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

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U.S. NRC HEADQUARTERS AUDITORIUM

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Hosted by the U.S. Nuclear Regulatory Commission

SESSION CHAIRS:
DAVID ESH, NRC/FSME

THOMAS NICHOLOSON, NRC/RES

PRESENTERS:

Andy Ward, Pacific Northwest National Laboratories

William Albright, University of Wisconsin

Craig Benson, University of Wisconsin

W. Jody Waugh, Stoller, LLC

Roger Seitz, Savannah River National Laboratories

Tim Gish, Audrey Gruber, Yakov, U.S. Department of Agriculture Research Service

John Gladden, Savannah River National Laboratories

Bob Bachus, Geosyntec Consultants

John Tauxe, Neptune & Company

Bill Kustas, & Martha Anderson, U.S. Department of Agriculture Research Service

Terry McLendon, KS2 Ecological Services Specialists, LLC

PANELISTS:

Ming Zhu, DOE Environmental Montoring

Garry Willgoose, University of Newcastle, Callaghan, Australia

Brian Andraski, U.S. Geological Survey

P R O C E E D I N G S

>>MR. NICHOLSON: If I could have your attention, please. We need to get started.

Yesterday morning we mentioned some housekeeping items. And I'll repeat them once more for those who are joining us today for the first time. This is the second day of a technical workshop on engineered barrier performance.

This is a formal technical workshop. It's being recorded via cameras, it is live web streaming, Go-to Meeting and teleconferencing to the four regions.

A public comment period has been scheduled for 5:30 p.m. today and tomorrow at 3:30.

Restrooms are located in the back of the atrium. In the event of a fire alarm or an evacuation, please take all of your possessions with you, exit through the rear of the auditorium, go up the steps to the security check and where you were this morning, out those doors and form as a group under the trees next to the security drive-thru booth.

We have to be responsible and account for all of you, so please stay together. You can leave the workshop at any time, but you're only permitted to enter through the security portals that you went through this morning. Make sure you take your name badge with the code on it.

At approximately 12:30 today we will break for lunch. You will be guided by the NRC guards up the stairs next to the security portal you came in and you can go to the cafeteria or the snack bar in either building.

No taking pictures are allowed in the auditorium. Please turn off your cell phones. No food or beverage, other than water, is permitted in the auditorium.

And finally, this morning each one of you should have received an NRC public meeting feedback. If you can please fill that in and leave it with us. And if you don't have the time, take it home and then mail it back to us, okay.

Now, this morning our session, session number three, is focusing on monitoring. The co-chairs this morning are Bill Albright and Craig Benson.

Bill Albright has degrees in environmental toxicology and hydrogeology. He is co-PI of EPA's Alternative Assessment Project with Craig Benson. Lately, Craig and Bill Albright and Jody Waugh have written a book, and they'll discuss it: Water Balance Covers for Waste Containment Principles and Practice.

>>MR. ALBRIGHT: By the way, my retirement plan depends on the royalties of that book, so I would appreciate it if everyone would purchase a copy. ASE Press says that we'll have printed copies in about two weeks, so looking forward to it.

We've only discovered two substantial errors, and there will be a quiz to see who can (low audio)

This session is on monitoring. I've been looking forward to this one for a couple of reasons. First of all, it's typical when you have a session like this that you know everybody that's going to talk and basically what they're going to say.

Of the five presentations today, I'm familiar with two. And the other three are largely unknown. In fact, one of the presenters I haven't met yet and I'm not sure if he's here yet. So I have his presentation, but I can't give it. So I'm looking forward to meeting Tim Gish.

Also, most of us have done some kind of developmental science and we tend to get focused on the results of our science and it's a little bit difficult to look back to the methods, the monitoring methods that we used. And that has made presentation -- preparation of presentations a bit of a challenge in a way. So that involves a little bit of rethinking of focus of the talk.

So I want to start right in. Our first speaker is, of course, Andy Ward. He has a Ph.D from the University of Guelph in soil physics and vadose zone hydrology.

He's a senior research scientist for the hydrology program with PNNL. And for 15 years he's been the manager of the development of the barrier development program, Andy?

>>MR. WARD: Thanks, Bill.

Hello. Sixteen years ago I came to PNL and shortly after the Prototype at Hanford Barrier was constructed there was a paper in Civil Engineering Journal, had a picture on the front of the Hanford Barrier that said "Do not open until 2094."

We're going to open it a little bit today and talk about some of the results that we've collected over the last 15 years.

So the Hanford Barrier is basically a combination of several years of research using analog studies and numerical modeling at Hanford, the site. It's constructed over natural waste strip, which is sort of unique within UV system, I guess.

And it was part of a treatability -- surface treatability test that was initially designed for -- intended to last for three years. We're now in our 16th year, so that's -- the primary objectives were to assess constructability of this rather complex cover to establish construction costs.

And the part I'm going to focus on today is the performance data which were intended to be used for verification of the remedy for refining conceptual models and to be used for model calibration.

So this over here, this is the actual barrier. This is a picture that actually was in Civil Engineering Journal. This is a tank farm over here, so you sort of have a modern approach to waste site management compared to the old method of the (low audio) system.

For testing and monitoring, the -- as I said, it covers the monitoring almost for 16 years, looking at stability, erosion, water balance and ecological processes. The circular tests went from '94 to '98.

Basically, there were two precipitation treatments if you were interested in climate change, so we actually irrigated one half -- about three times the long-term annual, which is 160 millimeters at Hanford.

So that was about 480 millimeters a year.

There was a thousand-year return storm in March of every year. And the ambient side, which remain unirrigated, received 160.

At least that's what was intended. It turns out that the three years of testing were years of very high rainfall. The ambient actually ended up being about twice the average, but we will talk about that later.

In terms of monitoring, the amount -- we've done routine monitoring since 1998, after the completion of the treatability test. And in 2008 there was a simulated range fire in which we basically burnt half the cover off, the vegetation off the north half, to look at sort of the recovery. And Steve Link talked a little bit about this yesterday.

So, again, before I talk about monitoring, we looked a little bit at the important processes and components. The barrier -- engineered barrier is a sort of a very tightly-coupled soil vegetation atmosphere continuum. There's a number of components that contribute to the function of the barrier, both biotic and abiotic processes that influence the dynamics of water, air and energy.

And over here, on the right, it may not be clear, but these are the equations that we typically have to solve in trying to simulate a problem like this. You're solving a partial differential equation for water and one for air and one for energy. And you're using the atmospheric boundary conditions at the surface to drive the system.

So, in terms of the things that we want to monitor, what I've done is to try to arrange the data in terms of the questions that were asked. And the first one is related to what or where you need to monitor. And first would be the surface, looking at ecological changes.

Steve talked about some of this yesterday. But what we saw after construction of the barrier, we basically vegetated it, there was an initial increase in the number of species in the post-vegetation period -- revegetation period.

So up until about '96 or '97, we had a large increase in the number of species. And since then there's been a gradual decline. And this decline continued until 2008, when we burnt the north half. And there was a sudden sharp increase after the fire. And Steve talked about that yesterday.

15 years or now 16, after revegetation, the surface is dominated by sagebrush species richly, so the ground cover is the same as analog site. On the Hanford site, actually where we've got most of the soil for the construction of the barrier, so things appear to be evolving towards a stable system.

The differences between soil cover and gravel slope, basically, we see some differences in the distribution of precip -- of vegetation on the -- there's two side slopes, which I will talk about in a minute, but we do see, on the north side here, this is the planted side and this is one of the side slopes.

If you have an above-grade barrier, you need a protective side slope and this one actually does have some vegetation growing on it. The shrub density is shown here and it is -- it's about twice -- almost twice what we saw on the analog site. This is expected because this cover was actually vegetated at a somewhat higher density than the analog site, with the intention of thinning things out, but the plants grew so well that I think the botanists and others were a bit reluctant to remove them after that.

In terms of some of the surface processes, animal use, it's basically you have a sort of ecosystem. In an engineered cover there's evidence of widespread use of the cover by animals. These are rabbit feces here, there's some vermin.

This lower picture actually shows an important component, you can probably see those dark specs, the surface has 15 % of pea gravel mixed in with the top one meter circle as an erosion control measure.

Jody can tell you guys all about that, because he was there at the beginning. So there is evidence of cottontail rabbits that's prevalent in the northeast corner. One section of the cover was extremely dense in grasses compared to shrubs. And this is where we saw a lot of this activity.

There's evidence of gall formation from insects. 70 percent of the cover had -- showed evidence of burrows. They were random, there's no real pattern to it.

I'm not sure how we would model this, but that might come up later in the day. But what we did see is that -- or what we didn't see was any obvious impact on the water balance.

Precipitation, I mentioned that there was a test where we actually applied three times the precipitation. We basically looked at the seasonal distribution of precipitation and we increased the applications and irrigation to meet the three times annual event.

The highest amount of precipitation for the monitoring period was about 138 millimeters. We do see quite a seasonal shift, some changes in the seasonal distribution and this, obviously, is going to affect performance.

The total amount of water that has been applied from '94. 2009 is shown here, and this is the irrigated side and this is the ambient side.

In terms of the processes we want to monitor, runoff and infiltration, the cover is instrumented to monitor runoff. And the maximum penetration depends, again, on the seasonal distribution of precipitation.

These graphs on the right side actually show, in this case, moisture profile in October of 1996. And then you see the red in front moving downward. I'll show you in a minute, when we talked about data gaps, how this becomes important.

But the unirrigated patch, the red in front, can reach down 2 meters. And the fine soil layer is 2 meters. It has a capillary break at the 2-meter depth, so we actually do see the red in front moving down 2 meters, except that the water content is usually pretty low over here, where this is about 20 percent here.

So this is -- the saturated water content is 49 percent, so it's still relatively dry. We see normally three-year runoff events. The first thousand-year return is still on the surface, it's bare And we got about almost 2 millimeters of runoff and from about 8 millimeters that was applied and we have about 7 grams of -- between the soil loss range, initially from 7 grams down to the 1 gram per year.

In January of '97, there was a second one, when the surface is frozen, about 36 millimeters have runoff. By this time the cover had pretty well-established vegetative cover. There was no soil loss.

And in January of 2009, the first runoff event since the '97 event occurred shortly after the cover was burnt and the vegetation was removed, .016 millimeters and about 2.2 grams of sediment from a pretty large area. So it's pretty effective.

The plant -- at least the soil combination, the soil admix is quite effective in minimizing erosion, but this can be monitored quite effectively with runoff blocks and other automated systems.

Near surface. Is continued -- one of the things you want to measure. This is a plot of the storage -- water storage and design capacity at 600 millimeters. This water storage block is from -- during the treatability test, where we irrigated, we got pretty close to the source capacity, but never exceeded it and, essentially, the cover has not drained in the moisture.

There is a few things to note that may not be obvious here. But what we did see, the maximum storage is dependent on location. These three graphs here, which may not be very clear, they have a 2 % slope on the cover, the highest storage occurs at the lowest part of the slope, the lowest storage occurs on the crowning, which makes sense, because it was designed for 2 % slope, and water moves laterally. We found another important observation here was that the minimum storage, which is the level to which the plants can remove moisture was somewhat dependent on irrigation. It typically went down to about 100 millimeters, but we found that on the irrigated side that over the three years that we irrigated we actually got an increase in that lower minimum.

It seems as though the plants were unable to remove all the moisture effectively, so they remained somewhat dry to normal. Interflow, this is a large cover with 2 % slope intended to shed water to the sites.

We do have some instrumentation, these are neutral access tubes that actually go horizontally at the capillary break. And what we did see in the early years of irrigation, you can see the capillary break, that's quite wet, there's water that moving inward, there's a high -- a large amount of water at the edges, it's sort of built like a bathtub, and you can see this accumulation of water at the edges here. Once irrigation ceased we see a steady decrease in moisture at the capillary break and it is now actually drier than it was when we started. So it's quite effective in limiting any kind of movement.

There is also horizontal access tubes under the asphalt layer, which is an impermeable layer. And what this is used for is to look at underflow and this one shows we usually get about a meter of -- water moving about a meter under the barrier and evaporates. And just like the storage.

Percolation, this is the Holy Grail. The cover has a curved asphalt layer that essentially divides it into like large lysimeters. If you take the resolution of our instruments that we use to measure drainage and also syphon and divide that volume by the surface area, it tells us that we can resolve drainage change of about 3 by 10 to the 5 minus millimeters.

There is no instrument up there that you can yet use to give you this type of resolution. I saw one of the talks yesterday, that talked about, you know, using lysimeter data in a qualitative sense.

But this is perhaps the most accurate measurement that we can get. It is fully automated, we record measurements every hour. What we see here is the percolation, this is actually -- this is not water that would go into the waste, this actually infiltrates the barrier down to the asphalt layer and we shed off to the sides and we measure it.

The top one here shows the irrigated rock and gravel side slopes. Initially, in the early part of it there was some differences, but over the long term, after we stopped irrigation, basically they ended up being the same.

This side is the unirrigated side. We have a gravel side slope here and the gravel on the top, riprap on the bottom, somewhat counterintuitive but what we do have here is a system where an open framework of riprap is basically experiencing what can be considered effective. When pumping, basically, you have the water from the riprap is being evaporated before it drains.

And it turns out that an open framework riprap, which we would think would drain quite tremendously is draining less than the gravel. This is something that we had to go back and add to a conceptual model in order to understand what was going on. This is the -- this graph on the bottom shows the drainage from the silt loam layer. And notice the differences in scale.

Up here this is 700 millimeters. And here, this is .3 millimeters. The performance criteria for this barrier is .5 millimeters a year.

And over 16 years, the most drainage that we found that is .25 millimeters in 16 years. So I would say it performs quite well. And it turns out that this water has been attributed to condensation from the pipes that travel under the system for drainage.

Evapotranspiration is by difference and you can see, again, changes in evapotranspiration rates over time.

I think I should speed up. Stability, in terms of data gaps, this was an interesting one because we have subsidence meters, basically some sediment gauge that is bolted to the -- affixed to the asphalt layer that was put in place after the first measurement was taken after the barrier was loaded, so we really don't know if any subsidence occurred.

But over the last 16 years we've been sort of within the error -- the error range of the instruments. This is a change in technician and instrumentation. At this point I probably should remove it, but, generally, here it's a pretty stable system.

Creep gauges. That looks at the movement in the side slopes, pretty much stable. Some of the tools, techniques and methods, if you're monitoring the barriers, basically -- you measure the fluid saturation, capillary pressure and perhaps the permeability. If you measure one, you can get the other using functional relationships, but we didn't -- saturation is very easy to measure. We also measure temperature and, as I mentioned, stability.

The idea here is that what we're doing is typically, on a relatively small scale, removing the large number of barriers that cover a large area. We probably can't have people going out to measure neutron, you know, in 200 barriers at once. We need to probably look at some more sophisticated techniques.

One of the things we've looked at is geophysics, surface geophysics. There's some challenges with the resistivity. If you make surface measurements, this one shows resistivity measurement compared to a change in nitro concentration at a location near the barrier. It does not pick up all of the vertical variations that you get. So there is a number of things that influence that, but there is some possibilities.

We looked at ground penetrating radar to cover larger areas rather than the point measurements, and what we see over time is that the correlation's length of these really high -- these dense measurements tend to change with time.

This has some implications for designing a monitoring system, in this case, point sensors.

The electrical measurements, we're looking at -- this is one approach that could be used. In the future, having electrodes beneath a liner or beneath an impermeable layer that would pick up regions for leakage.

Long-term insights from short-term monitoring, the idea of a leading conceptual model is important where you couple monitoring and modeling.

This picture on the right is an interesting one. As I said, the initial intent for this cover was a three-year treatability test. And ten years later there was a really intense rain storm that eroded this 40-inch channel at the base of the barrier. This guy is about 6 feet, he's standing in the trench. This happened over a relatively short period, less than an hour.

This also caused us to go back and look at the modeling, because we typically use daily averages of rainfall. That did not generate this type of scenario. If we did a 50-meter average (low audio) the intensity, I believe, for this type of site.

This is the more recent data, again, short-term insights for long-term monitoring.

This was after the burn. Again, somewhat current, the storage on the burned side increased more slowly than the unburned side, which we have now attribute to evaporation on the near surface, while it was not happening on the unburned site to reach a lower level of storage.

And in the Spring it declined at a much slower rate than the vegetative side, which would make sense. And at the end of year it was somewhat wetter. But two years later, there is no difference between the two, even though the ground cover is somewhat different.

