect and, no doubt, they cannot be perfect.

Preferential flow pathways form along roots and these cavities. The stem flow itself can also increase preferential flow along roots. So the type of vegetation and the amount of water which can funnel down the stem is another factor increasing the potential for preferential flow along roots.

I think that's a fairly recognized concern and risk.

Okay, and then plant composition and cover. If you have deep-rooted species, the risk of intrusion and preferential flow pathways will increase, I do believe.

Shallow-rooted species, in particular for ET cavs, if you have shallow-rooted species and they don't occupy their root zone where yearly precipitation occurs, can have the risk of drainage or potential percolation. Thus, you really have to adjust the plant community structure and maintain it to have the correct composition.

Low cover associated with fires and other factors can also increase the risk of erosion and drainage or percolation.

Now, I'm speaking in particular about arid western systems in the United States where fire is a rather significant issue. And I will talk about that specific issue with the cover discussion here shortly.

Significant cover of the annual grass is recognized as increasing fire risk in the western United States.

I've done research examining this particular topic and have found that in areas with high cheatgrass cover or a full range of cheatgrass covers -- if you have 48 % of cheatgrass cover, every time you ignite it, the entire area would burn. Large -- many hundreds of acres.

So, another factor. So, these are risks for caps and their functionality.

Animal intrusion and biointrusion in soils, again, and a well-recognized risk factor for covers, burrowing animals can compromise cap structures and increase the risk of percolation and erosion at the surface.

And it is also true that humans are animals and we will pose unpredictable risks. There's not much you can do about that.

Now, I'm going to speak about the Hanford Prototype Barrier. This is the -- my main position in barrier work here, and I've worked on this topic since 1985, initially with Glenn McGee.

This is a -- and now recently working with Kevin Leary, with the U.S. Department of Energy Hanford site, who was successful at justifying research topics on this effects of fires on this particular landfill cover and lucky enough to find funding to support it.

I've also been working with Anderson Ward, who was doing the hydrology of these systems.

So this particular cap, the Hanford Barrier, is about two-thirds of an acre on the top rectangular piece.

I revegetated this surface in 1994. And since it's a very dry, arid system, I used local species for the area.

We planted six grass species; Indian ricegrass, squirreltail, wheatgrass, Snake River wheatgrass, Sherman big blue and Sandberg's big bluegrass. And this was seeded in the fall.

The species' names have all changed and some have been combined into one species at this point. I was using native species for the area. I used what was called bluebunch wheatgrass but now it's been named to a different grass altogether. And then I grew two shrubs, big sagebrush and gray rabbitbrush, and successfully covered the surface.

Okay, that was done in -- before I get to this one. There's been some discussion on unpredictability and how to revegetate surfaces, of course. And I would like to describe a topic -- I know Jody mentioned something about subsurface soils being perhaps difficult to revegetate.

And I can say that these surface soils here were definitely subsurface soils and the revegetation was rather significant, primarily because it was fertilized and watered.

So we can make it -- or it can be made to work, of course. And when I did my particular project, it was planted in the fall of 2000 -- 1994, and the next spring -- or the next summer, I noticed that the entire surface was covered at a depth of about 3 to 4 feet, 100 % covered with a Russian thistle.

It had grown very well and very green because of the fertilizer. And this material has dried off in the fall, grew over into the adjoining tank farm, and I was yelled at quite a bit.

I can note that we did instrument this prototype cap and we have root tubes to the bottom of the cap surface. And I did note that within three years, that roots were observed to grow all the way to the bottom of the surface, about 2 meters deep.

Now, this is in 2008 this picture was taken. This is 14 years after planting and just before our fire.

The surface at this time was dominated by Artemisia Tridentata or big sagebrush. And you'll notice a lot of the shrubs, they're good at collecting tumbleweeds.

So lots of extra fuel was collected on this surface.

The surface worked very well. Absolutely no percolation in the system whatsoever, and very little, if any, erosion that's recognizable.

So vegetative cover, very high and continuous.

Some concerns is that as fuel -- what would happen if there was a fire? How severe could it be? Oh, it could be really severe, actually.

This was a very hot fire and it was burnt in September of 2008.

And this completely vaporized any biological matter on the north half of this Prototype Barrier surface.

The following winter -- this might have been January of 2009 -- I took a trip out to observe the cap surface and noted that a fair amount of erosion on the surface. If you can see, the snow is covered with silts of various amounts. So erosion has been a topic for me to consider too.

We put out erosion pins. We were concerned about this, of course, so we put erosion pins along the surface, 70 or 80 pins across the surface, before the fire. And then we measured it a year later, in 2009, after the fire.

And we did note, in the red areas, deflation or erosion of some significance. And then, to the east side of the surface, the blue colors are deposition. So there is some redistribution soils on this surface and up to 2 centimeters deep.

This is an ongoing and current research effort and I haven't read this year's erosion pins yet, but I -- it will be interesting to see how much more erosion is occurring.

Because, gravel admix is beginning to show up in some significance. The picture to the left shows an unburned surface. There was gravel admix mixed into the surface soils. And you do not note a large amount of admix gravels in the picture to the left.

Of course, after the fire, you see now the soils are much lighter. All the organics or a grand amount of organics were burned on the surface.

There has been erosion and now we can see what appears to be a significant amount of pea gravel on the surface. Whether this is sufficient to stop wind erosion further is to be determined.

So there are consequences to fire, and one is the increasing wind erosion and, no doubt, water erosion. And I'm not sure -- I did not measure that.

And also, I wanted to mention, in the picture to the right is a small sagebrush seedling arising from burned soil here. This particular species is not supposed to come back after fire in our area and it does.

Okay. As part of this effort to understand the dynamics of vegetation after fire, we conducted a seed bank study.

This was looking at seed -- soil samples before the fire and soil samples after the fire. And then these soil sample seed banks were compared with the original soil areas that had been unburned, the McGee ranch soils is what we had used, and then compared that to an area that had burned perhaps eight years ago. Just to compare it to see if the species composition from the seed bank is similar.

What we did notice at the McGee Ranch unburned area, or the natural system for these soils and the other field site, is that achnatherum hymenoides or Indian ricegrass is present at both of those locations.

It was not present on the barrier surface.

I had planted or seeded, as these did grow initially, but it did not retain, so it's not in the system.

Sagebrush occurs at all places and it occurred after fire. And, again, the general supposition is that sagebrush does not come back after fire, the seed bank is very short, very short of life, so it doesn't return. But we did find it arising from the soils on the surface after the fire and we did find it in the seed bank on soils after the fire. So we can conclude that it does retain the ability to grow after a fire.

Cheatgrass or bromus tectorum existed in all areas. And I can say that before the fire on the prototype surface, the cheatgrass particularly was in very low quantity, perhaps one % cover.

After the fires it's become more so. And in areas, like even oil burned areas, the cheatgrass is quite high.

So that's the highest risk in these surface -- at least in the Hanford site, which I would recommend, as far as plants are concerned, is shallow-rooted annual species of bromus tectorum, which are perhaps not going to extract all the water from an ET cap.

Other species that were not on the surface or were on the surface after the burn, descoranium pinada (phn) and some other grasses.

I wanted to say a couple of things about seed bank studies. They certainly are not perfect. As you collect these soil certain samples, you're sampling a large area and you're not going to see everything that could be on the larger area, again, that's a subsample of the area.

So I don't have everything that exists on the surface arising from the seed bank. That doesn't mean they're not on the surface.

Well, in total, we have eight species in the seed banks before the burn and after the burn. And this is a little bit less than in the natural area.

This is the surface of the Prototype Barrier one year after the fire. And in the distance you can see the unburned portion of the surface. This is dominated by big sagebrush and lots of tumbleweed fuel mixed in with it.

And to the left is the surface after the fire. Reasonably bare. And whatever is green there is tumbleweed or Russian thistle.

This is a just recently taken picture. This is 2010 now. And quite a number of things have returned to this surface and I'll talk about that in a second here.

You can notice in the front area a lot of brown annual grasses, this is bromus tectorum, cheatgrass, it's around the edges in some number and I see it moving into the surface.

The green matter, which is dominate on the surface to the native biennial, it's called hoary aster or machaeranthera canescens, it's a native species. It was in the seed bank, but not in any grand quantity, but it's dominate now.

Now, I want to talk about the species composition on this surface, as it's been tracked since 1995. And the relevance of this is, I guess, how many species can you have on a surface? You don't want to have a monoculture become the dominant -- you don't want to have a monoculture occur on the surface.

That is, essentially, what has occurred with sagebrush, which can cause the system so be somewhat unstable, to be determined if that's the case.

But, okay, in the year after it was revegetated, we had 24 species on the surface. I only planted nine, so most of these species came in from elsewhere. And I believe they were not in the subsoil surface, but on the surface.

I can't say that exactly, but there's a great amount of seed in the area. Seed flies in at all times and then it arrived on the system on its own.

By 1997, the system still hadn't established high cover with sagebrush and the maximum number of species it had was to, I think, 35.

Subsequent to this, the number of species on the surface has just gradually gone downhill, right through 2008. And I have to say, primarily, the primarily species on the surface is sagebrush.