Data gaps, I mentioned we looked at a lot of storage. These two plots show exactly the same storage, but the wetting fronts are at different locations, so if you're using -- if you're looking at model calibration, it depends on what the data will be used for.

If you're looking at model calibration, you probably need to get this detailed information. If you just wanted to use a water balance, you get the water content or storage at the beginning. At the end you do the balance for the ET.

I mentioned this one earlier, where we lost the early part of the data, we really don't know if any subsidence occurred after loading, but this is -- after that period, it looks pretty stable.

So a couple of the issues that can be addressed from this. The design, we have the side slopes that are above grade and there's lateral diversion layers that increase drainage.

We saw the case where the total of the side slope was eroded. It is not well-known how this water will impact barrier waste. And the question is: Can the impact be minimized at acceptable levels?

In terms of the performance, we still do a lot of point measurements and manual measurements, which I'm told a lot of barriers are still being constructed with metal access tubes. That rules out a lot of electrical methods that have much larger areas of interrogation (low audio).

Neutron probe, the zone of influence changes, varies from about 15 centimeters to 30 centimeters GPR. At Hanford we can cover up to 12 meters, we can interrogate a region of 12 meters if you have a PC tube rather than aluminum.

In terms of scaling, the geophysical methods, again, allow you to measure a lot of these state variables, moisture or some indicator of these variables, over a relatively large -- from relatively small scales to relatively large scales.

The impact. The big question is: Can we predict the long-term impact from the short-term there? We saw a case where we basically simulated a wildfire, we saw some very rapid changes in the first year, and after the second year, these changes were not apparent.

These are things that would have to be addressed with modeling, because we often -- we might even miss that event, it was such a short event. So this is what I wanted to talk about, and I guess there are no questions.

>>MR. ESH: Very good. Thank you.

>>MR. ALBRIGHT: My topic today is on the lysimeters that we use in the ACAP program.

The Alternative Cover Assessment Program -- let me page down here -- the program that the USEPA developed about 12 years ago. The main objective of the program or one of the main objectives was to compare the performance of the conventional covers of the day, which were compacted clay covers and composite covers or geomembranes over compacted clay, to these alternatives, which were often water balance covers, what we call ET covers.

And the idea was to compare the performance of those covers to establish this notion of equivalency. And the conventional covers were accepted technology.

And to come up with an alternative, one had to demonstrate equivalent performance, which was complicated at the time because the conventional covers were what I call material methods designs. In other words, they assumed the performance based on the use of certain materials, either membranes or compacted clay, and certain installation methods.

And given the material methods, you would assume performance and not really ever have to demonstrate performance. It's kind of a nice little way of side-stepping the issue there.

These alternative covers, though, they're site specific and they depend on establishment of some performance criteria so that you could design a cover and -- to meet those performance criteria, and design a monitoring system that would address the issues -- the needed issues for both of those covers was kind of a challenge.

We came up with large instrumented drainage lysimeters -- the lysimeter for direct measurement of percolation and the instruments give us a little supplemental data. And the combination, unfortunately, is a lot of interpretation of the data that we saw. ACAP was a widespread project.

Keep track of my own time here. I guess if I'm the guy monitoring the time, I get all the time I want. Is that right?

We went all the way from hot and unbelievably humid down in southern Georgia, Albany, Georgia our Marine Corps base down there, then we were up at Cedar Rapids where it's, of course, humid and wet cold. We were out in the arid west, both at cool sites and down at Apple Valley, where the misnomer is -- I believe no apples in Apple Valley. I think that was a real estate trick, I think. But it's quite hot, very arid, 4 inches or so a year of precipitation.

And we built alternative or water balance covers at all these sites. We built compacted clay covers at Apple Valley, at Cedar Rapids and at Albany, and we built composite covers that had geomembranes in it at several sites as well.

So we had a very good opportunity to look at performance and the mechanisms for all these covers at really very environmental conditions.

I have a few photographs here. It's easier to see pictures than to describe various lysimeters. Ours are big, but not as big as -- well, one of our sites is the Monticello, Jody's site, and it's the world's largest drainage lysimeter, and it's really 7 acres. Yesterday he said 7 hectors. I'm not sure anyone else picked up on that, but that's like a fish story, you know, it gets bigger.

It's really 7 acres and it's a quite large drainage lysimeter, but ours were generally 10 by 20 meters, which were still very large. They are essentially in instrumented bathtub or swimming pool.

We built this lined facility, lined the bottoms and sides, where we built a full-scale, in-depth cover that we wanted to test. And in the case of a composite cover there, it actually has a membrane in the cover that was welded to the side walls all the way around, and we collected lateral flow that came off of that -- off of that membrane.

This is the central crux of the lysimeter. It shows the geomembrane, the boot which is the sump that goes out to a measurement system. And, of course, our measurement systems were redundant. They were actually doubly redundant, we were able to measure drainage by three methods. Which is really good because we spent all this time and money building these sites and you want your data to be good.

And, as it turns out, instruments fail exactly when things are happening. You know the periods of high flow, that's when things give up. Snow melt occasions, like in a cold and snowy environment, that's when your instruments go bad. So you always want redundant measurement systems in a monitoring system of this sort.

This is a good slide that shows the scale and the methods that we used.

We didn't hand build these covers, we used reasonably full-scale -- a deforest kind of a toy instrument on a landfill or a mine site, but it's reasonably full-scale. And you can see the side walls that we used. And we're compacting a layer of soil in there.

We did use full-scale equipment methods. The roller that we used to compact our compacted clay layers.

We put in lots and lots of instruments; water content sensors, soil-water suction sensors. And we took a lot of undisturbed samples. This is Craig taking a sample. And I really cursed this method initially because it is a tremendous amount of work.

One of the things in monitoring that people don't realize, we talk about the methods, we talk about instruments, what we don't talk about is hard physical labor.

We do a immense amount of manual labor. We dug a lot of holes. Craig is digging around the sample. You can see PVC pipe on the surface, you dig around it and pretty soon you slip it over an intact, as-compacted, monolithic soil, take it back to the lab. And we were fortunate and we were able to do these as-built and then, some years later, to compare those properties.

We took many, many of these samples.

This is a three-lysimeters site in Portland, Oregon, actually near the Hanford reservation, where we tested three different cover there. And that was the last site we built, and that was the four of us that built most of these sites.

Picture -- a couple of pictures that show what they look like a couple of years later. This is a site in Sacramento showing two lysimeters there of different design. And a site in southern Georgia that had a water balance cover that relied on trees and grass to transpire the water back out of the cover. And, of course, there's a compacted clay cover, which was the conventional cover. Some would call it the cryptive cover for the site.

A few slides, and they're a little bit complex.

Craig actually showed this one yesterday. I want to go through this one a little bit carefully, just to show what we're looking at.

This is a site at -- what's that?

>>SPEAKER: (Low audio).

>>MR. ALBRIGHT: Well, I was trying to get rid of a little -- I didn't see it up there, but this is at Marina, California, near Monterey. It's on the coast of California.

We're looking at a few years of data across the bottom here. We're looking at precipitation and ET over here. And percolation soil, water storage and surface runoff over here.

Now, Marina has a very seasonal climate. Here we go, wet winter, dry summer, wet winter, dry summer, and so on. And every year, very predictably, these water balance covers are like storage tanks, you have a certain amount of water storage capacity, it's supposed to soak up and hold the precipitation during low evaporation or transpiration seasons, and hold that water for the plants that transpire back to the atmosphere in times when potential evaporation exceeds the precipitation.

So every year the soil would dry out and then it would wet up, and then it would dry out and it would wet up. And this is the water holding capacity of the cover. And every year, predictably, when we exceeded the water storage capacity, we got drainage.

Drainage here, drainage here. Now, if we just had the lysimeters, if we just had the measurement of drainage, which is a direct measurement of drainage, by the way, if we can hold it in a glass and point at the end of day and say this amount of water came through at this period of time.

If we just had the lysimeters, we wouldn't understand the mechanism. We wouldn't understand that the soil would wet up and dry out and wet up and dry out.

So the instruments -- and this is a critical point to monitoring. The instruments let us see the mechanisms, the important mechanism, which we knew and was expected to be soil water storage.

So when we exceeded the storage capacity, we got drainage. Now, there's some things we didn't understand. This is a site not far away, at Sacramento, California. And, again, we see multiple years of data in a similar climate; wet winter, dry summer, wet winter, dry summer, and so on.

And every year, when it rained in the winter, the soil would wet up and then it would dry out. And then the next winter it would wet up and it didn't dry out.

But what we saw, if we've only seen the lysimeter data, we would have seen the next winter, when the soil wet up and exceeded the storage capacity, we saw percolation. But we didn't -- but without the instruments, we wouldn't have known why.

What we would not have known was the previous summer, in this period right here, the soil didn't dry out. We're not sure why.

What we do know is that a few years later, when we went back and did an autopsy on the site and exhumed the site, we found out that all the plants that had originally be planted, they were all replaced by invasive species.

And so the site then went ahead and did a plant physiology investigation to improve their plant properties. But without these soils instruments, we would have not known that the reason for the drainage in this winter was incomplete dryness soil profile the previous summer.

So, once again, the crux -- and I will probably say this multiple times -- the crux of understanding cover performance is a combination of a direct measurement plus instruments.

The measurement gives you the context of performance, the instruments give you all the supplemental data that let's you interpret and understand the processes that are going on.

Now, lysimeters plus instruments can point to processes that change or degrade performance.

This is the compacted clay cover at Albany, Georgia. And we're picking this up, looking at just about a year's worth of data here. And we belt this site in March of 2000. So we're picking it up right here a couple of months into the life of this cover.

And you can see it rains -- this is precipitation, this blue line. You know, it rains all the time in southern Georgia. Kind of like it rains all the time here. I'm from the west, obviously.

But, initially, the percolation to that curve was slow and steady. It rained a little bit all the time. In fact, it rained while we were there. It rained day one, we put the membrane down, we got drainage right away.

But, it didn't rain for about six weeks -- which is what they call a drought there -- and the soil dried out. And we know what happens to clay when it dries out; it desiccates, it cracks. And we think that it establishes preferential flow pass.

When we saw the cover soils dry out and then when it started to rain again -- and bear in mind, this is six months after we built the site. Then, when it started to rain in the fall, late that year, we would get a precipitation event, immediately followed by percolation, a measurement of drainage.

And so that was a good indication of preferential flow through a compacted clay cover that had dried, dessicated and cracked.

Now, what you can't see on this particular slide, because the timescale is not correct, is that we saw precipitation, immediately accompanied by drainage, whether the soil was wet or dry.

Our eye can see the dessication cracks, but our eye can also see clay that when it wets up from precipitation, those cracks swell shut and our interpretation of swelling shut is the word "healing." We assume that this healing process goes on when those cracks swell shut.

Well, we saw rain, immediately followed by drainage, when the soil was both wet and dry.

So that damage to that cover persisted. It happened really once during this period, one critical time. And what we saw was that the fundamental hydraulic properties of that cover changed dramatically from that one serious event.

And, again, we went back four years later and we were able to do a lot of testing. That was the first site we went back and did postmortem and we were able to confirm that. But I'll talk about that a little bit later.

So this talks about how lysimeters and instruments can point to important processes that change the performance of the cover.

And -- now, that was a great talk, I enjoyed Kerry Rowe talk yesterday about the geomembranes (low audio) really enlightening. And you might find this slide interesting.

This was at Marina, California, again, the Marina site, but this is the conventional cover, which is a composite cover, it's got a vegetated topsoil, drainage layer and a geomembrane, and then compacted clay underneath the geomembrane. And we inadvertently damaged the membrane when we installed it.

And we knew it at the time as -- there was a little political processing going on that we couldn't avoid, so we didn't properly protect the membrane.

So what we see here -- actually, I don't have dates here, I just have number of days.

So we have -- this is a few years of data. And, of course, this is wet -- wet winter, dry summer, wet winter, dry summer, (low audio).

And now, the cover soils would wet up every year and dry out, wet up every year and dry out. And what we would see is this blue line here, the lateral flow, on the membrane, not the lysimeter membrane, but the membrane that's up in the cover, that's part of the cover design.

And what we saw is whenever we saw lateral flow on the membrane, we saw drainage through the cover.

That's the red line, seasonal drainage; winter, summer, winter, summer, and always accompanied by lateral flow in the membrane.

Now, unsaturated flow, anybody who studies it would predict very low flow rates through a saturated -- through a membrane defect under unsaturated conditions.

But when we have saturated conditions, the water is actually flowing on that horizontal membrane, then it will find every construction flaw or defect in the membrane.

What we showed was that it affected all of our sites. I believe the composite covers leaked some. Generally speaking, it had very good performance, vary slightly in the results we got.

Composite covers work well in all environments, given that there's proper construction practice. And what we showed here is the importance of construction practice.

We're seeing 50 millimeters a year of drainage through this cover, and that's a lot. So you have to build these right.

I'm really interested to hear Bob Bachus talk about differential subsidence later on in this session, because I think that's an issue for composite covers. Difficult to monitor a composite cover because the membranes are buried so deep in the cover.

Like I said, we had a chance to go back to our site at the marine base in Georgia to get the data they needed. They wanted to scrap our test pad and build a full-scale cover based on what we demonstrated there, was that these water balance covers can be -- can be equivalent if properly designed for a compacted clay cover.

And so we went back and asked if we could go down and take some samples because we thought we saw the development of preferential flow in the cover. And we wanted to go back and take some samples. And this is, again, an important part of monitoring.

Once again, we got out our shovels and we went back. And it's great working in a landfill. A lot of scientists are limited to bench studies. In fact, more and more, you see graduate students just do nothing but sit in front of the computer, you know, with their head out and their fingers out like this, you know, and that's research these days.

But those of us who are my age or about my age, knows that research usually involves -- or their work should involve some field work, even if you are a modeler.

And it's great working in a landfill, because you want a hole, they just say "how big," you know. And it's big equipment. We can see the

ACAP sites from space. Gives you a warm feeling, doesn't it?

Go on Google Maps or whatever, you can see -- you can see our sites. But we found some really interesting stuff and the ability to go back and dig up these sites. We found roots in the clay barrier.

Roots are not supposed to penetrate highly compacted -- and when we built the clay barriers in these curves, we followed the guidelines that were developed by Craig, back when he was a graduate student, how to really put down a good, intact, welcome-compacted, well-conductivity clay barrier.

We did them all this way. And we found roots right through them, especially down in southern Georgia.

We found roots in odd places. This is Steve Rock, who is sort of the heart and soul of the ACAP program from EPA, provided the funding and a great deal of support for the program.

This is our site at Apple Valley, kind of --

like I said, it's a misnomer. It's arid out there. And this is several years into the life of the cover. And do you see -- I mean, how much roots are you going to find out there? There's hardly anything -- that's the test pad. There's hardly anything growing on it.

Well, we did find roots. In fact, this is another kind of interesting aside. This little picture here is out of the compacted clay cover that we tested there.

Now, most people are familiar with the idea of a capillary barrier cover, where you put a fine grain soil on top of a coarse-grained soil and at discontinuity in core size is it's supposed to keep water up in the fine-grained soil.

Well, this is the bottom of a piece of the fine-grained soil.

And that's an indication that that's where the water stops.

Look at -- those roots were evenly distributed all the way across the bottom of that clay layer. And, you know what, there was -- and there's no plants in the top.

Where did those roots come from? But they were there. They were there in a very, very dense root mass and airily distributed. They were really rather impressive when we dug these samples up.

We took lots of samples, an in situ measurement of our north property and we ran big sealed double-ring infiltrometers. That's about a meter and a half across the inner ring there.

Like I said, a lot work. And we did dye tracer studies to look for preferential flow paths and they made for great photographs, too, with the green dye and the red Georgia clay.

We took a lot of very large intact samples. That sample is coming out of the clay barrier, so we dug down quite a ways to get to the clay barrier.

And this fellow here, who was a Ph.D. student at the time, was about ready to slip that big PVC ring over that sample, cut it off at the bottom, take it back to the lab and test it for both saturated and unsaturated properties.

This is four years, almost to the day, after we built the cover. And this is the cover that we thought we saw evidence of preferential flow. So we want to go back and test it under laboratory conditions, fully saturated, saturated conductivity and see if how the hydraulic properties have changed.

This is an important piece of monitoring. We've got to go out and get these samples. We all know that covers change. We talked about changing cover systems yesterday quite a bit.

But you got to do this to find out how they change. You can't just guess at it. You have to go out and take some chances.

Ideally, you don't want to do this within your lysimeter, you want to have a buffer area around so you can go do destructive sampling of various kinds.

We debated the relative importance of plant ecology versus geotechnical engineering.

And this is our site up in Cedar Rapids, where we had composite cover or clay cover and an alternative cover, a water balance cover that relied on these hybrid poplar trees. That's one of our poplar trees being wielded against the shovel there.

We looked at this slide yesterday. Craig had this one up. This is just an example of the kind of thing that we found out by digging up those sites or doing really extensive sampling some years after we built the site.

This is as-built saturated hydraulic conductivity versus in-service, several years later, saturated conductivity.

And, of course, as Craig said yesterday, the hydraulic properties had not changed, they would all plot on the one to one line here as you can see the saturated hydraulic conductivity of those samples increased -- with all cases, they increase more with fine-grained soils and coarse-grained soils and developed a little bit of guidance to tell how much and which direction these properties would change.

And this plot here actually is part of our report that we have in here, at the NRC. And I believe the review process is nearing completion.

I think that report, with appendices, is about 1,000 pages. Is that right?

So for those of you who have trouble sleeping, you're welcome to get a copy of this and file through it. There is an immense amount of information in here about the change in hydraulic properties with pedogenesis from wet/dry cycles, from freeze-thaw cycles, from biointrusion.

Soils change. And Jody is the foremost proponent of this idea that change happens in these soil systems that rely on natural processes. And you have to be able to predict to understand the magnitude and direction of those changes.

Lessons were learned. As I said, the monitoring for covers should include -- the context is always direct measurement performance.

Anyone who has taken Hydrogeology 101 will tell you that all they need is water content of the soil profile at various depths and the soil-water retention curve from that soil and they can calculate the drainage.

That's easy, the calculation is easy. But they won't see preferential flow. They won't see to flow that we saw in southern Georgia, where it rained and drained and the soil didn't wet up. It's because all the water went down those cracks.

So you have to have the context. The context is a direct measurement of performance of percolation. And then, to understand the processes. The processes that are in place and the changes that happen, you have to have supplemental data.

We like instruments in the soil. We like buffer areas for invasive and time series sampling and things like change in soil hydraulic properties, plant properties, which we didn't do nearly enough of in the ACAP program. It's a big unknown in the research.

We didn't involve a good restoration ecologist. We didn't involve Jody early enough in the process. So we didn't have a lot of as-built information.

And, of course, to look at all the plant parameters and ecological processes, it's really important to understand stuff. You need to do invasive sampling. You need to get a shovel out or backhoe, or whatever, and take those samples. And you need long-term monitoring to understand the long-term processes.

Our -- I think we dug up our last site when it was perhaps 7 years old or so. I'm not really sure. The first one was four years old, but all of our sites were, I assume, within the ten years of construction. And that's not long-term, that's kind of somewhere between short term and medium term.

So we have a good indication of how soil hydraulic properties change. What we need is more information on the plant properties and the ecological processes.

So, there are some suggestions for research and monitoring and I think they're well-founded. We were really, really fortunate in getting some late-in-the-project funding from the NRC and from NSF and from EPA -- and I can't remember everybody -- to go back and dig up all those sites.

But it was immensely informative. And it was something we didn't plan on at the start of the program, so we're really grateful for that opportunity.

And finally, a plug for this, it's the cover art for our book that's about to come out. And the water balance covers for waste containment. And Craig and Jody and I wrote this.

Jody was the author of the plant restoration ecology chapter and it's a real eye opener for -- most of us come from a soils and geotech background.

And your vegetative cover was your mouse and your computer. You put a layer of green and maybe draw some roots in it. But there's a lot more to it than that.

And Jody says over and over that it is -- his longest chapter in the book is just a brief introduction to the topic. And he, of course, needs to write up the full text on that, but it's a very good chapter and a lot of interesting information.

So, that's all I have.

>>MR. ESH: Let's see, we have (low audio) This is the first time we have met. This is wonderful. Let me pull up my bio here.

>>MR. GISH: Anyway, even though I left my office quite early this morning to allow myself time to get here, the security people tried to tell me that I didn't exist and so it took me quite a while to finally get past them. So, I apologize for getting here after you started, but, unfortunately, I should have allotted an hour to get through security instead of a half an hour. Anyway --

>>MR. ESH: I'll let you introduce yourself.

We have a short bio, but go ahead.

>>MR. GISH: Don't worry about that.

A few people already know me, anyway. I -- if it helps any, I got my bachelor's at Brigham

Young University, skipped my master's and got my doctorate at the University of California Bill Drury, a theoretical physicist. I specialized in fluid dynamics. I did a lot of work on turbulent flow processes preferential flow of atmospheric transport processes as well. And I've been working with Tom for a few years.

And some of this things we've done I'll talk about here.

What I would like to do here first is first acknowledge my co-authors on this Andrey Guber and Yakov. Neither one of them could be here, unfortunately, they wanted to, but they had other commitments and they weren't able to allow them to be here.

Obviously, I'm going to focus on contaminant transport and so -- and I really appreciate some of the things I heard this morning. I wish I could have been here yesterday to hear what was taking place.

But, typically, when we look at chemical transport, especially relative to this group, we have some kind of leak that takes place and there's a vertical component and there's a lateral component. Those two processes interact to take the compound off site where it can affect neighboring ecosystems.

I've been told that's a bad thing. Typically, if you look at something like, more specifically, the Hanford site, you might see something a little bit like this, where you have -- the contaminant itself can leak through faulty joints or welds and can interact with the porous material and fractured material -- fractured rock, to eventually move over to maybe an unsealed well or through a fracture in your porous media to eventually get groundwater systems.

So it's important that we actually understand how the compounds that are of interest, can be enclosed by soil material and fractured rock.

Now, this group may have different perspectives on what actually is soil. As a soil physicist, most of my work deals with what takes place in the shallow top 3 to 5 meters. Whereas, a lot of time, this group might be interested in something that's much deeper. But the main thing we're talking about, the physics, fluid dynamics doesn't change.

And so the laws that we're coming up with, the interactions are still valid.

In addition to that, I think most of us understand that what takes place between the surface and the ground water system itself governs when and where the contaminant is going to hit the water table.

So it's very important to understand what's taking place at vadose zone.

Now, throughout this, this slide is essentially here to kind of get you thinking along the lines of a modeler. And I think most of us understand, as we just heard from Dr. Albright, that we need to understand the system. Very critical that we understand the system.

But here there's -- I think there's an inner process here. And these things all interact.

Here is the concept that we're talking about, it's a modeling concept. They use models to help you understand where you're actually going to put your instrumentation.

And they use that to test and make some observations. And they test your concept, which then helps you understand, especially if there's abnormalities, a better understanding of what the system looks like. And then you redevelop your concept.

In this cycle, you have to repeat it a couple of times before you can actually understand your system.

Now, before we start actually talking about monitoring, I wanted to briefly go over the three basic types of monitoring processes that are used in literature.

Outflow breakthrough curves, instructor sampling and monitoring of the pore solution. This is a typical break throughout curve, where you have concentration of some tracer or contaminant as a function of time. Depending upon the methodology you use, you can actually have these methods for measuring fluxes. I prefer fluxes, if at all possible, because then you have the mass-per-unit / air-per-unit time or flux density and that actually allows us to get the relevance of the compound.

But sometimes, because the way the instrumentation is set up, you really don't have that ability.

But these outflow of breakthrough curves were initially developed by people working with columns, which were - then extends our philosophy to the field.

And there are, in the last or nine years, there have been field methods which allow you to evaluate fluxes. And we can talk about that at this meeting, if you're interested.

We don't have enough time for that right now.

The nice thing about these outflow breakthrough curves is they essentially average the transport mechanisms over area or volume. And as a consequence, they're probably the most reliable source of transport data.

The problem is, is that you usually get a curve. And if you have a lot of processes occurring -- for example, if you have different strata and they have different absorption capacities, then you've got -- the absorption rates are taking place in each of the strata, you could have degradation processes, this is plant uptake for the roots. All these things -- all these processes are going on simultaneous when you only have one curve. And so there's a lot of ambiguity that sometimes comes in to your discussion of those processes with only one curve, because that's a major drawback of the outflow process.

Destructive sampling was pretty similar. We'll talk about preferential flow a little bit. This is an example of where we have a piece of soil we put a dye on and the other we put 3 centimeters of water on. And you can see that we have this dye moving over a meter.

If you look very carefully, like down in here and over here, you can see it's actually past a meter in the area where we were actually digging up.

And what happens is if you were to just say, well, let me take a soil core-- transect our cores out and then average the dye concentration as a function of depth, you might get something like this, which makes it difficult to actually quantify what the transport processes actually are and how do you scale that process up?

As a consequence, people usually don't -- even though in the past we have, we no longer use concentration profiles from soil cores, destructive sampling, to help us evaluate the chemical transport times.

However, they are extremely helpful in eliminating ambiguity. For example, this particular screen, you can see that if you were to go back in this area (low audio) you can actually take samples out and actually notice that there's changes in density in that material. And that's one of the reasons why we weren't getting that information.

So, there's information you can get from destructive sampling which reduces ambiguity and so the other transport station might be actually working with.

The last major method is pore sampling. And this is, again, a typical cell profile or a biologically active region and some hydrologic horizons. Those horizons can be a wide range of things. They can be changes of texture, density, a number of things. But those horizons could affect transport.

For example, if you put a compound at the surface and then irrigate it or let rain move it, you might get something like this. This type of fingering is actually a rule of thumb, as far as these studies using dyes and other things, it showed that preferential flow is not an exception to the rule, it actually is a rule, especially when it comes to vertical transport.

So this kind of behavior is very common. Now, if you have some kind of apparatus where you're sucking up water at specific depths, specific screens and you're well-irrigated looking at certain concentrations, you see -- if you happen to be located in this area, your second sample would actually pick up a fair amount of dye or your tracer, but you wouldn't see anything with the others.

Well, you have the same problem with scaling this up as you do some of the other processes. And so when you actually look at all the processes, you can see they have some benefits; some are easy, some are very reliable, but they all also have problems.

And even though there’s been a myriad of papers written about each of these, our perspective is that you don't go with one process, but you actually use all three of them.

And this is what I think is a very critical part of the presentation. So if I put you to sleep, I want you to wake up now.

The whole idea is -- and remember, going back to that cycle that I initially talked about, you can use basic surveys to help us understand the kind of porous media we're dealing with.

You might even get some topographic -- some topographic information. Essentially, just get an idea from the surveys what kind of material you're working with. And then, from that, you then decide what type of geophysical instrumentation that you need, whether it be EM-38, GPR, resistivity or whatever other methods you want to help you understand nondestructive, what is going on inside the field.

Now, with that, you then bring in models, because you're going to use the models to help you understand where to sample, as well as to describe chemical transport.

So you come up with a model concept, which then allows you to take several cores where you get sand silt clay percentages, fractured media components, whatever you need to sample your site.

And they use pedo-transfer functions. Now, pedo-transfer functions are important because they allow you to take the various processes that you're measuring with your soil cores and actually develop soil-water retention curves or hydraulic characteristics, things like that.

Now, once you do that and because you know where your samples were taken, you can then distribute, spatially, those hydraulic parameters with depth and space.

Then what you do is you do some basic modeling. Again, going back to your first initial model concept, where you then do a Monte-Carlo simulation and get a range of transport values and velocities that might be of interest to you. And then you now run your transport experiment.

So you haven't done it until now. So you run your transport experiment and then you invite transport times. When you do that, if you’re like most of us, you'll find that there's abnormalities in your data.

So you used that analysis, saying, well, what do I need to do? You know, are there certain locations in the field that need to be sampled through any different type of geophysical tool to help me understand certain quadrants of the field I'm work working with.

So that goes back up to understanding the system again. So that cycle initially kind of repeats itself.

Now, that also may mean you have to change your model concept now. For example, initially you may have said there is no preferential flow and now you can say, well, maybe there is some preferential flow.

And that will determine, again, the kinds of tests that you need to run and the water you need to sample. And this continues until you finally do a decent job of describing the data.

Now, because you're talking about a system that's extremely complex in space and time, you're probably going to have to use model extraction processes.

Has that report been given a number yet? Okay, well, we've -- there's a couple -- I don't -- Yakov has got one.

>>SPEAKER: There are reports are on the NRC

public website, that talks about model extraction. (Low audio.)

>>MR. GISH: Okay. Well, it's the 2006 one that we have so we know about that. Anyway, so when we talk about model concepts, this kind of gives you an idea of what we're talking about here, as far as fluid dynamics are concerned. You can have the typical simple tipping bucket kind of paradigm for evaluating water content and chemical transport.

And soil physicists and geophysicists have been evaluating all sorts of models and they realize that if you really instrument a field really heavily and try to stick with one model, it's easy to do just a very good job, it measures some things not others. Like do a good job of measuring water content, but maybe not chemical transport times or vice versa. So there's been a lot of interaction on this.

And I'm not going to go through a lot of this, I cited Yakov work here of Pachespsky, 2006. And that's the title, Model Abstraction Techniques for Evaluating Soil-Water and Chemical Transport.

I would encourage you to actually look at that, it's a lot more detailed.

The nice thing about model extraction is, is that you can actually take a simple model, make it a little more complex. I can take a complex model and make it a little more simple. And the neat thing about it is you can keep the core processes that are critical and, yet, you can simplify it with the kinds of things you have to measure and the number of samples you have to take.

So there's a lot of cool things about using model extraction. So, what we're going to do now is actually show you a case study where we actually have done some of this.

Optimizing Production Inputs for Economic and Environmental Enhancement. And -- how much time do I have? Oh, okay, I'm making good time.

Anyway, what's kind of important about this site is that this area here (low audio) anyway, this area here is the main production area, it's about 21 hectares. It -- this is the top -- the high point of the field. Many of you have been there already.

And what happens, it all drains toward right here in the first order stream. And we have more data than you want to be shares with you right now. And we have over 80 scientists internationally that work on this site.

And these little yellow plus signs you see are soil moisture monitoring stations. Actually, we have more than that, but those little yellow markings right now actually make over 30 million soil moisture observations every year. So it's a very high density of instrumentation.

But we have a lot more than just -- (low audio) today. But we have, obviously, still have surveys and certain topography, we have over, I think, 50 mile -- 50 kilometers of ground penetrating radar data, EM-38, electrical resistance analysis and, of course, texture analysis. We've got, for the pedo-transfer functions we talked about before, runoff plumes to make sure we know if we can do a mass balance, as far as wrinkles in the surface.

New also have eight covariant systems. And I think Dr. Kustas is going to talk about that later on today. The nice thing about eight covariant systems is it does a complete energy balance.

So we know what's coming in and what's going out and we have some redundant systems with that, as well.

And then we have first the soil moisture data we talked about. Then we have wells for looking at chemical transport times, and we also have other wells for groundwater levels.

And then we have soil-water pressure head in (low audio) in the various locations. And we actually have about two more or three more slides of other ancillary data and instruments that out there, but this is the critical stuff that I think would be of interest to this group.

And what happens is, initially, again, we're trying to understand the systems, so one of the first tests we did to try to understand the system was develop a flux technique for measuring the vertical component transport to these wells-- our shallow groundwater system.

And what happened is -- and this shallow groundwater is caused by these clay lenses on the site.

And this block on your left-hand side, it's about 20 by 20 meters. The shaded area is about, roughly, 30 square meters. And we developed a technique where we can actually measure chemical transport times. And these are flux densities we're measuring.

And we did it three places. And you get the breakthrough curves on the right here; first, second, third replicates. And then -- and you can see that we had some high water distributions there.

And we also linked this up with the subsurface, understanding that the subsurface was having a tremendous impact on chemical transport times, as well as the seepage zones that might actually occur on the interface of the well itself is a possibility.

So what we did is we went back and took some more ground penetrating radar. In case you haven't seen that, I thought I'd put that site in there.

And what happens is, you can actually take the -- we've actually done enough GPR to actually look at the -- restricting the first restricting layer over the whole site and then using the geological programs to understand where the drainage would be.

Now, this is kind of important, because later on I'm going show you some transport data and the site we're actually looking at is right in this area here, and you're seeing -- very close to this major flow pathway right here.

And you’re gonna notice-- I'm going to show you some data and you're going to see that the tranport times there are much different than they are everywhere else. And that's kind of important.