The other species are scattered about, maybe not in grand number, but the total number of species here has decreased.

Then we had the fire in 2008 and in 2009, the surface opened up again. We had 26 species. And in 2010, I just finished collecting the data, we have, I think I see 34 species.

So the effect of disturbance and -- as far as number of species that can occur on the surface, is significant and this is a well-recognized process in disturbance ecology.

What is also of some interest here is that, especially after fire, the general suggestion is that systems are dominated the annuals and biennial species, as they are adapted to disturbance.

I didn't note that in particular. And, in reality, in most years, the number of perennials and annuals on the system have been rather similar. So I'm not certain that dictate about disturbances and dominance of biennials or annuals is really the case here at this site.

Okay. So, we have lots of species, highly dynamic, predicting plant succession is a tricky endeavor.

I would have to say what takes over initially is going to dominate the system for a while. And so, the primary species which are dominant here, as I had seen before -- well, before the fires, but the unburned half cover of the prototype surface covered -- sagebrush was

30 %. It dropped -- on the burned area, there's a few seedlings there and its seedlings have increased in cover so that species is regaining its position. Cheapgrass or bromus tectorum was very low cover in the sagebrush dominated areas, but its t cover has now risen to 3.6 percent. It's still not a lot, but it's definitely increasing, which is disturbing, because that particular species has a history of dominating western ecosystems.

The Snake River wheatgrass was not common in the area dominated by sagebrush, but it is becoming more prominent now.

Gray rabbitbrush has become more prominent. The hoary aster, machaeranthera canescens, has taken off and is now the dominant species on the surface. And this is annual -- it's a biennial species. It's always green through the summer, means that it is able to obtain water or do very well in dry systems.

So I'm suspecting its rooting system is near the bottom of this particular surface, but that's to be determined. Hopefully, we'll be able to do some root observations in the coming seasons.

Other species are coming into system; sweet clover, tumbleweed is still there. Right after the fire it was 19 1/2 % cover. Its cover has dropped. Now it's only 6 %. I think any risks associated with tumbleweed blowing off the system now is quite a bit smaller.

So if you can group these things into types of species, grasses, shrubs and forbs, forbs are the dominant species at the moment.

So are cryptogams, the on the surface would tend to stabilize systems. It's been documented since 1994, and they have risen to about a 28 % cover, means that they are covering a good deal of the bare surface on these plots.

After the fire, they were vaporized. The surface was clean and all I could see is a very light-colored mineral soil.

Litter, of course, was 45 percent in the unburned area and now it's dropped to about 5 %. So big changes according to fire.

An interesting consequence of this -- activity is looking at water status in the plants across the surface and this was done in September, quite the dry time of the year at this particular location.

I looked at sagebrush on the burned and unburned halves of the sur -- in the unburned half of the surface, at predawn or midday, it didn't matter.

The water potential was 74 bars. Quite dry. And the minimum I read was 87 bars, real challenging using a pressure bomb.

In the burned area, I did notice patterns. The west half of the barrier, west third of the barrier, it was slightly drier than in the middle or in the eastern part of the surface. So it could be a case that there are some patterns of water status in the system recognized by the plant water status work.

Okay. So those are some observations. And they're the Hanford prototype surface, which I preferred, and can potentially have consequences.

I can say that there's been no evidence of percolation or gross erosional patterns on the surface, so it may not mean much at all.

So, thus, just to determine how significant the consequence of the fire is, but --

Someother questions of concern here: What can be the effect of climate change? As the system gets hotter and drier, I think the risk of wind and water erosion is going to be increased because of reduced plant cover.

Increased deposition of sands could be the case. There has been evidence that sand deposition on such surfaces can increase soil-water storage.

Plant communities will change in unpredictable ways.

It could be hotter and winter. In our particular occasion, it's not going to be much wetter, but it definitely will increase the risk of -- that the soil depth design will not be adequate to store precipitation. Plants would probably take advantage of it, thought, and still take it all out, but we still do not know that.

Cooler and wetter. Soil freezing issues would increase. Still would be dry, but erosion would increase. Cooler and drier -- excuse me, erosion would probably decrease.

Cooler and drier is still going to be erosional issues and sand deposition.

Ecological changes. These are hard to predict. Invasive species I think are one of some concern. These species arrive, they all arrive over the next thousand years, no doubt, or forever. Plants are very -- the plants are very mobile on the earth's surface. So what we consider to be invasive species are unknown entities in our local area. The new ones at the Hanford site for which there's very little knowledge and very little research are kochia spocaria or it's called kochia, but it's a summer annual and it's quite an agriculture pest. Spotted knapweed, centaurea maculosa, Rush Skeletonweed, chondrilla juncea. These are deep-rooted forms of perennials and very difficult to control.

Secale cereale, or cereal rye, which has become fairly dominant at the Hanford site, even in rather dry areas. It's A much larger grass and may do better at restricting a lot of the surfaces, but that may be determined. Medusahead, taeniatherum caput-medusae, is another annual grass, like cheapgrass, that has entered the Hanford site and could become quite a serious problem.

There's a number of invasive species. There is not a lot of knowledge about them, so that's a risk.

How can degradation reprocesses be minimized? My own personal opinions are that a very thick soil cap will accommodate roots and store water and minimize plant-related issues. Keep surfaces flush with surrounding surfaces to reduce erosion risk. Extend cap dimensions beyond the waste forum to reduce, again, risk of subsurface water and roots entering the waste from the sides.

And I would have to say, continuous monitoring and adaptive vegetation management is a good idea for these surfaces.

I know there's minimal mon -- minimal maintenances at desired conditions, but I'm not certain that's attainable with new species entering the area. If they're unmaintained, the risks of failure are going to increase.

Changes associated with a good thing versus a bad thing. If you put thick gravel on a surface, it's going to increase erose -- it's going to reduce the erosion risk, but increase the percolation risk.

At that Hanford Protective Barrier we have put pea gravel on it to reduce wind erosion. It's becoming more prominent on the surface. What effect does that have on infiltration and water storage with the eventual risk of percolation has not been tested specifically.

And I guess I'm probably pretty much done. Oh, two minutes.

Okay, what can we do to improve designs and performance of covers on liners?

Root penetration through capillary breaks and compacted soil layers and clay layers can be used to define plant optimum communities for surfaces. It might go more towards grasses, which would be a fibrous root system. If they're deep enough, that might be a good strategy.

Understanding root penetration and percolation, root tubes is a good one to be concerned with.

I do believe that improved performance, we realize through continuous monitoring and adaptive management of the vegetation, burrowing animals and humans, I think we have to stay on top of this to reduce risks of reduced functionality in covers.

Thick soil covers will take care of most problems.

Thank you.

>>MR. BENSON: Okay, we have one more speaker in this session. And we're going to take a little break after that and have a panel.

Our last speaker, very glad to have Professor Kerry Rowe with us. Kerry is the vice principal for research at Queens University in Ontario and also a professor of civil environmental engineering.

Kerry's been working in waste containment systems as long as I can remember. As long as, at least from, in my career. And I think Kerry's probably done the most substantial research effort on understanding degradation of geomembranes, particularly in the context of realistic conditions within waste containment systems, so probably anybody worldwide. I think we can learn a lot about the longevity of geomembranes from their experience.

I'll turn it over to you, Kerry.

>>PROFESSOR ROWE: Well, thank you, Craig. As Craig has indicated, I'm going to be focusing on

geomembranes, with special emphasis on high-density polyethylene geomembranes used in, typically, municipal solid waste, simply because that's where most of the data is available.

Although, a lot of what I'm going to be saying is applicable to geomembranes is applicable to geomembranes and the other geosynthetics produced by from polyolefins, polypropylene and polyethylene.
I think the appropriate place to start is to remind ourselves that is geomembranes and, in particular, high-density polyethylene geomembranes have been extensively used as covers and as liners for landfills for around about 30 years.

And although I don't have time to get into details, we recently exhumed a landfill liner and cover after 25 years and it was still performing extremely well.
So geomembranes are excellent barriers to fluids, to liquids, and to most gases. We don't have time to go into today. But as Craig mentioned this morning, some gases can diffuse through geomembranes. And how they diffuse will depend on the nature of the geomembrane.

But that, of course, is provided they remain intact. And so our focus today is really going to be on minimizing holes and cracks in both the short and the long term.

Now, just to remind ourselves what's in the high-density polyethylene geomembrane, it's predominantly polyethylene resin, with about 2 to 3 % carbon black and about .2 to .5 % of additives and antioxidants. They come in a range of thicknesses, thought typically 1.5 to 2.5 millimeters thick.

We go back many years to the early use. It was truly a high-density polyethylene resin that was used. But these days, because of problems that were encountered with stress-crack resistance in those geomembranes, the resin is a medium-density polyethylene, it only gets cold high-density polyethylene because the mass of the carbon black puts it into that range.

Now, one of the key points I want to make to you in this presentation is that not all HTPE -- HDPE geomembranes are the same.

This slide summarizes some of the characteristics of six of the many geomembranes that we've tested. The ones in white were produced by Manufacturer A, the ones in yellow by Manufacturer B.

The obvious difference, of course, is thickness. And we will talk a little bit about the role of thickness, in terms of durability.