Now, this little network, if you will, of flow pathways isn't linear either. It looks more like this. This is just a schematic, so it's not exactly like this, but we have these cascading pools of water.

This is a natural forming system. The nice thing about this, all the information we're gaining here can also help you if you're developing the site, what you have to do to know how to monitor.

And now, in this particular case, when the water is flowing, of course, you fill up these pools with water and it slowly cascades down.

And then, as the flow stops or ET occurs and takes it away, you still have these pools. Well, the nice thing about that is you can sample -- if you where these pools are, you can sample those pools and actually use that information. Because, sometimes, preferential flow comes very quickly and these pools essentially capture it because convergence and flow is taking place.

And so, even though it adds some difficulty, it also could be a benefit. And I tend to like to look at the good side of things.

And so we can use that information to help us understand where to sample and how to sample.

Well, we know the next test we did, again, making this iteration, was to actually say, well, we're going to look at the lateral transport.

And so the vertical components kind have been amplified a lot, because it's only about 2 meters and this cube is about 25 meters by 25 meters.

But you kind of get the idea. Then we apply compound and pressure at a given area. And then we have a log of wells down the -- that we looked at concentration profiles.

This is kind of what it looks like, just to give you an idea. It's nice to show a real picture of a field.

We have runoff flows and runoff clusters to make sure nothing goes off-site to contaminant the wells a little further down. I'm going to show you a small part of the field, because I don't have a wide-angle lens on this camera.

And so you can see the facility tensiometers, but we have a lot of moisture capacity problems, MCPs and groundwater wells, which we have actually a sample at certain depths.

In this case, we were interested in what was taking place shallow, because we were irrigating twice a day in this little block and we wanted to see how that plume would move down gradient and we wanted to see what the concentrate was in that plume. So we were actually at three-foot depths.

Now, we talked a little bit about transport models, but the modeling aspect is like the monitoring aspect, in that it's an evolutionary thing that you first have a concept that helps you understand what the system is, basically, and as you get more information, it becomes more complex. It helps you parameterize it. And there are samples past and present, eventually forecasting chemical transport.

Here's one of them -- some of breakthrough curves that initially took place. Here we're using a 3-D no preferential transport model. We thought we would start off with that one to see how well that worked.

And you can see that in some of the wells, the first line of wells -- there are five of them, L5 through L9. And what happens is, you can see that the top three have to have an interesting breakthrough curve, it goes for a couple of months and then starts to peak out.

Unfortunately, even though working with a model and doing your curve fitting -- you have to do it manually, very time-consuming, the main thing to take out of this is you can describe the arrival time with a compound pretty well in those first three wells, but you can't describe the maximum concentration of the tailings.

So you've got a problem with the transport. Your model is not working here. In addition, you have eight and nine, where we're not really sure what's going on there, so there's been a lot of discussion on that.

To kind of focus more on the last one, here again is just five, seven and eight here. And you'll notice that on well 8, the concentrations are about where everybody else is, and it goes up very quickly and then it drops down dramatically.

Well, as it turns out, that every time it drops down, there's a big rain event. And what happens is, you have water converging in and it's diluting the samples, the concentration. And then it goes right back up again and it's more compound with moving into the system.

And so, what this is most likely -- this is occurring where those major flow pathways were on the aerial network I was showing your earlier, whereas that -- you have -- the system is dominated by preferential flow processes.

Now, so we've decided -- well, we were using chloride because it was cheap and easy to analyze.

So I thought, well, let's go back and get some acids, they're unique. A little more expensive, but you can do that.

And I just want to look at well 8, I have progressive data, but this is what's important here and you can see the breakthrough time for those wells, instead of occurring in three months, it actually occurs in a few days to a couple of weeks, to confirm that you have that preferential flow process that's dominating the lateral component in that particular location.

So, this is actually the last slide that I want to show. I have a couple of slides, a checklist of things that we want to be looking at, how these horizontal layers that are shrinking and cooling layers, actually influence some things you want to be checking on, but you can look on the site and check that out.

The main thing is that these horizontal restricting layers dominate chemical transport processes. And in this particular case, and we used model extraction, we can actually go back to a one-day transport model and actually do a much better job.

If we allow some preferential flow to take place, even though wells 5, 6 and 7 that you saw before, describe the peak concentrations in detail, you can now describe that.

So we know there's -- even in those areas which are dominated by matrix flow processes, there's still some preferential flows occurring there, whereas, in wells 8 and 9 and probably 12, there's a substantial amount of preferential flow that's taking place in those particular areas and you'll need a different approach to actually handle that, because actually there's no single model which allows you to have such a wide range in flow dynamics, between one being dominate by matrix and the other part dominated by preferential flow processes.

So, I'm not going to go through the checklist here, but I'll just leave that for you and say thank you and hold myself up for some questions.

>>SPEAKER: We are going to have questions at the end. You're part of the panel.

>>MR. GISH: Okay.

>>SPEAKER: (Low audio.)

>>MR. GISH: (Low audio)?

>>SPEAKER: 68.84.

>>MR. GISH: Okay, 60.84 is the NUREG that you want to look at for model extraction, okay.

>>SPEAKER: (Low audio) wait for questions.

>>SPEAKER: We have a ten-minute break.

Be back at (low audio).

>>SPEAKER: Let's get started.

Next on our list of presentations -- everybody sit down, we're going to -- as we know, we're starting early and going late, so we're going to try to stay on schedule, there's not too much room for stretching the schedule.

Our next presentation is John Gladden. He's going to talk about aerial remote sensing.

John received his bachelor's in marine biology from the University of Pennsylvania and a Ph.D. in biology from Emory University.

He's at Savannah River Laboratory and is currently manager of the environmental analysis section in the Savannah River National Lab, where he focuses on environmental and facility risk issues. He's the SRNL liaison to the DOE office of DND and facility engineering. He's currently managing a variety of projects for that office.

As soon as we get the radiation pointer going here, we'll start up.

>>SPEAKER: It's a sunspot. That's right,

it's a sunspot.

>>MR. GLADDEN: While we're waiting for that, what I'd like to do is introduce you to a little different perspective on how to do these closure caps and components.

We looked at these things from the bottom and we looked at them from the inside -- thank you -- and what I'd like to do is look at it from the perspective of the vegetation, and the kinds of things we can do with the vegetation and we will sort of develop that concept as we work through the paper.

Okay. And, basically, what I'm proposing is that we take another look at how we're approaching monitoring these systems.

And the way we're doing it now, this is an image of the complex at the Savannah River site. And there really are three components that have historically been major focal areas for how we're doing the monitoring for these types of systems.

The visual walk-down, which you send a technician down and he looks -- you know, does this look right? Does this look bad? Do we have erosion? Do we have vegetation dying? Do we got invasive species? Those sorts of things, which is heavily dependent on the rigor and training of the technician.

We have subsidence monitors. This particular system that you're looking at is somewhere between 50 and 100 acres and I think there may be two dozen subsidence monitors that go out and take topographic measurements of and basically survey these things in every year or so. That's the spotting measurement.

Perimeter wells are very standard kind of equipment for the disposal facilities. To my mind, that's the least satisfactory of some of the more current systems that are built have.

And probably in the last decade we have a lot of installed equipment, whether it in collection systems or you heard about a variety of different devices that have been installed in some of these caps, both production mode and experimental mode.

What I'll talk about -- I'm not going to say much more about caps and almost nothing about what goes on under the vegetation, except for these -- under the vegetation.

This is mostly going to be about plants, planes and spectrums. And so, to sort of get your mind wrapped around and not having to deal with tensiometers and lysimeters and those sorts of things.

And this is really the focus now of what is an alternative or a complement to the kinds of things that we're doing now, in terms of monitoring.

Closure caps: One contributor toward my thinking in this direction and starting to develop a research thrust was something we put together for Jody Waugh and Rich Bush about a decade ago.

And it was this map, it's the distribution of some of their sites which are scattered over a large section of countryside.

And I was envisioning what it took; how much money and, frankly, travel risk was involved with personnel going around to all of these different sites doing the monitoring of whatever frequency was required. And figure, probably, two to three days per site. I don't know what those guys charge, but at Savannah River, that's a pretty good chunk of money if you're doing it a couple of times a year.

So is there a better way to do this? Not necessarily the definitive analysis, definitive monitoring, whatever that might be, but thinking of it in terms -- and more in terms of screening tools. How do you routinely and effectively take the pulse of these sites without having to go in for the full MRI?

This sort of captures my fairly primitive view of what this problem is in these closure caps -- closure systems.

There will -- fundamentally, they are all about managing water. And this is sort of my simplified and idealized version of how this is supposed to work.

Precipitation falls on the cap, some of it runs off, some of it percolates down in the drainage layer and comes off. And all is right with the world, you've got your hazardous materials protected.

A fairly common occurrence, particularly in our neighborhood, where we're in a very humid environment, with hot summers, sometimes dry and sometimes intense rainfall, you do get erosion.

So you have everything else going on and you have some kind of disruption and the vegetation layer ends up with erosion cutting down into your other protective layers. It's not a desirable consequence, but you can live with it, because you can see it and you can repair it fairly easy.

Over here you have compromised barrier and you've got some water down into the waste form. Still something you can deal with. Not a desirable situation, but you can deal with it.

This is the one that we really have to avoid.

And in this day and time, this is just an unacceptable consequence, I think. It may be inevitable, but it's just an unacceptable consequence, because it doesn't protect the environment or the health of the system.

And what I'm proposing -- and this is my real heartburn with using the monitoring well approach -- is that the focus of our monitoring needs to be pulled back into the facility itself.

Once you have released contaminants from that facility, you got two problems. One is that you have contaminated the groundwater system. And secondly, I don't know how you guys -- how good you guys are with design and placing monitoring wells. There's got to be sort of a crap shoot to getting these things in a 3-dimensional space where you're going to intercept the plume if there's a leak. So I hand that one off to the more knowledgable groundwater people.

Vegetative layer serves several functions. It stabilizes the soil, it's sort of a traditional role in the ET caps, it's very important for removing water, pulling water out of the surface layer, the sponge layer.

Key component there, we know it changes over time, sometimes for the good and sometimes for the bad, but it does change. And that's one of the things that is predictable.

(Low audio) the question is whether the ecology of engineering is going to win. The ecology is going to win, it's just a matter of how long you're going to wait it out.

Can't penetrate into barriers, penetrate into the waste form. We see a number of examples where root systems have penetrated into places where they were absolutely were not supposed to go by design.

They will get into these cracks in the clay layer.

They're very aggressive, they're going to go after wherever the water is. You're going to find roots. So you have to keep that in mind.

So what do you do? We've approached this problem, reviewed this problem of root penetration as a liability, but, in fact, you can also treat it as an asset. It's something you can work to your benefit, because what those roots are doing is they are integrating what is going on in the some layer over space and time.

They are telling you what is going on in that soil layer. So if we just know how to read that signal, then we can use that as part of our monitoring tool, monitor suite.

We've seen this stuff, a number of things can happen, virtually all of which are bad when the vegetation layers compromise, so I don't really need to go through that.

We also have a lot of stuff. We have fox, we have coyotes. Our later source of challenge are armadillos and I wish you folks in Texas would take them back. They can dig through almost anything and they really make a mess on the road.

So, anyway, the remote sensing really focuses on the surface features. And the vegetation is basically your detector system going down through the soil mass.

What you're really looking at is what you can see on the surface is the response in vegetation to what is going on.

And the rest of this presentation will really talk about some of the capabilities we've been working on developing as we have moved ahead and fit some starts on this technology over probably the last decade.

The reason you and I have never run into each other is only funding money would come to me about every three year and do some more work on it.

Anyway, you can look at plant conditions. We demonstrated that. Certainly, whether it's healthy, unhealthy, alive, dead. We can look at the plant moisture which, obviously, is driven by what's going on at the rooting system. Is there moisture available in the root?

We can look at species composition on the cap. I've got a demonstration of that. We can look at the degree the (low audio) cover. Do you have the expected and desired amount of vegetation on yours closure cap? They're supposed to be there.

All of these are design elements. They're particularly critical for the work that Jody has been doing, where he has actually designed the species composition and how this is supposed the change as the cap matures and develops.

It's almost an objective design criteria for vegetation on the capping systems that he's working.

And then one of the parameters that Jody has indicated is of particular importance is the leaf area index, which is useful in developing measurements or could be useful for developing measurements of transpiration directly.

Very anxious to see what USDA is going to talk about, I believe, tomorrow, for some of the stuff that they are doing with the thermal imaging, because that may also be particularly valuable for looking at the transpiration rates.

Another simple cartoon, a couple of things that can happen, subsidence has got gotten a lot of attention, as has cracking in some of the impermeable layers.

What these two phenomena do is change the way water moves across the cap. And that is really the bottom line, either you're creating something of a sinkhole or you're creating a new path, a rapid transport path, through your barrier system, and the water and that upper soil layer is going to respond to that the distribution of the water.

Now, if you look down on one of these spots using a hyper-spectral sensor of some sort, whether it's a handheld or if you got a really, really good low flying airplane that has one of these things, you will probably see differences in color. And they may be sufficiently -- they may not be obvious to the naked eye, which is one of the problems with having technicians walk around on these caps, but if you look at them with the right detector, alternatively, may be visible to the naked eye.

You will see differences in color of the vegetation, depending on whether the site is particularly dry or particularly wet.

As I said, some of these things may be very subtle and may show up in non-visible portions of the spectrum or the may show the spectral ratios.

The point is that the condition of the

vegetation is going to change, depending on the water regime in which it is growing.

Old piece of data: This was shortly after the Monticello cap was constructed. And we were able to get access to some free satellite data, DOE satellite thermal imaging system, which also had some variable (low audio). And this is what it looked like. Pretty uniform looking structure.

And so we had this imagery and started processing it. So going from this visually uniform system to something that was processed using -- an image that was processed using a very standard vegetation index analysis. You see there is a lot (low audio) across this cap.

That was shortly after it was built and I'll show you some other data on that system later.

Same kind of thing at Savannah River. This is an image of the mixed waste management facility, hyperspectral image of the mixed waste management facility. And these two images as well as a portion of the HCAP for over one of the seepage basins.

And again, the key point is, these things look -- if you walk across them or have a natural color photograph, they look pretty uniform.

You don't see too much difference. You get out the hyperspectral imaging (low audio) you start looking at hyperspectral ratios, those kinds of things, and a lot of stuff pops out.

It was a very interesting story on how this particular image was developed. And if anybody is interested, I can tell you that story later. But, the point is, it's a lot of (low audio) in spite of the fact that it may look fairly uniform.

One of the things we were looking at and concerned about was water stress, water content of some of these systems. So we took some of this into the laboratory. And what you're looking at here is handheld data from a handheld hyperspectral imaging system with the wavelength on to bottom and a measure of reflect (low audio) on each of these wavelengths on the y-axis.

And what you're looking for in these types of analyses, is places where the spectral response is different. And it's very clear, as this experiment progressed over the period of over about three months, that we got some very striking differences in spectral responses, depending on which treatment you're looking at.

These two are very wet treatments. And you can see some of these things tracking the control. This one right here, as it goes through it sort of varies. But the point is, there are very special differences that you can take advantage of to do these analyses, and that's just for water.

Plant species and condition. This goes back to the Monticello cap in Utah.

These are data from a handheld spectroradiometer taken at about 2 meters elevation.

Again, we're looking at wavelength on the x-axis, spectral reflection on each of those wavelengths here.

And the only thing I want to demonstrate out of this is the fact that in this particular case, we can distinguish between live and dead Russian thistle at one of Jody's locations.

This is the sort of magenta and yellow distinction here. Over here, obviously, one of the things you might be interested is how much bare soil you got. The dark blue is the bare soil signature. We can see the dead wheat, we can see the sagebrush. Same spectrum over here as we see over here.

So you can get species differentiations using these sorts of data. Changes in species composition. We did an analysis in 2008, which is essentially a mirror image of an effort we did in 2002. And this is the results, looking at changes in species composition.

What we were doing there, literally, I (low audio) data last week.

And what you can see there, just a couple of highlights, is the sagebrush is in red and -- in both images. So you can see there's a significant increase in the abundance of sagebrush. Probably the biggest change that you see is the change in wheatgrass abundance, the green.

And then, over here there is not enough bare soil here to really come up and develop as a distinctive signature that you can map across this stuff.

Changes in leaf area, biomass over time, you can see that in this image. This came in last week. The important thing to notice here is the difference in the maximum value of the scaler.

We will be redoing this with a similar range of values.

Over here, in 2002, (low audio) a little over an order of magnitude change.

Is this stuff real? We've done a statistical analysis on measurements that were actually taken on the ground versus models we developed from the spectral imagery.

And we get very good squares, for those of you that do ecology or work with environmental data (low audio) our square .8. You can go to the bank with that one. Those are few and far between.

So this is simply looking at model versus actual measurements for leaf area index. In one case, just a straight up analysis. In another case, incorporating some of the species' specific data.

A lot of discussion on subsidence. This is another technology, LiDAR technology, topographic assessment.

And this is very common. This is an experimental facility at the Savannah River site. And it's partially tree covered so this lighter image system actually is an image process where we're able to remove the effects of the vegetation and actually detect these holes that we have made in the cap.

This particular data, I believe it was about 2-foot postings measurement every 2 feet across probably, 2-, 300 acres, with a vertical resolution of about 6 inches. And that technology is better today than when we did. This is readily available.

Why mature this: It gives you 100 % sampling. You can pick your (low audio). It detects phenomena that is not readily available, you can't really see with the human eye, because the human eye just doesn't see in some of these bands.

Ultimately, the acquisition process can largely be automated. I think this kind of stuff is available from USDA, and I'm sure you can pull stuff from DOD. They do these kind of things. The key is setting up the model.

Sensor maintenance and monitoring. Sensor maintenance is put off to another agency. I don't envision DOE ever developing this. And the cost of acquisition continues to decline.

So this has very great potential for the future as your first wave, your first wave of monitoring capability.

So what needs to be done? Some of this stuff -- I was looking back at this slide and pulling some stuff from old presentations. Some of these questions I posed to Craig Benson ten years ago in Baltimore, I think.

One of the key issues -- you know, the remote sensing stuff we can handle. We can develop these models for how to identify species and how to detect vegetation stress of one sort or another.

There are a couple of real key problems in here that can only be resolved by the engineering and soil scientists and those kind of folks in this room, is how big an event needs to be detected and over what time course?

Do I need to see something this size at the surface? Maybe I need to see something this size, or do I need to look at it every month? Do I need to look at it once a year? Is that adequate?

TC1:53:00

Those are the kinds of questions that you folks are the only ones that can really provide the answer.

The system can be designed to do that monitoring. The technology is out there. So, great potential. More development needed.

And then, right here, this gets to be a key. What are the criteria to regulatory acceptance of this technology as a component of the monitoring strategy? And that will involve, clearly, interaction with the regulatory agencies, a lot of interaction with the regulatory agencies and the public. What is the standard of proof that needs to be met before you actually deploy and rely on this technology?

A lot of folks help -- I've been in and out of this for a whole lot of years. The current effort we're doing is finishing up some work at Monticello and Monument Valley sites is being funded by the Office of Legacy Management. But a lot of other players, and I'd be happy to talk about this later with anyone.

My time is up.

>>SPEAKER: All right, very good.

>>SPEAKER: We have one more presentation in this session, which is about differential settlement and its importance on the performance of cover systems.

Bob Bachus, who I met this morning, pleasure to have him here, has worked at Geosyntec for about 20 years as a geotechnical, geoenvironmental engineer. His focus has been on landfill design, construction and performance monitoring.

He's worked on geotechnical analysis supporting the Fernald disposal facility. He has a bachelor's and master's from the University of Illinois in Chicago and a Ph.D. in geotechnical engineering from Stanford.

I was particularly interested in this one. Differential settlement is a big question, big unknown in cover systems. And this particular presentation is maybe a little bit outside the monitoring realm, but it's really important for us as to cover systems and we're pleased to have you here.

>>MR. BACHUS: I hope it's not too far out of the realm.

Bill and Craig, I appreciate the invitation. And this is a little bit -- may be a little bit different, as Bill said, that we haven't heard much today about differential settlement. Although John had indicated that at the Savannah River site that -- I think we'll kind of segue here a little bit.

I do want to acknowledge a couple of people that helped me, at least in terms of thinking of this-- J. Beech and Leslie Griffin, both with Fernald experience.

Just wanted to kind of put this in a bit of a framework. Remember here what the workshop is, this particular section on monitoring, monitoring and performance.

So we want to talk a little bit about instruments, talk about the concept of monitoring. And specifically here, the first time that I had heard this idea of differential settlement.

So what I want to do is very briefly talk a little bit about engineered cover system. Just about engineering these cover systems, very briefly, because there's just a couple of components that I want to have you focus on.

Talk probably about -- most about differential settlement, just what it is and, certainly, from what I heard today, put that a little bit in perspective from an engineering context. And then, a little bit about monitoring, what we can have, build a little bit on what John had said. And then, a small case history that I think you might find interesting from this idea of how covers or, you know, how a soil cap might perform.

The first thing I'll notice here is when you look at a cover on some of these facilities, whether this happens to be the Fernald cover, which is a low-level radioactive waste, but the first thing that you notice is -- as I said, I noticed it, is there was a heck of a lot of soil there, and it's thick.

And so that's significant from this component, this idea of differential settlement, is that we have -- it's going to provide a load because of the thickness, but there's a lot of soil there.

And these soils perform different functions. And I'll get to that in a second.

Craig probably mentioned some of this yesterday, I just wanted to -- just to summarize a little bit about the soil component, because if you're talking about differential settlement, you're talking about some type -- somehow you're losing mass somewhere. So when you lose that mass, if it's soil, what are some of the attributes of soils?

Well, remember, soil is performing in these caps several different functions. It could be hydraulic, it could be drainage, it could support vegetation.

So when you say soil, the soil wears different hats at different times. And there's some characteristics of soils that we heard about already today. They erode. Soils are particular.

Okay, they are generally relatively small particles, indiscreet particles and they will tend to erode with time.

As Craig and Bill found out in their investigative studies, when you put these in a cap, you expose them to the environment, inherently, they will crack. And these cracks will persist, as Bill had indicated. They heal, but they really haven't healed.

So what does that mean? Does that mean these preferential flow pads -- these preferential flow pads then lead to erosion. So, just kind of the mechanism of that.

So, what do we know about this mechanism that we'll call settlement or -- let's talk about settlement first.

And the first thing that we note, whether it's any type of subsurface material, waste, hazardous waste, municipal solid waste or soil, what do we know about the mechanism of settlement? And the first thing is that there's probably about four attributes or four components to that.

One is mechanical compression. You put load on something, when you put a load on, it deforms.

Okay, if it deforms -- if it deforms, does it deform uniformly, and what controls that deformation? That's point number one.

Point number two is a concept called raveling.

This is probably, as I'll allude to it a little bit later on, is probably the most important component that I'll talk about, at least from what I heard this morning, is raveling usually means that -- what happens is there's some mechanism that the soil that was there goes away. It gets eroded away, it gets displaced, but, basically, you start to create voids in the material.

So that's our second mechanism.

The third mechanism is one of physical, chemical, some type of a process closely coupled with the last mechanism, that we'll call biochemical or biological, where there is some time of degradation.

So, if there is degradation, either biologically driven, chemically driven, that will observe mass, that will result in mass loss, then, in fact, how does that get reflected up to the surface?

So those are the mechanisms, relatively simple mechanisms.

So what we're concerned with is that if we had a cap for your facility and we knew that the cap was going to subside 10 feet, and every square inch or centimeter SI units or -- it goes down uniformly, we don't care.

But it's the differential component that is the problem that can -- that can cause some of the problems.

So let's take a couple of really extreme examples, but I'm going to kind of temper them a little bit. This is what we'll call the worst case condition. This is what I'm worried about that John had said, you know, how big are we worried about?

Well, if you have a void that is created in the mass -- we won't talk about exactly why that occurs just yet -- but the concern is what's going to happen to that cap when you have that mechanism occurring there.

And so, the first thing we want to look at is now, for maybe the first time, let's look underneath the cap and see what's causing that.

And there are a lot of cases what we see is garbage. And in your case it could be encapsulated garbage or whatever. And the first reaction that a lot of people see with this, and when you look at this and you go, you know, how -- you can't predict this stuff.

You're not going to -- and the answer -- the data suggests that oh, contrary, this material actually has very predictable deformation properties.

And I'll show you some data on that a little bit later on. But you can see that when you ever put waste or any type of material in the ground and you mix it with soil, you're going to get some parts that are stiffer and some parts that are different from this.

So if you were to look at, say, an encapsulated -- something where you have differential degradation or raveling, where you end up with material that sometimes that material -- and this is what we in the landfill business will call the rusted refrigerator analysis. That, you know, there's your rusted refrigerator and now when that refrigerator or that component goes away, then there's your void. And that's the problem that will affect your cap.

We can also see this kind of run in reverse, where that may be a canister of some type, you know, it's surrounded by soil, the soil goes away and the canister stays.

So you can see that, basically, we're talking about some changes that occur. So what does that mean relative to you?

And if I were just thinking about this, and I talked to a couple of people at facilities, and it seems to me that from the DOE perspective, is that -- and the NRC perspective, that the issue is one of, are we talking about legacy sites or are we talking about new sites?

Because, first off, those we -- I would at least anticipate two completely different mechanisms. If you go out to some place like Savannah, where bill just showed, where you have an old trench fill or something like that, that, you know, you don't know what's down there, you might not want to know what's down there, you certainly don't want to dig it up. And that you don't know how the material was encapsulated and what those changes are.

That's one type of problem.

The other type of problem is what do we do going forward? And when we go forward, what do we do with that information, in terms of can we predict that, where we may have waste placement plans.

And I know in talking with Bill, one of the questions in terms of going forward is that, yeah, you know, we got these waste placement plans, but we don't really want do that. It's really complicated. But, in fact, if you could adopt a waste placement plan and you encapsulate these materials, you account for the mechanism, you will avoid problems in the future generations.

So, it seems to me that there's two fundamental conditions that you have.

The other aspects about -- said about differential settlement that I think, to recognize, is that when -- you remember that slide with the garbage and the waste is there and sometimes it's not there? In our mind -- and I'm going to just set the stage here a little bit, I don't think that differential settlement, short of raveling, I don't think the differential settlement is a huge issue at most of our facilities.

Raveling in grade creation is a big problem. Differential settlement by itself is not a major issue and I'll give you -- and I'll show you in the case history why I believe that.

And I think part of the reason that we see that is that, intuitively, we may look at this and we say, well, you know, if you take something that has a hard inclusion and a soft layer and you put a stress on there, then, all of a sudden, this is going to compress and this is going to stick out in the air.

And Mother Nature doesn't like that. Mother Nature doesn't do that. What Mother Nature is going to do is say, well, if that's softer, I'm not going to put as much load there. And so the stress is tremendously distributed, there's a very nonuniform stress field, but what it does is it tends to recalibrate the ground surface.

And so what we find when we see differential settlement problems for the -- now, if this is for building foundations or embankments or slopes, yeah, they can be a little bit of a problem. But this is typically what we see, small cracks.

Now, if this is a cap -- if this is a cap and they have water infiltrating that, that could be a problem. But, in fact, the problem with differential settlement in a cap is that it's going to exacerbate the cracks that Bill and Craig and others have seen in the materials themselves. So these now become even more preferential sources for water.

So let's look at these mechanisms now and let's put on our D -- our NRC or our DOE hat and look at those type of things.

Number one -- and I say "DOE" because of the low-level radioactive -- that we're use used to dealing with in the encapsulation.

Mechanical compression, very predictable, but probably not a tremendous problem, in the absence of water.

I think raveling is the biggest problem that we find and that physical, chemical and biological activity is probably -- and you can enlighten me -- I think that these are relatively small contributors, because one of the things that we notice even in solid waste, municipal solid waste, it has a high organic content that degrades much faster, even these degradation processes are slow, in that what it tends to do is take that differential stress model and it tends to even things out.

So when you can take a process and make it very slow, what it does is it tends to make things much more uniform. So that's just a physical observation there.

So if we look now at a cap -- and now, this is not one of those great big thick 12-foot caps, but let's just look at a couple of these ideas of the two driving mechanisms. And that was mechanical and the raveling component.

First thing we recognize is that these caps, remember, have different functions. Okay. So they're going to have hydraulic functions, they're going to have drainage functions.

So the question is here, where does the differential settlement come from? And it seems to be that where it comes from is, number one, the weight of this cap can cause settlement down in -- and mechanical compression, in the underlying foundation. Or, you can get raveling and if the water gets through the cap and you don't have a hydraulic barrier, then that material can come down here and that's where the problems occur, as John had indicated.

So, how do we measure these? We can measure mechanical compression, we can measure time-dependent compression. And we have these various tools, whether it be looking at it visually, by aerial, by LiDAR, by aerial survey, settlement plates. And I'll talk just a little bit about that those instrumentation.

We can build, as Craig has demonstrated, very large equipment to determine properties. We have a very good understanding of some of these properties, because we can make instruments to mon -- not necessarily to monitor, but to predict that behavior.

And the prediction and the settlement characteristics are very predictable. You put a load on and when you put a load on, you can start to see deformations.

So, what are some of the instruments in monitoring that we might do? Well, the first thing is, you'll notice that -- and we've heard a little bit today, this morning -- visual.

Visual has a lot of -- particularly if you're looking for the raveling phenomena, visual is probably a very good way, unless we can take some of these things that John had just talked about, and to get a signature from the spectrum to show these valleys over very large areas or depressions, it would be very encouraging.

Aerial surveys, again, it's going to be limited by the resolution. Being able to go 2-foot by 2-foot for 6 inches of vertical relief, if you can do that over a whole site, this would be a tremendous way to get an early indication.

Settlement plates: Very similar. Very simple. A lot of things monitoring things -- the problem with settlement plates or surface monitoring points is, again, and I just go back to John's talk, and remember he said that over a couple of hundred acres they have ten of these.

Well, you've got to put the settlement plate where you think you're going to have settlement or there's a problem.

So just recognize that. It's a good instrument, but -- we can bury these if we want to see what's happening with various agents. That's been done before. I'll show you a new slide of that.

A couple of newer, at least more mechanical techniques that might be interesting, at least certainly for research purposes. I'm going to show you an example of a hydraulic sensor, where you can get a settlement profile over a very large area, and what the results of that come up -- have come up with.

And also, relatively recently they have come up with some geotech styles that in fact are instrumented with fiber optics that in fact will be able to determine small vertical displacements.

So if you had an area -- and I'm not going to put on my geotextile manufacturing hat here because, you know, you've got 100 acres by-and-by product and you can put it over 100 acres and that will be your retirement plan, Bill.

But there are techniques now where we can use sensors that are buried into the cap that can determine vertical displacements.

I wanted to tie a lot of this together in a small case history demonstration.

It's not a cap, but it is kind of like a cap, because this happens to be a municipal solid waste landfill. There's 60 feet of old waste, so this kind of gets back to the legacy site underneath this. And what we wanted to do is put on another landfill on top of it.

The interesting thing about the cap at the old landfill was that the cap at the old landfill, which is what's shown in gray over here, here's the old waste, that cap is about 6-foot thick and it was dominantly soil and it had been there for a very long time.

The question was, well, if you load that soil up, are you going to now attribute this to a lot of differential settlement?

And, by calculation, we said no. How did you do it by calculation? Well, we assigned uniform properties, and when you assign uniform properties, you get uniform response.

Pat ourselves on the back.

The agency said that ain't good enough.

So we try and model it and we actually built a 10, a 20 and a 30-foot platform over -- Bill -- about 3.2 hectors, okay.

Okay, so, very good, this is a 10 and-a-half acre site that this was built on. And the interesting thing about this was because we were concerned about differential settlement -- and again, the key takeaway from here is it's 60-foot of -- for all intents and purposes -- uncontrolled old waste, a thick cap of soil and now we're loading it. We're loading it with 10, 20 and 30 feet.

In a modern cap, you may put on 10-foot of soil to provide that barrier.

So how did that old waste and that cap perform when it was subjected to load?

What we did was we basically buried a pipe, a plastic pipe, and we measured the settlement profile under loads, measuring settlement at one-foot intervals. Across here. It took a long time to monitor this.

It was basically a hydraulic -- a low-level pore pressure cell that you could pull along and you could measure the pressure at various points.

And we also supplemented this with settlement plates at the surface, as well as with depth.

And we could then monitor what the mechanical settlement was, what the time-dependent settlement was and, most importantly, what the differential settlement component was.

So we have an idea of the mechanical compression of the waste and the potential for differential. Did this with depth, various instruments, and we plotted this with time as the construction was going on.