I mentioned a few moments ago that antioxidants are put in. Now, these are trade secrets to the various resin producers and so we don't know exactly what the antioxidants are typically in a given geomembrane.

We get a bit of a clue, in terms of two index tests; one is a standard oxidating induction time test or OIT test, and the other's a high pressure IT test. And where we see differences in those numbers from one product to another, it's telling us that there is something different about the antioxidant package.

The other very important characteristic is related to the resin, and that's its stress-crack resistance.

Now, what I want you to observe from this particular slide is that even a given manufacturer with a given thickness of geomembrane, produced at different times, can have substantially different antioxidant packages and stress-crack resistance, which is an indication of a somewhat different resin.

And you can see that in both cases, although in the case of the membrane 7809, you can see the antioxidant packages much more similar. And that will be the three geomembranes they compare when talking about the effect of geomembrane thickness.

So if we start looking at the short-term processes that can increase radon release and water percolation, the greatest risk, of course, is to holes being formed in the short term. The most obvious of those is during construction, but that can be minimized by good design, good quality control and quality assurance.

Then, once it's constructed, we can get holes due to activities, especially above a completed liner or cover. And that could be due to man, it could be due to animals.

And both can be minimized by good design and site use restrictions. And, as you've seen in a number of slides here covers -- a component of the barrier system is to, say, minimize intrusion by burrowing animals.

The last item I want to list is excessive differential settlement. And that is something that was briefly mentioned this morning by Mark and will be discussed tomorrow in session three, in one of the presentations. So looking at the long term, there are four different modes of degradation that are commonly discussed in the literature.

Biological degradation is the first on my list. And it's generally considered to be a nonissue. Then we have ultraviolet degradation. And this is why the carbon black is put in. Sometimes part of the additive package is there to help reduce degradation from UV.

And, of course, the best protection is to bury it. So the carbon black is not going to protect the geomembrane forever if it's left exposed, but it's there to allow you some time before you cover it, but the best solution is to cover it quickly.

Then there's extraction. And I mentioned that the antioxidants are there to protect the geomembrane. In fact, they're there to protect it from the next item on the list, which is oxidation.

And those antioxidants can migrate out of the geomembrane. They can diffuse out of the geomembrane, into the adjacent fluid. And then, lastly, is oxidation. And we're going to be focusing our attention on that.

Now, oxidative degradation is typically considered to have three phases. And I show here a diagram published more than a decade ago by Hsuan and Koerner, where it's plotting the property of interest that's retained in percent versus time.

Now, that property of interest could be the tensile strength, for example, or in the case of high-density polyethylene liners, I would submit that the property of greatest interest is its stress-crack resistance, because once that's gone and the geomembrane starts to crack, it will cease to be an effective fluid barrier.

Now, the first stage in this process is the depletion of the antioxidants. They're the geomembrane's equivalent of vitamin E for us humans. And once they're depleted there is an opportunity for the polymers to be attacked by things called free radicals, that we don't have time to get into.

But once the antioxidants are gone, we

don't immediately see a change in the properties. It takes a while before enough activity is going on to cause changes in the polymer chains that we actually measure a change in the physical property, such as tensile strength or stress-crack resistence. But once we enter stage three, then we do detect changes in those characteristics. And, typically, people define failure as the point where the property of interest has reduced to 50 % of its original value. And the service life of the geomembrane is taken as the sum of these three times. In other words, the time of initiation of the use of the geomembrane to when it's down to 50 % of its original value in some particular property of interest.

Of course, that's not failure in the real meaning of the word, because the geomembrane has still got 50 % of that capacity left at that point in time. So it's just an indicator, not the actual point where it ceases to perform its design function.

Now, when one is assessing the characteristics of how long it takes these various stages, the traditional way to do it has been to take a geomembrane and insert it in the fluid of interest.

And then, if we're dealing with antioxidant depletion, which is important, because it's the first stage in the degradation process, what we typically do is we plot the oxidative induction time at some time T, relative to the original value versus time.

And you can see shown on this plot a data points for a geomembrane in air. This is a specific geomembrane. And I have to emphasize that because geomembranes have different properties, the times taken depend on that particular geomembrane's characteristics.

So this is a geomembrane at 55 degrees in air. And you can see that the data points, which are the triangles, fit fairly well by a first order of to the K curve, which has a parameter S, which is the depletion rate.

Now, if we take exactly the same geomembrane at the same temperature and immerse it in water, we get that depletion. If we immerse it in leachate, municipal solid waste leachate, we get the curve in yellow.

Now, this particular test had been running for ten years at the time the data was collected for this particular slide, and you can see after ten years, 55 degrees C, we are still within antioxidants left when it's in air. The antioxidants were depleted after about nine years in water and after about three years in municipal solid waste leachate.

So, the key point here is that the degradation rate is going to be very much a function of the nature of the fluid that is in contact with the particular geomembrane.

So the service life of a given geomembrane is a function of the fluid it's in contact with.

Now, if we take that data that we just looked at 55 degrees, and these are the slopes of the plot, the degradation rate S -- in fact, it's actually the log of the degradation rate S, plot against one other temperature, and we do that at various temperatures, we get a straight line in this plot.

And from this what's called erroneous plot, we can then predict how long it would take for antioxidant depletion at any particular temperature of interest, and given we've done it for three different fluids here, for three different fluids of interest.

So that's what we're going to do now.
So taking that data you just looked at, we can predict the antioxidant depletion time. Remember, this is not service life, this is simply stage one of the service life.
And what you'll notice is if we predicted 35 degrees, which happens to be a very relevant temperature for municipal solid waste landfills, the depletion time in air would be 65 years, in water, 35 years, and in municipal solid waste leachate, ten years.
You can also see that temperature is rather crucial.
So, looking at the results in water, you can see that at 20 degrees the depletion would take about 95 years, at 35 degrees C, 35 years, and 50 degrees C at 15, it would take 15 years.
So now let's talk about the objective geomembrane thickness. So we're plotting here on the left axis of the log of the OIT, which is a measure of how much antioxidant is in the geomembrane at a given time T.

And in this case the geomembrane is at 70 degrees C. And we're looking at the data for a 1.5-millimeter thick geomembrane. And now for a

2-millimeter thick in the same municipal solid waste and now, 2 1/2 millimeter thick.

And you can see that as the geomembrane gets thicker, the slope of the line is less. And that means that it is going to take longer for depletion of the antioxidants.

Now, for these particular conditions, we can, if we take the data at other temperatures as well, project how long it would take to deplete antioxidants at a given temperature for the three different geomembranes. So 35 degrees C, for example, it would be 13 years for one half millimeter thick geomembrane, 17 years for 2 millimeters thick and 20 years or 2 1/2 millimeters thick.

Now, if the temperature is 20 degrees of course it's better. We're at 45, 57 and 66 years or what is the first stage in the aging process.

Now, I do mention that is the first stage.

So now let's look at the data for the three different geomembranes. Plotted, as the property retained, where the property of interest here is the stress-crack resistance and where the test is conducted at 85 degrees C.

And you can see that there was a lag time before there was any change. That lag time is the stage one and stage two. And then you can see the property of interest, in this case, the stress-crack resistance, reduced. And it reduced to 50 % of its original value in about 22 months for the 1.5-millimeter geomembrane.

It's reduced to 50 % for the 2-millimeter geomembrane after about 26 months and for the 2 1/2 after 36 months.

So you can see that for fairly similar geomembranes, thickness does make a difference. Now, this is data at 85 degrees. Why do we do tests at 85 degrees, because things happen in a time we can actually measure them. As we go to 70 degrees it takes much longer, and once you get down to 20 degrees, well, you saw how long it takes just to complete the antioxidants. That's beyond my post-retirement project.

So antioxidant depletion time, the 2-millimeter thick geomembrane was about 30 % more than that for 1 1/2, and the 2 1/2-millimeter geomembrane, about 50 % more than that for the one-and-a-half.

If we look at the full service life, based on that data I showed you, for the 2-millimeter it's about 20 % more than the 1.5, and for 2 1/2 millimeter, about 70 % more than the 1.5.

But I want to emphasize here, again, that this sort of comparison really only makes sense if the other characteristics are essentially the same, because the aging is not just dependent on thickness. That is one important factor, but it's also dependent on the antioxidant package and it's also dependent on the resin that's used.

Now, the limitation of what I've just shown you is that it's for geomembranes in a fluid, whether it's air, water or leachate.

Now, geomembranes in practice are not sitting in a fluid, they're usually part of a liner system, and often a competent liner system. So the question then arises, how realistic are those tests which are the most easy to do and, therefore, the most commonly done of what actually happens in a landfill.

So we have been doing tests for a number of years now in our geosynthetic line of longevity simulators where we can place a foundation there, a clay liner, in this case a GCL, a geomembrane, a geotextile protection layer. And then we can have a drainage layer, which could have water. In our case, municipal solid waste type leachate passing through it. And also, we can examine the effect of pressure. We can also heat these to any particular temperature of interest to us.

And we've looked at the range from 22 degrees to through to 85 degrees Celsius. And that shows you a photograph of these simulators, most of them there in action.

So what I want to do is now compare results for the same geomembranes immersed in leachate versus with leachate flowing above it, but within a simulated liner system.

And, again, because we're focusing right now on antioxidant depletion, which is stage one, we're plotting the log of the OIT, which is a measure of how much antioxidant is left, versus time.

And we've got data here at a number of different temperatures. At 26 degrees you can see things happen very slowly. 55, much more rapid. 70 and 85. And you can see, again, the very dominant role the temperature plays.

Now, if we do the same thing but in our landfill simulators, you can see the same type of behavior, but the slopes and the curves are quite different.

The focus on that -- let's look at the data just at 85 degrees. And if we overlay them, you can now see the substantial difference in the depletion of antioxidants in -- leachate-immersed versus in a composite liner simulation.

To show you what that means, just in terms of the first component of the depletion time, we're plotting here the calculated antioxidant depletion time versus the temperature for the leachate-immersed in blue and the composite liner in yellow. And you can see a very substantial difference.

In the table here, the results are summarized at three different temperatures. So, at 20 degrees we've got 135 years versus 35. At 35 degrees, 40 versus 10. And at 50, 10 versus 4.

Even in the simulated liner, you can see that this is not a big number. Remembering, though, it is just stage one.

Now, on this slide I want to compare results we got for two different geomembranes during this same type of comparison.

And what I want to draw your attention to is that both of these geomembranes have the same standard OIT of 135 minutes, but very different HPOIT. One was 660 minutes and one was 240.

And one might, at first glance, look at that and say, well, 660 has got to be a lot better than 240, that must be the one to go for.

Well, that's not necessarily the case.

If we compare the results here at 35 degrees, you can see when immersed in leachate, geomembrane 2 and 7, the spread is 10 to 15 years. And in our composite liner, both are about 40 years.

At 20 degrees C we're looking at a 35 to 45-year range and at, for the composite liner, 135 to 130. No practical difference, really, given the variables in the calculation.

So, again, what I want to emphasize is the properties of geomembranes are not necessarily the same, but also, these index measures don't really tell us what we truly need to know about the antioxidant packages that are in our geomembranes. And perhaps we're not asking for enough.

Now let's go to the full three stages. And you can see here that we're plotting the percent of a property retained. In this case, for leachate immersion, and we're looking at tensile strength at break.

And you can see that the antioxidant depletion time was less than 12 months at this particular case. The induction time was only a few months. And, in this case, the time to 50 percent of the original value was about five and a half years.

This is why we need to perform these tests at elevated temperature and leave them at elevated temperatures for a long period.

At 70 degrees, I still have not reached the point of normally defined failure after about 12 years of testing.

We have enough data to project the slope of this line, but you can see that fitting a line through limited data leads to some variability.

Now, based on the data we have, we can make estimates of service lives of geomembranes, and these are estimates that are made at two different points in time from exactly the same data set, except more data.

So at 35 degrees -- in 2005 I made predictions on data I had in 2004 of 130 to 190 years. And that range really represents the possible range of interpretation based on the data available at that time.

Based on data in 2009, that's changed to 240 to 370.

So the point I'm making here is we're being very conservative in our interpretations. And as time goes on, we are getting probably much better, but still we don't have enough data to give totally reliable numbers. But, the good news is, these are fairly large numbers.

At 20 degrees, the numbers are even bigger, over a thousand years, which is getting to be quite positive. And also remember, these are immersion tests. We haven't been running the simulator tests for more than a decade, which is needed to be able to get these three-stage projections.

The last thing I would like to talk about, issues that are specific to low-level radioactive waste if you in fact have any significant radiation coming from that waste.

And the first point I want to make is that whereas everything I've done up to this point in time has been based on our work, this part of the talk is based on what I found in the literature.

And going through that, I would say there is a paucity of really relevant data relating to the effect of low-level radioactive waste on the service life of geomembranes.

The literature indicates that HDP degradation by high-energy irradiation can be similar to that due to UV radiation and that the mechanical properties change due to irradiation degradation by chain scission.

That's similar to what we've been talking about. But, at a total dose, in the range shown there.

The impact of irradiation is determined primarily by the total absorbed dose and the presence and absence of oxygen. The impact of irradiation on polymers and on HDPE in particular is determined primarily by the total absorbed dose and the presence and absence of oxygen. And at high absorbed doses, polyethylene becomes very hard and brittle and, hence, subject to failure.

Some research is being done on the ultimate strength half dose, which is a measure of what dose is required to reduce the property of interest to half its original value, in a vacuum.

But, of course, we're not dealing in a vacuum. And, with air, which has got oxygen available, irradiation can be expected to provide the activation energy for oxidation of the geomembrane to occur.

So, the service life of the geomembrane could be reduced by any significant heat generation. Whether it's from within the waste itself, or it could be, if it's not buried deep enough from the grass fires you heard about in the last presentation.

From high pH leachates -- so if you're stabilizing the waste in some way, that increases the pH, that can affect it. And, of course, irradiation from the waste itself.

And I would certainly express the view that more work is required to establish the effect of these types of waste on stress-crack resistence and, hence, the service life.

Now, there are various mitigation measures that are being proposed. I'm quoting here some from Knox report in 2005.

And the first of these three are in fact ones that would be equally appropriate for geomembranes in really any application, certainly the landfill application.

The last is low radiation dose right by shielding to reduce the total dose absorbed by the HDPE over whatever period of interest.

So, to conclude then, not all HDPE geomembranes are the same and, hence, they're going to have different service lives. And the ones I've given here are for the particular geomembranes that I tested.

The service life of geomembranes is very sensitive to the nature of the leachate. And, other things being equal, the thicker the geomembrane, the longer the service life.

Antioxidant depletion is three to five times faster for geomembranes immersed in leachate than any composite liners. So the projections we make, like somebody gave a short while ago, are quite conservative compared to the buried situation.

Based on the immersion test that we've been running for well over a decade now, it appears that the service life of a geomembrane in municipal solid waste leachate would be likely a thousand years or more if the temperature is below 20 degrees C, but, only a few decades if that temperature stayed at 60 degrees C.

And lastly, more work needs to be done on the effect of low-level radiation on the service life of geomembranes.

Now, reported quite a lot of work done at Queens there, and I would like to acknowledge my collaborators, particularly Richard Brachman at Queens and Grace Hsuan from Drexel, and the army of students through several generations of graduate students who required to keep tests going for one to two decades.

And, of course, those who've had the patience to be with us and fund our work for the period of time that it's been funded. So, thank you.

Okay, we are doing the take a ten-minute break, so that will bring us back at 4:30 and then we'll begin our panel session.

If the panelists would come back a few minutes early and come up to the front table to kind of get things ready for the panel session.

Okay, thank you.

>>MR. BENSON: So we'll get started. Thank your. Just a couple of new faces on the panel.

Let's see. Bill Albright all the way on the end there. Bill got mentioned a number of times today. Bill is a research hydrogeologist at Desert Research Institute in Reno. DRI is part of the University of Nevada system.

And Bill's been involved in vadose zone hydrology and containment systems probably for 20 years, 25 years. Bill?

>>MR. ALBRIGHT: (Low audio.)

>>MR. BENSON: Well, he's one of the folks that hasn't been introduced today. And then, we moved three more people over. Kevin Leary.

Kevin is with the Department of Energy in Hanford. Kevin is kind of managing a lot of the cover programs at the Hanford site. He's a certified professional soil scientist for Oregon State. He got his MS in hydrogeology and hydrology from the University of Nevada, Reno, and the same place that Bill is from as well.

Kevin has got extensive experience in this area as well, been working in containment systems in the remediation industry with the DOE complex for about 30 years.

And so we are very glad to have these two folks with us as well.

What we have is six different questions for this session.

The way that we had structured this particular session was to have these five kinds of overarching talks in the beginning to kind of set a background for the panel discussion, and then to go into these six questions to get the panel's response to them.

So what I would like to do is we'll just begin with the first question. And I'm going to throw it out there. And what I would like is we have some -- the people who were not speaking, so that it will be Bill and Bob and Mark and Kevin.

It's interesting, all you guys are right on the end. That wasn't by design, but depends how you define the good seats. So we would like to give you the opportunity to speak first, and then if the others have some things you would like to add to it as well.

Does that sound good, Jody?

All right. So our first question is: For all types of covers, what are the most significant short-term and long-term alteration processes -- notice that I changed that a little bit -- causing increases in radon release, water percolation, erosion and bio-uptake?

So we're going to start at the end there with our new participants.

>>MR. BENSON: (Low audio.)

>>MR. NICHOLSON: We're on go-to meeting and we have folks on line, so it's important to speak into the microphone.

>>MR. ALBRIGHT: That sounds good. Thanks, Tom.

It's always challenging for me to talk after Craig and Jody because we've done so much work together, and -- based on what I'm going to say tomorrow.

But one of the things that we noticed in the ACAP program, we had the unique opportunity to go out and decommission the sites, which is -- hardly anyone gets to do an autopsy on your research project. And we started -- we were looking for the development of soil structure, because we thought we saw an indication of that in our performance monitoring.

But the soil geomorphologist that we worked with said no, soil structure doesn't happen in two years, in six months, in four years.