So what we see at the top here is the loading history. And here is the settlement profile. And you look at that and you go, wow, that's differential settlement. This scares the bejeebers out of me.

But remember, look at the scale over here, this is in scales of feet. This is in scales of hundreds of feet.

And if you take that data, the same data, and look at it in realtime, what you see as looking like a Dow Jones average over here over a couple of weeks, basically says that making measurements every foot, 60-foot of uncontrolled material, this is behaving very uniformly and very predictable to the thickness of the waste, and the magnitude of the load.

So we don't have to work worry about the composition as much -- as much as how thick is it and how much are we loading it and if we can control that, short of raveling, short of raveling in the voids.

So I think the key here is that, from this component, that I think we're very confident in being able to do that.

So I think the implications that I see at some of your sites is that in the absence -- excluding raveling, because I think raveling is a completely different animal. We've got ways that we can -- that we know that voids occur and they don't come to the surface. We do this in karst or limestone drains, where we see sinkholes develop at the ground surface, but they don't come up to the top.

There's mechanisms for being able to that. But when they form, they're catastrophic and they're going to attract much more water. You know, do we have any early indicators of that.

And that the time-dependent settlements I think are going to be very small, relatively small, because that's what certainly we see when we have materials that are degrading, at least organic materials, slowly, that this is now slowly, over tens of years, and we see very uniform behavior.

And one final point. I talked with Bob Phaneuf a little bit about this this morning, and I'm glad that this came up yesterday. We've been talking a lot about hydraulics.

Here's another monitoring component, another monitoring constituent.

Let's look at why we put a cap on. And when we put a cap on, remember, we have waste and then we want to cap it. And this particular case happens to be a landfill, so I still have a gas load there. You might not have, you know, any organic material in there.

But, what we know is that when rainfall hits that cap, it's really a function of where are you in the stage? How much waste is there, how much of your cover is on, what type of cover is on.

And through a study that we were part of with Drexel University and the University of Illinois, with USEPA, where we looked at the performance of subtitle D landfills, that the behavior of the leachate collection system is very predictable and, in fact, you can see this trend, as you see up here, that the amount of leachate that you generate drops precipitously with time, at the various stages of the landfill.

So, if you were to look at leachate generation rates -- because we know from leachate generation rates that we can correlate in the municipal field -- and this also goes to hazardous and industrial waste, that we part of the study -- that we can correlate leachate generation rates with the age, the type of landfill.

And here you can see that -- you know, that can see at various points that in early stages of operation versus at post-closure conditions, how effective a cap might be.

And we've also seen this, this happens to be data from Barnwell, that this goes out for a long time after closure. And we see these same trends of decreasing leachate generation rate.

So if you had this information and you were monitoring this and you see spikes in your leachate generation rate, now that's where you start going out and looking for the raveling issues.

If -- so this would be another tool in your toolbox, an indirect way to be able to at least see the manifestation of that differential settlement component.

So, the recommendations -- at least now I'm going to put the engineering hat on. I didn't see a lot of data out there, you know, that was published. And it would be nice to see that on these facilities, as to what that would be.

So if there was any type of recommendation, is it seems like a lot of data that -- at least I was aware of and had access to, was kind of visual reports. But, you know, certainly, I'm learning something today relative to the data that may be out there.

Certainly, having that information available looking at leachate generation rates and being able to see, you know, if we can get early indications of the raveling and then make that information available.

So that would be, you know, kind of helpful, I think, if we wanted to understand the mechanism a little bit better at your facility.

Bill, I appreciate it. Thanks.

>>SPEAKER: Why don't we have a break before we start our panel discussion. So let's be back here, say, at five after 11. By my watch anyway.

>>MR. ALBRIGHT: Our panel for discussion of monitoring issues is going to include the presenters and two additional panel members, Brian Andraski, who you know already, and Bill Kustas, who is here. He has a presentation this afternoon. Bill got his BS from the State University of New York in environmental science in forestry, his Master's and Ph.D. from Cornel in

civil and environmental engineering.

Since 1986 he's been the research hydrologist with the USDA Agricultural Research Service Hydrology and Remote Sensing Lab. Their research focuses on application of remote sensing for quantifying water energy carbon fluxes at multiple spatial and temporal resolutions.

This is a real interesting topic to me. It's hard to quantify -- directly quantify rapid transpiration. So we're happy to have Bill here.

And since Brian and Bill have not presented in this session, they're going to spend a couple of minutes going over some of their research interests.

So, Brian, it's all yours.

>>MR. ANDRASKI: Thanks, Bill. Bill doesn't not know it, but I guess I've got 50 minutes or so to take.

I think it's two or three. So this is going to be fairly a short and sweet impromptu, if you will. But I just wanted to make people aware of a USGS research site that's been -- work has been ongoing at this site. The Amargosa Desert research site, now under the Toxic Substances Hydrology Program. The work under the toxics program began in 1997. But prior to that, the USGS had been doing work at Betty low-level waste facility.

And that work actually began in the mid to late 70's. So USGS has had a present in the vicinity of the Betty low-level waste site for a number of years.

But, basically, the Amargosa Desert research site, the focus -- we're doing a variety of different types of studies, but the main focus is trying to gain a better understanding of water, gas and contaminant transport processes in an arid environment.

And when I mention arid, it's pretty dry. We're only about 20 miles east of Death Valley National Park, precipitation averaging about 4 inches per year.

We have plenty of thick unsaturated zone to play with. Depth of the water is about 110 meters or 370 feet below land surface.

Some of the, again, the work that we're doing, aside from the initial work that USGS did, that was the only work that was done actually within the footprint of the Betty facility.

All of the other work, primarily since about early to mid-80's, were working adjacent to a facility which is presently -- the low-level waste site opened in 1962. It was the first commercial site in the United States, and it closed in 1992, after their 30-year lease had been completed.

There is a hazardous waste facility that's still in operation at the site. That opened, I believe, 1970, and those operations are continuing.

So, in terms of the basic studies that are done, we've done work on soil-water balance, water movement, under both undisturbed conditions, so kind of native soil, native vegetation.

We've also done work under disturbed conditions, where we created or used simulated test stretches to try and replicate to try and replicate or simulate operations that were occurring next door.

What are the effects? You have a natural environment and we had a handle on what's going on there, but what happens when you quote-unquote, muck up the system and change what Mother Nature started. So we've done work along those lines.

Also, contaminate studies, again, the primary focus is on low-level radioactive waste or mixed waste.

We've done a fair amount of work on -- looking at tritium. Also studied carbon-14. And recently we looked at elemental mercury, in terms of gas transport.

The mercury came up -- I guess I won't get into that story of how that came up, but it was sort of like somebody asked, well, have you looked for it? No, we haven't.

We did, and we found it. So sometimes when we're not looking for things, we discover it.

Actually, the tritium contamination is -- does extend some distance away from the footprint of the waste facility, and that was actually a surprise.

We had installed some deep boreholes to look at atmospheric pumping and barometric pressure effects on water and gas transport. And somebody decided to use tritium and carbon-14 as two tracers.

And when those first set of samples came back, the person that collected those samples, everybody asked "What did you do wrong?" Because we had high levels of tritium and also carbon-14.

And at that time, something we didn't know and something that we have been pursuing in our more recent research, is that we have -- our primary transport away from the low-level site is preferential or lateral transport, primarily vapor phase or gas phase transport of tritium, and that was supported by the mercury study that we've done.

And we're monitoring or seeing distances of transport up to 3 or 400 meters from the waste facility. And that was a surprise, because when we compared it with a standard model that one would use to look at tritium diffusion through the unsaturated zone, the models only predicted that it should go about 30 meters.

So we're seeing it about an order of magnitude further than that. And, unfortunately, I can't give you a reason why, that's part of our ongoing investigation at this point in time, in terms of that enhanced transport that we have for the tritium transport.

We also have done some methods development work. One thing I'll maybe mention as part of this panel is, we've developed a simple solar distillation method, where we sample plants and we solar distill it and put it in a Ziploc bag, set it in the sun for eight hours, take that water and use that to analyze for tritium.

And we've been successful at using that to map two or three different plumes within the vicinity of the waste disposal site.

But, with that, I'm going to leave it and just highlight, we do have a web page. If you do a search on Amargosa Desert research site, it has a complete bibliography that will describe the work that we've done and objectives. It also has a photo gallery. So I invite anybody that's interested to take a peek at that or, if there's other questions, feel free to contact me.

My e-mail address and contact information are included with that website.

>>SPEAKER: Brian, the website is at the top of the page there.

>>MR. ANDRASKI: Okay, yeah.

That's -- so, NEVADA.USGS.GOV/ADRS is the URL for that site.

Thanks, Bill.

>>MR. KUSTAS: I don't have any visuals to show out.

I'll be presenting some of the research in the afternoon that sort of gives an overview of some of the work that I've been doing on evapotranspiration.

Our lab does cover a wide range of wavelengths, all the way from the visible (inaudible) to the microwave. We have major programs in remote sensing of soil moisture, using passive microwave and radar technologies.

We have a -- we have a number of scientists working in the hyperspectral soils, so I was very interested in John's talk today about what he's trying do with hyperspectral data, looking at water content and vegetation, vegetation stress.

We also have a modeling component, some of which Tim discussed today, Tim Gish, in his talk.

That particular site is a site where we have multiple projects involving remote sensing and trying to look at variable applications of nitrogen and the impact on vegetation growth and trying to monitor that with remove sensing and hyperspectral type data.

We also have a modeling area involved in a soil-water assessment tool, which is called SVAT.

It's a modeling system that the Agriculture Research Service has been implementing throughout the U.S. It's being used as a tool to assess water quality impacts from agriculture. It can be used for a number of other applications. They're now developing an urban component to that.

Our focus is on developing the modeling tools and techniques that can incorporate remote sensing data because, as John mentioned, the spatial information is quite unique with remote sensing.

And when you can get it at different resolution, it provides a lot of information that we cannot obtain by any other means.

We have a strong emphasis on trying to use this type of data, either from aircraft, from satellite from the ground, to improve the predictability of our modeling tools, whether it's hydrologic modeling, water quality models.

We are also looking at the potential of use using it with some of Tim's work that he didn't mention in this particular talk, but on volatilization of herbicides.

We're finding that both climate and soil moisture and other properties on the surface has a major impact on the volatilization rate of herbicides applied for agricultural purposes.

So, I'm looking forward to providing you more information this afternoon.

Thanks.

>>MR. ALBRIGHT: Very good. Well, I think everybody has read the questions.

We have a room full data gatherers and modelers, we should be able to generate some discussion, if not a good argument, here about -- you know, one of the things I've noticed a lot in looking at cap design from municipal waste is it's quite common to see a cap design application where the soil properties were derived from a database. They determined that the soil was a whatever, sandy clay loam.

They got the hydraulic properties out of the database and they're representative of sandy clay loams, and they did their modeling. And have no use for modeling because they have great faith in their model's ability to predict performance.

So the question is -- and this is the DOE world, where performance is especially critical: Do we think we get from our monitoring exercises data that's sufficient to support our PA modeling?

Is that a loaded question? That should start an argument, don't you think?

What modelers think they have the right data from monitoring their sampling?

Come on, somebody's got to start things going here.

No takers. This is going to be a short panel session.

Guys, you better jump in and address your needs.

Yeah, go ahead, Kent.

>>MR. BOSTICK: My name is Kent Bostick, I'm with Pro2Serve.

I was one of the original UMTRA modelers. And how I addressed the problem of looking at flow through UMTRA covers, originally there was a model that predicted -- the DOE had a model that predicted saturated flow through UMTRA covers in desert regions.

These were monolithic type covers, and since there was no natural analog for that, I said that can't possibly happen, but they said the model predicts it. And so I had a big fight with the modelers and with other modelers, and we went out and instrumented the Shiprock pile.

And we did it with section lysimeters and we had a weather station and we also took a variety of core samples, both in the cover and in the tailings, so that we can document the performance of this cover.

And the idea was to make an argument to DOE that these covers would behave as barriers under unsaturated flow, that they wouldn't saturate with time.

And the biggest problem that I had was getting the upper boundary condition to the model.

In other words, what happens at the tailings cover interface, because, in UMTRA, we're worried about performance assessment, worried about the amount of water that comes through the cover, that goes into the tailings, that then comes out the bottom of the tailings, then is diluted by groundwater underflow. And then there's some geochemical properties that may also attenuate it.

But, ultimately, we're looking at what the concentrations are at the point of compliance.

And so, the basic argument started with the cover is, well, what is coming through cover? And, you know, the model the DOE had had a climatic simulator in it, but it was producing the wrong boundary conditions for the top of the model.

So what we did was we instrumented whatever was the top of our model, in this case it was the drainage layer above the radon barrier.

We instrumented into that and got the moisture content and suctioned that and used that as upper boundary conditions for our model. And then, based on that, we were able to look at moisture propagation through the tailings.

And so, I guess what I would like to see is more of a holistic approach to modeling, where people don't just look at what's happening at the bottom of the cover, you know, really what's coming out of the bottom of the cell and what's happening in groundwater is an issue.

And, you know, the lysimeters, if -- for instance, if you take what comes out of the bottom of the lysimeter, I guess it can give some validation to how a climatic simulator would be in a model.

But I think that there is some room for discussion there on how accurate those -- you know, all these parameters that you put into a model. Of course, we're still going to get into the models later on, but this section was mostly about monitoring, so I'm kind of agreeing with Bill that we should have monitoring in the cover to determine, for instance, what the processes are and whether we're missing some of them, that we're not just collecting the flux data at the bottom, but also to look at what the long-term performance is of the disposal cell altogether.

And I guess my plea is for instrumenting the waste also. For instance, for moisture content, so that we know what's happening in the waste and instrumenting below to waste horizon so we know what's coming out of the bottom.

>>SPEAKER: That's a good point.

My main point that I tried to make in my presentation is that the major performance -- the direct measurement performance from the lysimeter establishes the context in which all other information can be interpreted.

Kent, your question about monitoring below waste containment facilities is a good one. I would like Tim Gish to address that. Actually, monitoring the deep vadose zone, especially below the containment facility, that's a tough nut to crack.

It's hard to get there. It's almost necessarily a point measurement.

Tim, do you want to take that one on?

>>MR. GISH: Deep vadose zone monitoring? No.

I think one of the problems that we have is that a lot of the techniques are typically used TO measure concentrations. And that's where the problem comes into play.

And -- because as I tried to show in one example, where we had preferential flow of CREAM, and near well 8, there was a lot of mass going through there, but it's diluted. So if all you're looking at are concentrations. We really don't know what the flow through that regime is and so you're actually in a mass flux. And there aren't a lot of the methods for actually quantifying that. And that's one of my big concerns, is how to interpret that data.

Unfortunately, I think sometimes we get concentration data that is high and it may not mean very much.

It may not -- because, oh my goodness, we reached a certain threshold, this is really critical, and I'm really excited about it and I'm really concerned, but I'm not really quite sure we know what that means.

An analogy to that would be, most of what surface runoff is. And if you have a runoff event, but it's a very low flow, you can have very high concentrations of your constituents in that.

But you know it's not a big deal because the flux is low because you don't have all this water runoff. And so you may have much, much less than 1% of what you're applying and so it's just not an issue.

On the other hand, you could have -- if you had a really large rain event that took place and a lot of water coming off and you have low concentrations, the concentration by itself may not mean very much, but when you measure it with the water that's going through the system, that's a huge amount of compounding.

We have had 15 or 20 % of the compound going off. In which case, it's a big issue.

And so, that's one of the main reasons our lab and other labs have been trying to develop flux protocols to actually do that. I shared one with you that we developed back in 2004, which should give some kind of vertical profile.

We've never actually tried to put one of those below a barrier, though. But the problem is that would be expensive, too, by the way.

>>MR. ESH: Bill. Oh, go ahead.

>>MR. TAUXE: You're on stage and you can't see us out here.

John Tauxe with Neptune and Company. I got the mike from Tom Nicholson here, who is aware -- he sponsored a NUREG that I helped co-author about monitoring poor performance assessment and how to design a monitoring system that helps the performance assessment, which is sort of the question you're after, it seems to me.

I'll move a little closer. Is that better? Okay.

So this is regarding monitoring poor performance assessment.

And one of the major take-home points from that NUREG is that -- now, I'm a modeler, but I also enjoy doing field work and so I appreciate both sides of the issue.