But when we went out and traced the covers with a backhoe, we discovered development soil -- significant soil structure in an extremely short period of time.

In fact, we know at one site it happened about six months after we built the site and that's -- was not known to happen.

And I think what was a very significant finding on our part.

>>MR. LEARY: Well, I cheated a little bit; during the break I kind of jotted down some notes on some of these questions. So bear with me, I'll kind of give you eye contact and try to read some of the notes. But, I guess, the first thing is the ultimate goal we're trying to accomplish here is risk reduction. And I think if you take that into consideration, I think a lot of the stuff kind of falls out.

In my opinion, working in barriers like 30 years, is subsidence I think probably is one of the biggest issues.

And I think one of the things we need to develop -- and I met with that challenge right now in a couple of landfills I'm trying to close in Hanford -- is good geophysical tools, enhanced geophysical tools for locating areas of potential subsidence.

And I think there's a lot of room for

improvement in that. And I think the other thing that I know Craig has been really harping on today is understanding the national system.

I think both present and future impacts to the covers. For example, for future predictions, use like a probability systems model like GoldSim. As you pointed out, Bill, soil pedogenesis certainly is a big factor. And as I was talking to Craig during one of the breaks, soil pedogenesis really increases as you increase your climate, as far as water.

In real arid climates, one of the things I did in my career is map soils for two years and mostly worked in the order of ritasols and very little soil development.

And as you get into wetter climates, you get more and more soil pedogenesis. And I think, you know, as -- from a landfill perspective, the more precipitation you get, I think the more you're going to have to worry about soil pedogenesis.

Lateral flow of moisture, I think in arid areas we kind of blow that off. But I think, from a long-term perspective, when you're talking about thousands of years, I think we really need to look at that transport of water along soil contrasting textural barrier -- layers, because if you think about it, when you disrupt the natural soil environment and you dig this hole in the ground, you're kind of creating a hydraulic sink.

And so if you really -- you know, over 5, 10, 20, 30 years, you may not see a lot of moisture but if you're looking at containing a system for thousands of years, I think you really need to evaluate, you know, is it significant and what kind of changes you can make in the design system of the landfill.

Some of the other things are biointrusion, climate change. Steve talked about plant community change. And again, another thing is develop realistic standardized future intruder scenarios.

I've worked with other sites and I think intruder analysis is kind of all over the map. And I think people really need to come up with a standardized approach to that.

Also, develop standardized placards and look at the psychology of long-term placards and warning people into intruding into waste. And start with the end in mind.

The other thing is establish detailed institutional controls.

I know from the stakeholder perspective, that's probably been -- one of our biggest challenges at Hanford is there's a lot of mistrust of us to be around, you know, a long time from now, to really inst -- to keep these ICs, you know, going, because our government has been around less than 300 years and we're telling, you know, some of our stakeholders, hey, we're going to keep intruders out for 500 or 1,000 years.

So I think, you know, there's been talk about bonds. I'm not sure that's not a bad idea, maybe look at the tribes for passing down: Knowledge. There's been a lot of discussion about that.

Just one other note is on Steve Link and one of your comments about old root channels. I kind of agree with you, but one of the things I've observed in the field when I mount soils is a lot of old root channels will actually form decay in place, will actually form organic matter in place and will actually, you know, hold water. So, in some places that may not be an issue.

Okay, that's it.

>>MR. NICHOLSON: Bob?

>>MR. PHANEUF: I agree with a lot of what Kevin has just said.

I think from our perspective, a lot of our experience with cover systems has been with the solid waste landfills and how we see the sediment happening there. And with that, how that disrupts the effectiveness of the impermeability of a clay barrier and such.

I think, you know, ways of getting around that are looking at composite covers. And from a lessons learned perspective, how they might be better if you're trying to minimize infiltration from, you know, say the northeast or more humid area, where composite covers are good.

The other aspects of this, too, with looking -- and maybe looking forward with respect to radon release, the new generations of geomembranes that might be coming out online, the EVOH geomembrane, which is a co-extruded polymer. Of course, we don't know the

longevity of these materials yet. But, on the other hand, they are much more impervious to radon and they show a lot of promise with helping us out with -- maybe from even naturally occurring radon for subslab construction, but also with indoor air quality issues with corrective action sites and so forth.
So as we go forward, we should be looking and encouraging industry to develop these new materials that might address some of the shortcomings of what we've seen in some of this.

Of course, the others that are out there, erosion is always there. Again, solid waste landfills, some caps and covers in the northeast, you've got conditions, conditions and other things. Our landforms aren't typically flat, but we will see a lot of those landfills tend to be more noticeable mounds and slopes. So the geotechnical aspects, the veneer stability of those facilities for the long term is an issue on some of them.
Not sure if, you know, we get into some of these mixed waste, Texas, and that -- the new facility approach there, that they're approaching there, again, if these

things tend to be large landforms and take more waste, then the cover systems and veneer stability systems have to be looked at from a geotechnical aspects.

>>SPEAKER: I guess the answer to part of this has to go "it depends." And, you know, it depends on the waste forms you have, the regulations you're under and other issues.

But, from our perspective, I think like he was talking about earlier, if you have substantial differential subsidence, I would think that is more catastrophic than most any other failure mechanism.
A lot of the other things are things that -- I think one of the things that we need to be doing is looking at -- for the systems that we have, for where we're at, for the type of waste forms that we're using, what are potential degradation mechanisms?
And then you need to be going through those for your facilities and going "Which one are the most significant ones? Which ones are the ones I can design out of the system? Which are the ones I have to consider in my performance assessment, because I can't design it out of the system, because I know that it's going to happen?"
In our case in Erie, I probably -- the two I would say most important to us are subsidence, and then our pine tree succession

over time, where we have roots down to 12 feet or more. Those two are probably the two biggest degradation mechanisms that we would have there. Now, some of our other sites have no subsidence, potentially. Other folks are going to have different priorities on what are the primary degradation mechanisms. And we need -- we can't do a one-shoe-fits-all on that. We have to look at our systems in a whole.

>>SPEAKER: Good point, site specific. Other members of the panel want to comment on question one? Jody? Just grab a microphone. It's called free flowing.

>>MR. WAUGH: Just briefly a little bit of follow-up on some of the discussions we had on ecological changes.

Earlier we were talking primarily about temporal changes, succession from one plant community to another and the uncertainty of that. Steve mentioned other alien plants coming in, invasive species coming in, and that we don't have any idea what they might be in the future, and the uncertainty of trying to predict that. But we also see some uncertainty in the spacial patterns that develop over these large acreages. But I'm mainly talking about water-balance covers, where the cover relies on the vegetation to remove moisture. Very subtle changes in soil properties and in aspect, and one layer might have been a little more compacted than another to begin with, or the seed bank might have been a little bit different to begin with than the other.

And you start to see a kind of a patchwork that might form. And an example, I'll go back to the Monticello site, where initially we saw some perennial grasses coming in and sagebrush, and this is good because our data says they're going to pump a lot of water.

Then there are these patches out there of this cheapgrass that Steve was talking about earlier, this annual that's shallow-rooted with a short growing seed, it doesn't pump much water.

Why are these patches forming? And so what's the uncertainty associated with how these form and may change over time. So is spatial patterns are important too.

We make this assumption that everything is uniform, you know, over the whole site, and that's -- as far as the ecosystem dynamics, that's just not the case.

>>SPEAKER: I guess I'd agree with that. From my perspective, I guess the biggest single challenge is the fact that when we construct these facilities, that the surface property and properties of them are very different from what is natural or would naturally be on a landform if that were in equilibrium, what would be the erosion properties, hydrology properties, the vegetation properties.

And as a result, the properties actually evolve very rapidly, exponentially, at least at the initial stages of it. And so you end up having rapid changes in vegetation, rapid changes in the soil, rapid changes in the hydrology and erosion. And the question is: How can you actually figure out what you're going to see in 100, 200 years from now, or maybe 10 or 20 or 30 years of monitoring and be able to say something about the issues of patchiness of vegetation. For instance, is one area that we have a lot of interest in in natural environments, absolutely natural evolution of arid zone vegetations.

It may come about as a result of the natural way that vegetation likes to maintain its water supply.

So it's -- but we can only monitor for a few years, but we then have to predict out. And how do we guarantee what we're going to see when we predict the outcome 200 years from now?

>>SPEAKER: If I can just pick up on two of the points made a little earlier. In terms of the long term, it seems to me that one of the biggest challenges keeping people off the site, as you mentioned. Even looking at sites today, I've got working one site that's got very heavily contaminated with arsonic.

All sorts of signs around telling it, but people's perception of risk is very different when it's something they might want to use recreationally or for some other purpose, than what it is when they're worried about being in their backyard.

At this particular site, there's all sorts of signs around. There's fences. People just pull them out of the way, go in, have picnics with their kids, building sand castles with contaminated soil, dirt bike tracks.

And that's today when they can see it

there. What's it going to be like when it's covered up and it looks really nice?

I think that's really a major challenge in terms of the long-term protection of these facilities, no matter what sort of cover you actually put on top of it.

The other point I would pick up on is Bob's about new materials. And I think there are some excellent new materials and the EDO actually talked about we've done a lot of work on that in terms of diffusion, it's an excellent material.

But the big question with all of those new materials is how do you get enough long-term data to be confident to use them when you're dealing with lives of -- or contaminating lifespans of hundreds, in some cases thousands of years?

And that means we need to be not just getting the research on how well they perform as a diffusion barrier, but also, at the same time, get the work going on what's their long-term performance going to be.

Because, otherwise, we got this great material you would like to use, but we don't know how long it's going to last.

>>MR. LINK: I'd like to add two points on one of the vegetation issues. And to reiterate, it's very difficult to predict the species composition of an area, temporally and spatially. So there -- unless you want to get into predictive models looking at plant succession, we may simply come to the conclusion that continuous monitoring and vegetation management might not be a bad idea.

And that would resolve a number of our long-term issues.

That's a funding and policy issue.

>>MR. BENSON: Anybody from the audience want to ask one (low audio) which is no longer up here.

(Low audio.)

I know a top secret password to get in.

But let's -- we could --

>>SPEAKER: (Low audio)

>>MR. BENSON: So for others who want to -- is there a mobile mic?

Could we take that back and just introduce who you are and ask and add your remarks.

>>MR. TAUXE: John Tauxe with Neptune and

Company. And to remind folks, the first question is about, you know, what are the most significant degradation processes going on.

And there -- it's one thing to look in the real world and another thing to look in modeling space.

And I sort of live in modeling space, and the way I would approach that is to -- as you will see in my talk that I'm doing tomorrow afternoon, is to include as many processes as you can imagine will be there influencing the site.

And then if you run your model in a probabilistic way, you should be able to do a sensitivity analysis at the back end and determine for a given model at a given site what -- which of those processes are the most significant in degrading the cap or, ultimately, in producing risk from whatever is in the site, which is the real goal.

And it may be that the cap isn't even important. That's always a possibility.

>>SPEAKER: (Low audio.)

>>MR. WRIGHT: Hi, Toby Wright with Wright Engineering.

I guess one of the principles that I learned back in grad school was the energy of a system. And 10 CFR 40 Appendix A talks about primary subsurface burial to minimize the energies into a system for erosion protection and for waste isolation.

It seems to me that we can talk about the legacy sites, the sites that are there today that we have to wrestle with which aren't going away, but there's a component for future design that I think we should focus on.

And I think industry, as well as the regulatory community, needs to look at a stronger emphasis, perhaps, on decreasing the potential energies that those waste isolation systems are subject to.

>>PROFESSOR WILLGOOSE: I guess you need to think separately about, for instance, old mine sites as opposed -- you know, and tailings to low-level repositories. Low-level repositories, you can bury, potentially. But with mine sites, because -- unless you're actually removing a lot of the mineral and the rock, almost invariably, you will have more rock than you can put back into the hole in the first place.

It expands by about 30 percent, say. Almost always end up with more material than you can fit back in the holes and you've got some sort of above-ground structure.

Now, what you'd like to do is have the stuff that's above ground be the least toxic or the least impact on the environment.

But if you're pulling up stuff that's high something like that, it may not be possible because of the mine planning or that sort of thing, to actually have that stuff be in the lower ground.

So, in a lot of cases you're stuck with having stuff that you prefer to be underground, above ground, and there's not much you can do about it.

>>MR. NICHOLSON: Is there anybody on the phone that wanted to -- let me see if there's any phone questions and then we'll get yours, Kent.

Okay, we'll take one more on this topic and then go on to question three.

>>MR. BOSTICK: I have a comment on subsidence. My name is a Kent Bostick, I work for Pro2Serve. And I -- subsidence was brought up as a

major issues, especially for areas where they were putting -- disposal areas where they are putting waste into boxes and the void spaces in the boxes and how they collapse.

And, for example, I think that we've had some success on Oak Ridge Reservation of the EMWF by putting fill and cementitious materials into these boxes to prevent them from subsiding.

And that's one of the requirements of the waste exceptions criteria is they can't even get to the landfill and get it accepted unless it meets that criteria.

So, you know, then when they have all the waste stacked, they can place the cover. And so I think that that resolves some of the issues with that subsidence, for at least waste areas.

For UMTRA covers, of course, that's a pretty big problem and for title two sites, getting all the water out so that you can have a stabilized cover.

And we're looking into that at the Moab project right now, how to got the water out of the pile. And we are moving it to, of course, a disposal cell, so it will be dry by the time we finally place the cover there. So it's not such an -- it's not such an issue on UMTRA piles.

>>SPEAKER: So some engineering means to manage differential settlement issues?

>>MR. BOSTICK: Yeah.

>>SPEAKER: Idaho uses grouting in boxes and other structures as well and I think Hanford does, too, I think. Is that true, Kevin? Grouting in boxes and some structures --

>>MR. LEARY: Yes, we do. Yes, we do, especially --

>>SPEAKER: I made a comment earlier in the day that wasn't recorded because I didn't have a microphone, and I was asked to make it again. And that was that, for example, we shouldn't disclude the importance of the low conductivity properties of the tailings.

You know, there's a lost of emphasis on covers, but, for example, you know, everybody's worried about pedogenesis and the cover, well, there

is no pedogenesis in tailings, because it goes through a ball mill and the thing's ground and any soil structure is completely obliterated.
And the way tailings are laid down, there's a hydraulic and that prevents water from actually moving out of the tailings. And so the tailing are really the second line offense.

So even though you see all this business about, you know, well, the covers are increasing in saturated conductivity, that water still has to make it through the tailings.
And from field studies so far, it doesn't move through the tailings at any appreciable rate. And a lot of -- especially in engineered tailings piles, where we have taken the tailings and relocated it, it's been dry during the latter part of the UMTRA project. There's almost no seepage at all.
So I would like everybody to put all this cover talk into that context and remember that there aren't any performance standards really for the cover, that the standards only have to be met in groundwater so that you're allowed dispersion by groundwater underflow

underneath the cell and all the geochemistry that's beneath the cell that can attenuate those contaminants.

So just because the cover is changing a little bit, doesn't mean that the UMTRA performance cell isn't working as originally planned.

Thank you.

>>MR. BENSON: And I think that's one of the points that we tried to make this afternoon as well, is that there's a system. It's not one element of the system, it's the whole system that we really need to consider. And in a performance assessment, that's going to be part of it. And understanding how elements of that system function go into that performance assessment as well.

But any particular element doesn't necessarily mean the system itself is failing or not meeting its form performance objective. I guess that's just a slightly different way of putting that.

Okay. So what I would like to do is move on to point three.

I think we covered two as well, but we really haven't talked about perhaps some of these longer term changes

with climate.
How our perceptive might change if we have significant changes in climate over the next 100 or a thousand years.

Anybody on our panel want to remark on that?

>>MR. LEARY: I'll go ahead and jump on it. I think -- again, it depends. I think kit accelerate some processes and slow other processes down.
I think you need to understand your entire system before you really try to predict the future.
I think that's one thing that -- we're getting there, but I think we need to do a better job, and that is understanding the system.
For example, as I mentioned earlier, as you get increased moisture, you're going to get more rapid changes in soil pedogenesis, which could, you know -- will affect your performance one way or another.
You'll have changes in your plant community, as Steve pointed out.
I think you'll have increases in your microbial population, which will affect how the whole system

works.

You'll have increases in soil organic matter because you'll probably have a denser plants community if you have more rainfall. If you have more rainfall, you'll have decreases in your soil pH, which will affect your system.

So I think there's a whole bunch of factors that you need to take into consideration when you're looking at chronological and ecological changes and how they affect the degradation process.

>>SPEAKER: Anybody else want to remark? I'd just like to go back to question two on liner systems and their function. And I hate to do this to you, but there's an important --

>>SPEAKER: Give me the (inaudible.)

>>SPEAKER: And it is the function of the system. Kent brought it up, the system working together, but the fact that -- from monitoring our systems, where we're really anal in New York state about monitoring that performance, looking at the -- when you say the degradation of the liner system, one of the things that causes more of that influx of fluid

is the instance of the drainage blanket and building up heads on top of that liner system.

The low drainage blankets that we put on top of these, whether it's on cover systems or on a liner system, make a big difference on how well that membrane is going to work as a barrier.

Ecologically, looking at the changes, climate, ecological changes in your state. In New York state we have upstate New York and we have New York City and Long Island. Upstate New York we can get away with using the cool season grasses and so forth in our shallow cover system designs, veneer covers, have drainage systems on slopes. The root systems for these cool season grasses only go down 6 inches or so.

Here we're hearing about the warm season sort of growth and vegetation that we have deeper root penetration. These are really aggressive root systems, but those are systems that we have on Long Island, perhaps in New York City that might get specified or you may see these other warm season grasses overtaking them.

These sytems have aggressive root systems seek out that

drainage layer, clog it then, all of a sudden, that drainage was there to promote geotechnical stability of the veneer. All of a sudden it's gone and we have geotechnical problems associated with that.
But, other than that, what Kevin said was good.