But the modeling -- the modeling can inform what parts of the system may be most important. And, especially if you do probabilistic modeling, where you can get into sensitivity analysis, and this is something that I'll talk to on my talk this afternoon, it can help direct what parts of the system are the most significant.

And as Tim pointed out, a lot of the current monitoring is oriented towards concentration which, in and of itself, is not -- it's not the information you need, what you need is flux or something like that.

But I would argue that perhaps even that is not what we want, because if the system is performing as it's designed, meaning it's actually containing things, then, ideally, you will see no flux any way.

But, that sort of noninformation is not particularly helpful in determining whether the system is performing as you want it to, because it's just the end point of it all.

So one of the major points of that NUREG was that once you have identified what parts of your systems are most important, you should monitor things -- monitor physical processes or states that are -- that contribute to that most important process.

So, if it turns out that water infiltration is very important, then monitor water contents or water flows, if you can, in the cap or in the waste or various parts.

If it turns out that biotic activity is the most important, then monitor the biotic activity. Not necessarily -- you don't monitor it for concentrations, for the results of what it's doing, but you monitor -- for example, the biotic activity, if you decide, like we did at the Nevada test site, that ants are a major contributor towards transport of the waste.

And the most important factor is how deep the ants go, then, you want to monitor for that parameter that the model says is the most important parameter in your model, is how deep the ants go or how much material they're moving.

So you monitor those parameters that are identified as the most significant in your system, whether or not they are concentration or not.

That's the end result.

But what contributes to that end result is something else going on in the system. And what you want to do is monitor that something else that's going on in the system.

And I think that's a good use for models, assuming that the assumptions in your models are correct. The thing that bothers me on occasion is, how do you find the assumptions you haven't assumed?

That's hard to get those into a model, and it's -- so how do you monitor for (low audio) research is what you do when you don't know what you're doing.

>>SPEAKER: Well, if I could address that for just a moment.

I spent three years modeling. And the number one thing I learned from the three years of modeling was how little I knew about the stuff I was modeling.

The point being, and it almost goes back to your point, is one of the highest and best uses of the modeling work is you've got to have monitoring and research data to ping against that. And what you're looking for, to advance your knowledge, is where are the disconnects? Where does your model prediction not match the reality.

And that is -- that's how you start to learn what you don't understand. It tells you how to focus your research and monitoring initiatives.

And, frankly, we're stuck with modeling for predictive capabilities, but I don't believe anyone who is a practitioner and is taking this stuff to the public and regulators, as well as suffering through the technical scrutiny of their work, is going to say this model is perfect and every parameter in here reflects reality, as well as the structure of the model.

That's not going to happen.

So you need to look at the models in terms of this reflects our best knowledge and understanding, but our best knowledge and understanding is not necessarily complete.

>>MR. GISH: I would reflect also the comment that was made in the audience. I think a lot of times we can use models to help us get a basic

understanding of what's going on and where instruments tend to be placed and what processes need to be evaluated. And then, as you run tests, you can see these abnormalities you're talking about. And then you have to go back and re-evaluate your model concepts.

And that process helps you understand the system, okay. That's kind of the whole point of my talk, I think.

And so I think that there has to be this interaction in models. If we think that there is any model that exists that's going -- some Gestalt (phn) model, we're really wrong. We're really troubled.

People have always been trying to do that because things are very dynamic, spatially and temporally.

And then you have the scale issue, which no -- I haven't heard anybody bring up yet, but let's be honest here, you know, when all these things we're measuring, they have different scales of observation; some were at the four scale, some were at several meters, and some are hundreds of square meters. And they're trying to link up how those components link to describe a process.

And a lot of us in this room have tried to do a mass balance for something on the size of a waste disposal operation, and that's a real disaster.

Then you start saying, well, I did my point measurements and I think it represents this process.

And it really doesn't describe that process accurately. So it makes that large scale thing, whether it be recharged or whatever it happened to be very difficult to quantity because of the amount of variability.

So I think we have to keep on evaluating our models to see what's most effective. And the only way to do that is to understand the system. And so I think there's going to be several iterations, depending on how complex your system is, it may take more iterations.

Years ago -- 20 years ago, even in the soil physics community, we're a lot of people who believed in preferential flow dynamics, because it was very difficult to quantify and they would take the soil (low audio) and looking at concentrations and didn't see it.

And it wasn't until later that there were a lot of things that they now understand that preferential flow can be quite important. And the more research we get, then the more we evaluate models, we understand that, ah, it has impacts that I didn't really understand.

So, our understanding isn't perfect, the models aren't perfect and the monitoring strategies aren't perfect. And so, there's a lot of work still to be done. So --

>>MR. ALBRIGHT: Go ahead, Tim.

>>MR. GISH: No, that's it.

>>MR. ALBRIGHT: You know, we can all agree that monitoring and modeling should feed back to each other, but let's get direct.

What don't we have right now?

I mean, we have people that model, we have people that do a lot of monitoring, some that do both. Let's come up with some examples.

Jody, I know you have some. When we started the ACAP program, we were soil scientists and soil engineers, essentially, and we, you know, ignored largely, the plant processes -- the importance of not only the plants, but the plant processes and how they interacted with the soil. And we came very late in the game to realize that we should have collected a lot more data first about plant processes.

And we just missed the boat there on some things. Jody, I know you've got ideas of things you would like to see collected. Craig, you probably have a few. But let's be direct.

One of the reasons we're having this workshop is to come up with some ideas and get some direct suggestions.

>>MR. ROCK: You can call on him next, but I already have the microphone.

>>SPEAKER: Oh, sorry, is that Steve? I didn't see you there.

>>MR. ROCK: It is.

Hi, I'm Steve Rock from USEPA. And I find the conversation about monitoring and modeling always very interesting.

One of the things that I find often missing is a focus on the purpose of it, the purpose of the modeling purpose of the monitoring to feed into the modeling. If you're purpose is to convince a state regulator to approve your design, then, of course, you want the minimum monitoring possible to make the model look better, right? Because it's always much more convincing with fewer of those pesky points on it.

If your purpose, though, is to protect -- you know, protect an aquafer forever, you want to do a slightly different job, all right.

And what somebody's already mentioned, it's very expensive to drill underneath an existing waste site and put in a monitoring point, but it's hideously more expensive to clean up an aquafer after it's been contaminated. In fact, we can't, all right.

So I want to remind us that this is actually really serious stuff we're doing and that it is entirely possible to drill underneath any of the UMTRA sites and put in some century wells, if we wanted to. Even if we had the -- and the technological capabilities are right there.

I mean, we just saw, under a mile of gulf water, they drilled a hole and hit a 7-inch pipe.

That is awesome, all right. There isn't anything that we can't do to protect our water here.

There isn't anything we can't do to make sure that we build these systems so they actually work.

When the modeling gets into uncertainty at 500 years, that's because we're not -- well, we don't have enough information yet.

Data, of course, is not information. And information is not knowledge and knowledge doesn't get us to wisdom yet. And we can't predict -- we monitored ACAP for five years. Can you, with any certainty, tell me what's going to happen on any of those sites we monitored five years from now?

If you had a really good model, you might be able to convince somebody. I'm not sure you can convince yourself.

>>MR. GISH: That's Yakov's model, by the way.

>>MR. SEITZ: Okay, Roger Seitz from Savannah River National Lab.

And one of the concerns that I have from a PA, performance assessment implementation perspective, is I see the need to collect some of this new information and some of these new monitoring techniques, but how are we going to use that information in a very public environment?

And you need to make sure when you're collecting this information that you've talked to the stakeholders and they understand the purpose for collecting that information, because there's always this tendency, whenever something unexpected happens in a public environment, something's wrong and you'll spend a year or two trying to explain why it really isn't a problem, it's just a natural thing that happens when we're trying out these new techniques.

So you need to make a distinction between compliance and improved understanding. Make sure the stakeholders understand the purpose of what you're doing and the limitations.

>>MR. ALBRIGHT: That's a good point.

I see Craig is starting to fidget here in his chair a little bit. I better get him his microphone.

>>SPEAKER: (Low audio.)

I was thinking about you, Roger, as I was listening to this. And I was -- in the research environment we do experiments and collect data and we reflect on mechanisms all the time, that's kind of the research environment. But the practice environment is what mechanisms do we have in place and what procedures -- what procedures do we have in place so that we can evaluate whether the mechanisms in our model really represent reality.

And when we collect monitoring data, what data do we collect and what process do we have to allow us to kind of go back to the PA and say, well, that mechanism we need to refine.

I guess in the context of what you just said, I think that makes it even more complicated because it requires that you tell the stakeholder that we have a model that's imperfect, perhaps.

So do you have any -- could you elaborate on that, how we go about, in practice, essentially evolving our models based on the information that we gather.

>>MR. ALBRIGHT: Anybody else on the panel?

>>SPEAKER: Maybe I can put that off until the afternoon when I -- in my presentation I'm going to try and talk about that. But I think it fits very much with what Tim was saying.

In practice, I mention the performance assessment maintenance process.

So we go right -- we go from the very start within the DOE 435 system of we're doing the best we can with the information we have.

We want to have enough information and enough confidence in our model to make a decision that it appears that we can operate this facility safely.

At the same time, you recognize there's

uncertainty. And the maintenance process gives you the opportunity to identify those areas, commentors, peer reviewers may have identified comments. The maintenance process gives you that opportunity to go in and look at those things in more detail.

So it's an iterative approach, we've -- and that's built in to the regulation, the DOE regulation.

>>SPEAKER: How do the stakeholders react to the uncertainty? I mean --

>>SPEAKER: Well, I think we all know -- it's a very difficult problem.

We're dealing with things we're trying to do and guarantee quote-quote, provide reasonable assurance that it's going to be safe for thousands of years. So there is a lot of uncertainty.

And in my presentation I'll talk a little bit about don't just focus on the models, don't just focus on the monitoring.

There's many different activities that you can do. And actively involving the stakeholders so they understand the challenges that we face trying to defend these things but, more importantly, they understand all the different activities that we're doing at these sites to help ensure that what's being done is protected.

And there is a wide variety of things that are done.

>>MR. TAUXE: I'll try to make it short, because I know a lot of people want to say something.

But I just wanted to touch -- I'm going to dodge the stakeholder question, but I want to respond to Craig's question about how do we update models as data becomes more available and that sort of thing and also how this ties into uncertainty.

If you build a model that incorporates uncertainty parameters in it and then run it in a probabilistic sort of context, then do a sensitivity analysis about what is important that's contributing to different aspects -- end points in the model. Maybe you're interested in the concentration here, the flux here, or in the performance assessment world in dose, or what really should be more properly called risk, to future humans or environment, whatever, pick your favorite end point.

And you can determine what in the model is the most significant contributor, because in any model, no matter how complex, it will be just a handful of parameters that really matter.

There's just a handful of knobs that if you turn them it changes your particular result. Most of the other knobs, you can turn them all you want.

So don't waste your time on collecting data that doesn't matter to your risk. This is sort of -- the whole thing comes into the context of decision-making. When you tell them they have to make a decision about this site, like should we add more protection to it for the aquafer or whatever. Do we want to reduce future risk?

Then you determine an end point that makes sense. And this sort of comes in with EPA's data quality objectives. What is the question that you're trying to answer? What is the decision you're trying to make? What information do you need to make that decision in a defensible manner? And what's the quality of that information that you need?

So the model can help in that point.

Now, I make no claims that any of the models that I write actually have any predictive value. In the words of George Box, all models are wrong, some are useful.

Its utility is not in its predictive value. Utility is in its -- in its demonstration of the system and, yes, it does require that you have at least -- it's only good to the extent that you've captured the processes that are actually going on.

And you might be missing something and it's hard to avoid that. But if you can use the model to help determine what's important and what you need to go out and focus your resources on, get more data of a certain quality, then that's how you get that information.

And I think that we're all in the covers context here and maybe the cover doesn't matter at all. But -- in which case, you put your resources somewhere else. But this is the utility of the model, as far as I can see, and how it can direct where to go for monitoring and more data gathering, whatever you need, until you can make a comfortable decision, a defensibly decision about what it is you're trying to do.

>>SPEAKER: In a nutshell.

Bill asked the direct question, what would I like to be able to monitor primarily from an ecological standpoint or an ecophysiological standpoint?

You know, we're really good at measuring transpiration rate on a leaf scale or on a stem scale and we're finding ways to try to scale up to landscape scale. Whether it's an energy balance technique, we're actually trying to scale up based on some sort of cover data.

I guess what I'm really interested in is how we can scale up but to landscape scale but not lose the patchiness in the vegetation that may influence where water is being extracted and where you may have percolation.

But you could -- you might measure on a large area what transpiration is averaged over that large area, but I want to know in a spatial scale where -- how transpiration is occurring and use that to get a better understanding of where percolation might be occurring.

I think we have somebody this afternoon, Bill Kustas, who will probably address that.

>>SPEAKER: (Low audio.)

>>SPEAKER: In fact, he's on the panel now, good.

>>MR. KUSTAS: Now, are --

>>SPEAKER: (Inaudible) question.

>>MR. KUSTAS: I didn't put you in the crowd for that question, either.

No. But my talk will address some of that issue and how we might approach that problem, because it's a real problem in agriculture. A lot of what we're trying to quantify, in terms of improving irrigation efficiency and looking at within-field variability and yield variability we have to deal with these problems. And one way we're trying to do that is with remote sensing. It has to be at the appropriate spatial resolution.

So we grapple with that and we're trying to develop means to deal with that. And some of what I'll show touches upon that issue.

>>SPEAKER: One of the things that has attracted me to the remote sensing and the spatial analysis kind of paradigm is, once you're in the digital world and you have these imagery -- and this imagery and you've done the analysis, if you have figured -- if you develop models to flag your problem areas, whatever you're looking for, whether it is a piece of land that's too dried out, or the vegetation is showing stress, whatever it might be, or subsidence, with the digital imagery, you can actually identify those few pixels and put x/y coordinates on them.

So what that allows you to do, is whether you're out -- and naturally, there are -- one of these other Godforsaken places that the UMTRA guys have their caps, you can actually pin this down through GPS coordinates so you can go out and put an individual, a knowledge individual in the field to check out whatever that issue is, because there -- come back to this issue of we only know what we know.

And digital models, these imagery models that we develop are going to flag issues, but they're not necessarily going to tell you exactly what the issue is.

So you're looking for almost a tiered kind of monitoring approach going back to what's the question you're trying to answer. In the case of some of these water flux measurements.

The measurement -- the number or piece of information you're going to want at the point of exposure is different from the information that you're going to want at the containment structure itself.

Point of exposure, concentration is

important. And the containment structure itself, flux is what you really need to know about. So -- and a lot does come back to this specific question, whether it's a macroscale or whether you need to know what an individual plant is doing.

So it comes back to what is the question and making sure you have a clear definition of what that question is and what your options are for going after an answer.

>>MR. LEARY: Yeah, I would like to get back to what Roger -- oh, Kevin Leary, DOERL.

I would like to get back to what Roger had to say and that is with monitoring data, what do you do with it and how do you do with it.

I think the important things are what, where and why and what do you do with the data.

We had a struggle at Hanford with the state regulators trying to get regulatory authority over vadose zone monitoring data or vadose zone monitoring, period.

And it's been a real struggle because -- I mean, there's an obvious reason why EPA has never promulgated regulations for vadose zone monitoring. You know, what trigger levels do you establish, you know, what do you monitor for.

And so I think the key thing that we should use this monitoring data for is, is to make us, as caretakers of the land, figure out what kind of mitigative measures -- I would use the word "corrective action" but that has RCRA connotations. But what kind of mitigative measures do you want to take to fix the problem you're detecting with your monitoring system?

Does it mean thickening your cap? Does it mean designing a french drain around your landfill because you've got a run-on problem? Do you have deep-rooted plants? You know, a whole fleet of things.

And I think, as a minimum, as caretakers of the land, I think it's our responsibility to do the right thing and fixing the problem.

And I think that's the bottom line that we really need to focus on with monitoring data.

I think the other thing, too, is, you know, what is representative of monitoring.

I've heard many times from stakeholders, why don't you do a slanted hole underneath that landfill?

Well, how representative is that, you know, if you're doing a tension -- a suction lysimeter, how representative is that if you have maybe five or ten taking an area of maybe six or seven, you know, square inches when you've got an acre -- 45 or 80-acre landfill.

So those are the kind of things I think we really need to think about.