>>SPEAKER: I would want to add one thing about root activity. I know there's lots of correlation between roots growing where water is. And that's generally accepted practice or understanding of how roots behave. But I would like to suggest that roots can also do another thing, is grow where there is absolutely no water, for apparently no reason, but they do have their own reason, we don't know what it is.
I think it's looking for minerals, but I've noted shrub roots well below yearly wetting front in Hanford soils, about 9 feet, and precipitation was not even close to that.
So roots are in many places and not always looking for water.

>>MR. BENSON: Any other comments on climate change? Anybody in the audience or on the phone?

>>MR. NEWMAN: (Low audio.)

>>MR. BENSON: Let's get you a microphone. I apologize for that. We got folks on the line and they can't hear you unless you're on the mike.

>>MR. NEWMAN: Mike Newman with Neutron Energy. And my question, Dr. Willgoose, was about the climatic regime and specifically the rainfall amounts that were involved with the slides that you showed of the failures on the covers from various mine sites. What sort of precipitation was involved with those events, over what kinds of periods of time? If you have that information.

>>PROFESSOR WILLGOOSE: For the simulations what we actually used is the weather reports and the Monte-Carlo weather generator, too.
That's normally what we do. The particular ones we did there, which we did back in '92, we had 20 years of rainfall record there and we just ran that 20 years 50 times for a thousand years.

That was, essentially -- we were just struggling just to get everything else going without actually landing on top of that weather simulator.
But we actually have just recently been doing some work

looking at extreme events. The particular site of Ranger had a tropical cyclone, a hurricane, come out almost straight out of the site about three years ago and flattened pretty much everything in every direction.

But when you run the extreme event, even though it was a very, very extreme event, you know, something like a one in 100 or 150 year event.

When you compared that with a cumulative impact of just average events year after year after year, it was just like a little pimple on the landscape. It really is driven by the average impact of the -- extreme events typically are not that important, even though they look important at the time.

The issue with climate change, I guess, is the same issues that we have with all hydrology, is that at the current time, out of the climate change predictions from JCM and that sort of thing, we can't get sufficient information on extreme patents of rainfall to accurately estimate what the impact on changes in the rainfall models will be, in terms of changes in the runoff.

That's a problem that everybody in the hydrology community worldwide has, it's not just limited to this application.

>>MR. BENSON: Anybody else want to add to that question or should we move on to the next page? All right. We'll move to the next page.

So many of these are related as I read them. We've answered some of the questions already, but I think there's probably some specifics to question four about -- that we haven't addressed.
How can degradation processes be minimized and radon release percolation, erosion and bio uptake be reduced for various ecologies and climates? What type of, perhaps, strategies might we take to minimize or reduce these impacts.

Want to start in the panel? Bob?

>>MR. PHANEUF: (Low audio) Sorry about jumping for that.
In this question you mention quality assurance, quality control. I'll mention something I mentioned before, which was construction quality assurance.
There is a distinction and quality construction and

performance of these systems right from the get-go. So 97 % of what we've learned with doing liner integrity surveys on landfill liner systems and constructing them, 97 % of all defects happen during construction and exist in that system right from the get-go.

So, again, we can prescribed all the types of liner systems and double liner systems in that, but I think really we've got to come to grips with using the best available technologies and evaluating these systems as we build them.

And one of them is electrical resistivity testing, which is relatively economical to do. It can be done on a cap, it can be done on liner systems, and it happens after the gorilla activity of placing a drainage blanket on top of these -- and these membranes, we characterize them as being pretty tough, but it's heavy equipment and in placement, they're quite frail.

So with respect to that, that technology evolved -- has evolved, it's got ASTM standards. It's becoming more recognized. We're going to be putting it into our regulations, not only to do just do the upper liner system, but also the lower liner.

We're getting a lot of kickback on that from the regulating community, saying that you're going to disrupt the construction process, you're slowing me down by doing this.

But, that's that lower liner system, the concerns that we have for longevity of this. And it's that double liner system technology that we can maybe (inaudible) off longer liner performance with these systems, with that lower liner system, and protect it and so forth.

So I think using the -- looking at design by function, what you expect to see and so forth, but also don't forget construction quality here.

The other aspect on this topics, we're making our jobs harder as regulators. We're adding to the potential fodder that, you know, if people -- or folks from Ihatelandfills.com get their say, we're going to have to be addressing all these things.

But I want to, you know, for the record, also say that with monitoring over 30 double-lined landfills with groundwater monitoring around it and core pressure release systems which is a large lysimeter, so-to-speak, large portions, 70 % of those landfills being picked up and monitored for quality issues, we have not found in 22 years of monitoring, now over two decades with monitoring that, that these systems are working.

And that does require proactive maintenance of the drainage systems and so forth but, nevertheless, they are working.

And I wanted to get that said.

>>MR. BENSON: Good point. Others?

>>SPEAKER: I guess one thing with this, I'd go with what John Tauxe also said is prioritization of what are the primary degradation mechanisms that have any, you know, meaning to you before you start trying to minimize.

If it doesn't matter to your, then you don't do it.

I guess the other thing is, and a lot of stuff that we've been talking about, is trying to get the systems in, as well as we can, in equilibrium with nature, if possible.

Okay. And a lot of times, for covers, a lot of times what minimizes the natural variability is depth of the materials that you're concerned with.

>>SPEAKER: Bury them deeper?

>>SPEAKER: Bury them deeper, yes.

>>SPEAKER: Of course, that depends on the depth of your groundwater, too.

>>MR. LEARY: I think, you know, a couple of good points. I think, first, you need to understand the system and then design accordingly. I think those are just real key points.

You really need to understand the system you're working in, which includes your waste form, your physical environment, and then make your design accordingly.

I think we might consider possibly developing a standardized performance standards for caps or liners for specific areas.

And result scenarios for calculating -- burying design parameters, such as burial thickness, gravel admix, riprap, biointrusion layers, soil texture compaction, et cetera.

I know right now I'm working on closing out a landfill. And, for example, we're struggling with calculating barrier thickness because a lot of people -- well, have you thought this scenario? Have you thought about that scenario?

We reviewed some of the material you've handed out in some of your classes. And we're still struggling.

And I think one of the keys -- and it was someone -- somebody brought it up earlier, is really looking at when your peak dose concentration occurs, and I think at that time, using maybe modeling, you need to predict the likelihood of some of the climatic conditions that may enhance the recharge to accelerate the concentration, you know, maybe accelerate the peak concentration in your system?

I agree with what you've said, Mark, and maybe establish rigid ASTM standards for barrier QA/QC. I agree, I've heard up to 90 % of the failures are during construction and maybe consider putting together some real stringent ASTM QA/QC processes.

I think the other thing is understanding your microbial processes. I think people kind of undersell that.

For example, a project I worked down at a Nevada test site was a -- they've actually, by the way, predicted, in some of their own landfills, up to 40 feet of subsidence in some of their landfills, because they did not have very stringent waste acceptance criteria at NTS back in the 60's, so we're talking 40 feet, which is pretty substantial. So I actually came up with the idea and got funded to UNLV professor to isolate various microbes to accelerate the container degradation process, kind of opposite of what most people want.

Because at the NTS, steppe to groundwater in two of their disposal areas are 900 feet -- one's 900 feet and the other one is 1500 feet to groundwater.

So we would like those containers to fail during, you know, our disposal or institutional control process so then we can, you know, affix the barrier accordingly. I think some of the other things you need to do is have redundant monitoring systems and implement that into the barrier design to allow for long-term monitoring.

I know we've heard a lot of discussion about failure of monitoring. And if we're going to expect these to perform for 500 or a thousand years, we need to build that in the design; how are we going to monitor the success or failure of those systems. And I think that's really an important thing.

The other thing, too, is I think you need to take each system as an individual area. For example, some areas can be erosional, some areas can be depositional. I know Dr. Dave Schaffer (phn) at DRI has done some work at Nevada test site, where he's found it's actually a depositional environment.

So, I think it depends -- when you make a statement that, you know, all barriers are going to erode, I think it depends on your current and predicted environment.

>>MR. WAUGH: Here is a question for my neighbor here.

I think it's related to this session four -- I mean, number four and number six, perhaps. But, Garry, you were showing probability of gullies forming over a landscaping over a disposal cell.

Have you looked at using those probabilities to actually design in a gully system from the onset so that you can place those gullies and have them armored as part of the design?

>>PROFESSOR WILLGOOSE: Subsequent projects to this involved the mining company actually providing us with a number of designs, some of which already had a drainage network on them. And, in fact, having that drainage on them localized the probabilities of failure to the areas so they become more predictable.
So there are things you can do to the design of the landform that actually mean that your risk failure is not spread right across the landform, but is more localized. You can never completely make it predictable, but you can certainly localize that.

And, in fact, much of what we've done in terms of design strategies with the mining companies has been specifically to try to localize the problems to the areas where they can cope with them. And so, in some sense, I was thinking when you're talking about the settlement issue, of course, you -- question four is sort of do you actually want to always reduce your degradation process? Because there may be times when you want to accelerate the degradation process that's going to happen naturally anyway, and do it while you're there to fix it up or keep it under control.

I mean, erosion processes are an example of where we looked at situations where we can armor the surface up artificially. We had to have detention basins so we can keep digging them out, for the sediment and that sort of thing and armor the surface up naturally.

And then do something that is going to be long-term stable. In some sense, the ideal in Australia would be to walk away from the site, you know, with the low-level repository. That is not likely the case, but the objective is to sign them over to the government so they become a crown risk.

>>MR. BENSON: Any other comments from the audience. Tom Nicholson?

>>MR. NICHOLSON: I'm very interested in, Steve, you said that you thought the roots not only are looking for moisture, but also minerals. And, Kevin Leary, you commented about microbial activity.

I'm fascinated about how the system evolves with regard to both microbial and geochemical activity and whether you'll understand that well enough to know how that affects both cover and minor performance?

>>MR. LEARY: I think that's a good question, and I think there is a lot of room for understanding the system and how it affects the system. I don't think we really understand -- you know, for example, you can if there's areas for vapor transport of organics up through the cap, you could actually seed your cap material with a microbe that might degrade specific organic vapors that you're concerned with.

So I think there's a lot of room for research and development, you know, in that particular area.

And I think, again, understanding the geochemical environment I think is key for, say, example, liners, that was one of my comments I was going to have with number two, but since we skipped ahead, I didn't mention it, but I think really understanding the geochemical environment of both the waste materials you have in your facility as well as your surrounding environment will really affect your design and also how well your barrier and liner perform.

Did that pretty much answer it?

>>MR. NICHOLSON: Yes, but I'm also interested in the various microbial communities that live there and how they interact with both burrowing animals and roots and other vegetative material. We've been fortunate enough to interact with Pacific Northwest National Laboratory. They've been teaching us an awful lot about microbial activity, especially with regard to remediation of uranium. But it is a very complex issue, but I was thinking, you know, what would cause degradation of a cover liner, and I automatically think of the chemistry of this leachate and the microbes and all the things it involved. We haven't said much, except, Dr. Rowe, you did mention temperature and the thickness and you didn't really get into the interaction chemically between the leachate, the microbes and the membranes of the various plastic materials.

>>PROFESSOR ROWE: I guess I was certainly trying to emphasize that the chemical characteristics of the leachate, or perhaps more generally the fluid in which geomembranes contact, it may be leachate, it

could be in the soil, core water of the soil underneath the geomembrane, as well, certainly can affect the long-term performance of the geomembrane.

In terms of microbes, I haven't done any work myself, but looking through the literature, it's not seen as a major risk in terms of microbes attacking the geomembrane, how the microbes my change the geochemistry is a different issue and that comes back to, yes, the geomembrane is a function of the fluids it's in contact with.

>>MR. BENSON: Okay, anybody on the phone?

>>PROFESSOR WILLGOOSE: Just sort of a general comment about this. Is it -- in the climate com -- people -- ecologists in the climate change community are in the midst of quite a debate in terms of arid zone as well.

It's that -- one of the questions is: Is the vegetation in the arid zone actually limited by water or is it limit by nutrient availability.

And the immediate assumption has always been that it's limited by water. But, in fact, there are quite large ecology communities in

Southern Africa and western Australia where the plants have got adaptions and actually take something like 25 % of the metabolic energy of the plant solely to generate acids to release phosphorous out of the soil.

And these are some of the most arid places on the planet so, clearly, the plants must be limited by phosphorous, otherwise they wouldn't have this adaptation.

So, I mean, there are some real unknowns, in terms of the interaction between geochemistry and water and vegetation. So we still have no idea how they work.

>>MR. BENSON: Okay, well, let's go to take one more question. We've got about five minutes left, all right. And we are going end at 5:30.

And we actually have two questions, but I think perhaps we'll just kind of take them together and I'll just kind of throw these out to the panel.

One of them is about unintended consequences.

Can the desired changes to reduce one degradation mechanism perhaps cause some unintended consequences and result in other types of mechanisms which may affect performance?

So, by remedying one thing, can we create change -- undesired change to another? And then, other kind of lessons learned or understanding of our degradation processes that we can use to create systems that will function better?

So I'm going to throw both of those out there. Anybody on the panel who wants to chime in and then we can get a couple questions from the audience, then I think we'll wrap up at that point.

>>MR. LEARY: Just real briefly -- and Jody and Andy, correct me if I'm wrong, but I guess one example would be the use of riprap on side slope.

I know that, Jody, you've used some riprap on some UMTRA sites and he's actually found an increase in soil moisture and a propensity for deep-rooted plants; is that correct?

And at the Hanford site we've got one slope, side slope that's got riprap, and it's actually still very dry. So I guess just a little word of wisdom, maybe is to be careful, what applies to one side may not apply to another. I think you need to take into consideration such factors as climate and slope aspect.

I think all this -- and what kind of soil you're using, maybe all four of those factors maybe affect why at Hanford, the Hanford Barrier, we're not seeing an increase in soil moisture. I think, you know, just aspects alone, maybe the prominent wind direction is drying out that side slope.

So I guess just caution to people here that, you know, be careful of -- you know, observing some consequences, make sure that it does or it doesn't apply to your sites.

>>SPEAKER: I think the rest of that story, though, is talking about tradeoffs, means that collecting water is good if the purpose of the cover is radon attenuation.

>>MR. LEARY: Yeah, that's true.

>>SPEAKER: If you fill the pore space with water, you can slow the radon. So if you allow the plants to grow and let Mother Nature take its course and it starts to dry that soil more, then you have to

recognize what the balance is and dry it out so much that it would no longer affect the radon.

>>SPEAKER: That's true.

>>SPEAKER: So that's another factor that's taken into account, what kind of disposal facility you have.

>>MR. BENSON: Question from the audience?

>>PROFESSOR WILLGOOSE: I guess, an example that I can think of sort of the tailings facility and we had done a few years ago was that one of the objectives was to maintain as much water in the rehabilitative structure as possible, because it was an acid mine drainage generation site.

But then you ended up with all sorts of geotechnical issues because, essentially, materials are wet all the time, which actually made it very difficult to in fact maintain the water on the site, because they have a dish structure and, essentially, the dish was collapsing around the edges.

So, I mean, particularly, water issues, I think, and water management issues between surface water and groundwater is a real challenge sometimes.

>>MR. BENSON: Any others?

>>SPEAKER: One concept that we picked up on is the proper storm water management around these sites and probably building off of that. And Kent discussed this during one of the breaks with me, too, that, you know, dropping off storm water runoff on the upgrading site wasn't necessarily the smart thing to do.
But you wouldn't believe how many times, when you have, after all the (inaudible) containment system, a bunch of somebody elses getting the storm water management aspect of this contract. And that's exactly what they come back with. It's the absolutely worst place they can be.

The other thing with -- one of the unintended consequences again from our salt waste expert, again, lessons learned and thinking ahead of how the new systems are going to work, is using our double liner systems or our drainage systems in there to collect gas for use on solid waste.
Very efficient system, where you've got the drainage system all in contact with the waste below grade. So we figure, well, we tap into that and help capture gas

for these facilities. Well, what happens if we overdraw in that, we introduce air into that system and anaerobic decomposition method deep in the bowels of this system and, basically, we cause biological clogging in the system with that.

So there we thought we were solving the gas problem, we created a leachate clogging system with biological growth.

But biological growth does happen in these systems, it doesn't take a lot and you can get that to happen. Precipitation of certain metals, materials, you know, if we fixate our hazard waste with a lyme addition or something like that that's high pH, it will cause chemical reactions in the system where we get what they call this biowrap forming in these systems. Very hard to clean out. You need to design accessibility of these systems to clean and maintain them.

The other aspect of these things, too, is maybe looking at the containment system as a means of remediation. Our leak detection system in our double-lined landfills, if we did have a release bad enough that needed to be corrected, we could easily induce an

inward gradiant system in that system to cause inward gradiant to maybe stop the outward release of contaminant and collect it from the inside.
So there are things like that that we should think about. And when we build these things, from the get-go, is how the containment system is being used as a form of a remediation tool.

>>MR. BENSON: I think we'll wrap up now. I'll add a couple of comments of my own. I think of intended consequences, I think of a classic liner. (Low audio.)

I think a lot of the things that we talked about today, we heard some comments from people; Kent, John, from our group here, is that system (low audio) really the essence of performance.

And our view is not look at an element, but how the system functions and predict the best possible information we have about cover properties, liner properties, waste properties, so we can make a good and informed assessment of risk and containment system that can manage that risk within reasonable cost.

I think those are kind of my take-away messages that I got from this session and our discussion today.

I think this was a really good day. I think I appreciate all the speakers from this session. I really enjoyed it. I learned a lot. I appreciate all the comments.

Tom, are there any logistics for tomorrow morning you'd like to mention?

>>MR. NICHOLSON: The one thing we do need to do right now -- thank you Craig and Jody and the panel. Is there anyone on the phone system, anyone wishing to make a public comment or question? Anyone from the public?

If not, we'll reconvene tomorrow morning at 8:30. If you could by here and go through security.

Leave the material you want on the table. Don't leave anything personal, but you can leave stuff on the table, especially your name tags. We'll probably start promptly at 8:30, so if you can get here early tomorrow, that would be great.

Thank you so much.

>>SPEAKER: Okay, have a good evening.

>>SPEAKER: If there are any session three people here for tomorrow morning, please come up and talk to me for a minute.

(Workshop adjourned)