>>MR. BOSTICK: One of the reasons why vadose zone monitoring could be useful is that -- to prove that not that things are leaking, but that they aren't leaking. For example, like, you know, most UMTRA sites that I've looked at, you know, I think that after transient drainage, the flux beneath the tailings coming out of pile is going to be next to nothing.

So when people are saying oh, well, we have to change traditional UMTRA covers into ET covers or we have to recap all these sites, you know, a few experimental sites might -- might put that issue to rest, saying at these sites it doesn't matter, you know, nothing is coming out of the bottom of the pile, we don't need no change the covers.

And also, monitoring the tailings themselves, which show that virtually no water is moving through the tailings.

So, for instance, rather than go out and assume these cover are leaking and spend millions -- hundreds of million of dollars replacing them, that would put that issue to rest.

>>MR. HUBBELL: There is really -- this is Joel Hubbell. We've done a lot of deep vadose zone monitoring, seen a lot of it done around the country. However, the why -- there's not a lot of -- there's not an immense amount of data on deep vadose zone monitoring. Getting the instruments in there, getting them placed, trying to figure out what they mean when you get the information. We're really in the exploratory phase, I would

say, for a lot of these sites.

We go onto a site and often put some instruments in, we try to put in multiple types of instruments because it may be in the tensiometric range, it may be in the psychometric range.

And so you've got to figure out, you know, what's going to work beforehand, you've got to figure out a way to get it in there, figure out what -- is it really representative of what you want it to be telling you? And then, go a step beyond that, you know, Ron has been working in the shallow vadose zone forever, but, you know, these waste piles are typically deep vadose zone and we just don't have a lot of data anywhere.

That's one of the things that I think we need to pull together is together is all these disparate databases to try to figure out what is going on in these deeper vadose zones.

>>MR. ARLT: Let me just make one comment real quick here. It sounds as if you had -- it sounds like if vadose zone monitoring is important, it also sounds like it's difficult and this is an

area of maybe intensified research needed.

And that's one of the objectives of this workshop, so I would think that this is an area that we could, maybe at the end for session six, identify that this is something important, that we need to do more work in this area.

>>MR. ALBRIGHT: Yeah, that's a good point, Hans. Kent has only experience with the UMTRA sites and as he's already said a couple times in his workshop, he's really pretty convinced nothings coming out of the bottom of those tailings.

Well -- and it may be and it may not be. I don't really know. I haven't collected the data, but your point there -- Joel, and that is deep vadose zone monitoring is a difficult one, and Tim initially declined to address that issue. Then he got into it a little bit.

I mean, he could probably go on for days, if we let him, addressing that issue he didn't want to address. But that's, I think, an excellent area for deep -- for additional research.

We have, perhaps on the phone -- I don't know if there's anybody or how many people are participating with us.

So if there's questions or comments from outside the room, this would be a good time to bring any in.

>>MR. GISH: I'd like to add one more point to this deep vadose thing. We have a tremendous amount of data we collect on our site, but one of the problems that -- when you're trying to -- and you mentioned in your talk, too -- if you have this thermal flow process that occurs along some restricting layer, if there's cracks in it or faults, then it -- you lose it, it goes deeper.

And one of the problems with a lot of those deeper methods, we're trying to look at (inaudible) there's uncertainty into how continuous those restricting layers are.

And so, when you talk about the need, that's -- even though I don't work that area, that really deep stuff, the fact is, I know you need some new tools to actually evaluate that.

Because we're having trouble with that ourselves. If you GPR and you have 20 megahertz, you get good definition on the top 3 meters, but the fact is, even at that, if you take transections every two meters, you have continuous cover, but the fact is you're averaging over a certain area still, a meter or two wide, and the (inaudible) just average over that volume.

So if there's cracks in that, you don't see that. You don't see that. So water could be moving generally down that.

And so you think there's something going on there and you have to depend upon things like your soil moisture sensors and your profiles to say, ah, do I have plumes or did it all of a sudden disappear. Will I expect it to or did it all of a sudden disappear?

>>MR. ALBRIGHT: Yeah, and even in the shallow vadose zone -- Brian, I'll get to you in one second. Even the shallow vadose zone at our compacted clay cover in Georgia, we would see rain and drainage and the bottom sensors in the cover

might not see the water go by.

So that's an inherent limitation in the combination in between the current monitoring and modeling.

Modeling depends on the water actually reaching the matrix down deep to produce drainage.

>>SPEAKER: There's a number of times -- I can show you data where we have significant water flows, you know, one or two meters, and it didn't get to 50 or 80 meters.

It's very highly-spatially variable, things are not one dimensional, they're 3 dimensional. So there's all sorts of problems.

>>MR. ALBRIGHT: Brian?

>>MR. ANDRASKI: Well, I was just going to follow-up on the deep vadose zone, some of the work that we've done where we do -- we're highly under-sampled when it comes to using deep boreholes, because they're so expensive.

But we did discover or we've seen that we do have preferential contaminant transport through gravel layers, which we've substantiated by core samples from those boreholes.

But something that we found probably within the last few years was the USGS Geophysics Group out of Denver actually used D.C. Resistivity and they were able to -- our peak concentrations for tritium and other contaminants tend to run between 20 and 40 meters below land surface. And then D.C. Resistivity was actually able to map that layer.

They were unaware that this was a preferential flow path for us, but by combining the soil physics data with our contaminant data and the geophysics, it was something that we found was very useful for our site.

>>SPEAKER: And even when you have deep vadose zone information, you're still monitoring around waste piles. It's extremely difficult. It's a very abrasive environment, number one. It's also physically demanding because you're putting your sensors in and then you're trying to monitor them after they've been placed in the ground, and a lot of times there's damage and you don't end up

always getting the information that you suspect, you know, that you predict you will get some time in the future.

We've done monitoring, I guess, in the deep vadose zone for about 11 years now, down to about 30 or 40 meters. And one of the nice things about the deep vadose zone is that things stay relatively stable at those sort of depths.

So you can actually track over time, but the difficulty is really the sensitivity of the measurement. Water content seems to be almost useless at those depths, but water potential seems to be very valuable because you can actually track that over time.

But then you've also got difficult environments also, like in Texas, where you've got clays which is actually geologically fantastic, but we don't know much about clay.

>>MR. BOSTICK: Can I say something, as long as I got the microphone.

This is Kent, Kent with Pro2Serve.

People have brought up the idea that the

UMTRA covers are changing and the idea is okay, well, what does that mean for those of us that have maybe either replace the covers or deal with performance assessments in the future.

And the easy way of looking at that is what's happening in the tailings, okay. You don't have to go into the deep, deep vadose zone. And, for example, our moisture content is increasing in the tailings. That would be because you don't have to worry about fracture flow or cracks in the tailings because they're covered by radon barrier. And as you get deep within the tailings, there will be no dessication cracks.

The other thing is that, to some degree tailings, at least within a reasonable approximation, they're fairly -- you're not going to get the soil forming structures that you would if it caused preferential pathways such as in soil, because they've all gone through a mill.

So instrumenting these things and looking at the change in water content would just be able to tell, whether, does the change in the cover matter, in terms of performance.

And so, what I'm saying is that we can, you know, solve some of this doubt by just taking some core samples with time. And tailings aren't that toxic, you know, you can drill down in there. I mean, people walk on the tailings at Moab and, you know, they have a TLDB, so you're not at risk to drill through the tailings just to drill through to get periodic core samples and look at the moisture content.

And is it increasing? Is it decreasing? My bet is that it's decreasing with time, which would show that the covers are performing as they are performing. And that takes the whole guesswork out of, well, what does the degradation of an UMTRA cover mean?

>>MR. ALBRIGHT: I'm going to take that microphone away from Kent here. I think to sum up that, Hans, you're looking for research data. Kent's comments are good. And what he's really looking at is the performance of an entire system and, generally, he maintains that the tailings

doesn't change properties, doesn't change moisture content.

That's probably an area of investigation, to look at some of those tailings and to see if there is changes going on and to see if there isn't movement of water going on.

And that's a good point.

>>SPEAKER: Just to emphasize, this is supposed to be on a general engineer barrier covers. And not just for tailings in the UMTRA. But it is a point --

>>SPEAKER: It may be --

>>SPEAKER: -- with the information (inaudible) if this body believes that vadose zone monitoring is important and it is very difficult to interpret the information or make sense of the information. And I would just say that's an identified need and one of the objectives of the workshop. But that's up to all the people here to decide.

>>MR. ALBRIGHT: Yeah, I agree. I think, though, that the tailings themselves could be

regarded at least as an analog for cover performance.

>>MR. SETLOW: Well, actually, I wanted to make a short -- sorry, Loren Setlow, EPA in Washington.

I've been listening with an awful lot of satisfaction to the discussion that's been going on here, you know, with Kent's discussion and Steve Rock's point and certainly the panel members, Hans as well.

But, in the presentation that I made yesterday, I was talking about the review that we're undertaking currently for our UMTRCA-based standards. And when we go back and take a look at it, a lot of the monitoring that has been going on has been a result of -- certainly for the mill tailings facilities, because what we've been asking for in our regulations is help -- environmental protection standards is monitoring at a point of compliance for certain concentrations of various contaminants.

But, in reexamining what we're doing and what we've done in the past, and looking forward to what might be useful should we revise our regulations in the future, part of what we have to balance is what are we going to require industry to do through the requirements we provide to the NRC and the Department of Energy and its agreement states?

If you were to remake these regulations and requirements for what would be required of industry through NRC or DOE, what kind of monitoring data would be most useful to the long-term institutional control of these facilities to ensure that we don't have future excursions?

Would it be, in fact, the establishment early on, during the early operational phases or even preoperational phases for a company that's going to develop a conventional mill, to establish these deep wells under net -- the tailings impoundment, or would it be a requirement that they do certain -- establish certain kinds of monitoring equipment or these deeper wells during the closure phase.

So that when they do the post-closure monitoring, then they can establish, with some confidence, the performance of the system such that it can lead to DOE for the institutional control.

And so, I would look for recommendations or suggestions from this panel and, certainly, even from the workshop, as a possibility to say the things that should be investigated as potential for any reconsideration of these standards.

>>SPEAKER: I would argue very strong -- well, there are two situations. We've got one situation where we've already had releases. We've got contamination in the vadose zone, saturated zone, whatever. There's another situation where we are building these new facilities and we have or have recently built the new facility and we have confirmed that there is no existing contamination that we're dealing with.

I would go back to a point I tried to make in my presentation, and I think a point that Steve made, is the objective is to prevent a release.

The technological challenge is to figure out how to monitor the containment structure itself.

Rather than some sort of a perimeter well system.

And I believe the key to developing that system is understanding what the precursors are to a failure in a particular type of containment system. And what you're monitoring -- what you're looking for are the development of those precursors, having those things show up.

What that means, I don't know, that's out in engineering space. I think there may be some things we can do with the vegetation, which I was trying to point out. But at some point you got to get at the bottom of this thing, at the bottom of this containment structure, and have some sort of a monitoring scheme that will tell you when -- you know, ideally tell you before you're getting a release, because once you've had a release, you got exposure to the public, you got a contamination problem to clean up, which is going to be more expensive than dealing with a remediation in the containment structure itself.

>>SPEAKER: Bill?

>>SPEAKER: If that's the case, then I think we can maybe narrow this down.

I mean, from my understanding from covers, is that there are few barriers that you can rely on on all these different types of covers.

If you have the composite layers, the geomembrane, that seems so be very promising. If that's your main barrier, I would think you would want to try to monitor that as close as responsible.

If you have an ET type of cover and you're really interested in the vegetation and capacity of the soil and so you want to zoom in on that, monitor that. If you're relying on a silty loam, like the Hanford Prototype, then you're really interested in the soil and what happens that silty loam in the future.

If you have an UMTRCA site with clay cap, then you're really interested in that radon barrier or, like Kent was saying, the radon clay barrier with the tailings. And you would want to try to monitor that.

I think somehow, if you understand your cap and you understand a lot within the cap, then you can focus on that particular part. So then I think with maybe, you know, specific suggestions, how can you monitor a geomembrane.

Yesterday, I heard -- I forgot who said it -- somebody said with the geoelectrical survey. Say, for example, you had bad management and the tractor went over it and they -- you know, they caused a rip in the geomembrane, you know, to have certainty you can go back and -- I'm not quite sure what the geological survey does, if it's 99 % certain or whatever, but that sounds like the way to go. That sounds like, you know, a good way to monitor that. You're really relying on geomembranes for a hundred years.

Anyways, I would think some how you could narrow it down if you're really interested in a particular barrier.

>>MR. PHANEUF: Bob Phaneuf, New York state

DEC.

I think, John, you hit, I think, part of it right on the head, which is the containment system monitoring itself.

Largely, and the analogy that's here is that in 1988 we couldn't permit a municipal solid plant in the New York State, because nobody trusted liner systems, they were relatively new and so forth.

So we ended up putting in a requirement for a double-liner system, a better liner system being on the bottom. And in our humid climate in New York state, we didn't think realistically that we wouldn't collect anything, in fact, you would collect liquid there. Condensation, other things. even Yucca Mountain has drip shields for condensation, for God sakes. So, I mean, a very dry air.

So, there is liquid in these systems. So we basically then took a look at that from a -- more or less a water balance method, simply looking at, you know, the preceptive loading that you might be look at, the type of drainage that you're going to have in these things and what the upper liner system performance is.

And that's the whole premise of our monitoring system is to be proactive in monitoring that system and understanding increased and -- and knowing that it increases flow into that secondary system.

It's our witness zone and it's our monitoring zone.

I see a lot of energy and thought being given as to how we can monitor this, but the whole thing, and you said it right there, that the whole premise of this is to prevent a release.

If that's the case, double-liner systems, leak detection systems, monitoring that, I think, is part of that. Granted, you know, membranes -- Mr. Rowe indicated, you know, service life, 1,000 years.

It's not good enough for 10,000 or 50,000 years. But on the other side, I think that data can start to feed the systems, if we're in these arid conditions, what could we expect in that detection zone between them.

I think we would get 1,000-year service out of some of these liner systems also in those conditions.

So, I see a lot of this.

The other thing with respect to you asked, well, where would we put our monitoring wells around the system? Other databases are out there too, the electrical resistivity testing. That's where we come in after we replaced the drainage blanket material. I feel pretty confident that we can find most defects that happen. But after waste gets put on top of it, you can't go there.

However, they do have devices that you can plug in underneath the liner system that's on a grid basis, that can get you down to a pretty decent area of understanding in relation to liquid movement through the liner systems and, again, using electrical resistivity methods on that.

Those devices are there, we haven't employed them, but maybe this might be one of the instances where something like that would be helpful to prove some of these negatives that we've got good containment.

>>SPEAKER: I want to see, just real quick, a show of hands, how many people want to have a comment to make?

Craig, two, three. Okay, we got ten minutes.

Craig, go ahead.

>>MR. BENSON: Craig Benson. Bob, it's interesting, what you were thinking is what I was thinking. And Bob Bachus talked about this, too.

You've got this monitor -- built-in monitoring system and Kent wants to monitor what comes out the bottom of his tailings pile, well, that's what a double composite liner provides for you, a monitoring system, right?

And I was going to ask you, Brian, I mean, if you had a double composite barrier beneath your site, would you have seen the tritium that -- before it got into the environment?

Because I do think we have the technology to do this, actually. There's a lot of debate about whether that's what we want to do for low-level waste, but from the context of monitoring, it's hard to beat.

>>MR. ANDRASKI: I don't have a good answer for you. It was one of those where that -- and that's something I didn't mention, was the facility, the Betty facility has no liners, there were no liners required.

Based on what we're seeing. Again, we don't have -- we do deep vadose zone monitoring, but they're vertical boreholes adjacent, outside the footprint. We don't have any monitoring below.

So we don't even know for sure if there has been a liquid leak.

Everything -- primarily what we've seen, all of the monitoring that we're doing adjacent to the site is driven by gas or vapor phase transport.

So, therefore, in terms of a liquid, we got -- I'm not sure if there a liquid contaminant component.

>>SPEAKER: But could you monitor the gas phase in a double composite liner, just like you

would the liquid phase, but the gas phase is included in it?

>>MR. ANDRASKI: It's basically what the discussion -- it's not worth moving from perimeter wells, where you just keep moving and monitoring it. The closer you can monitor, the better off you're going to be, in terms of trying to get an early warning system. You can't get much earlier than being right in the cell or adjacent to the cell.

So that's a good point.

>>MR. ROBERTSON: Terry Robertson, Washington state.

I wanted to address Craig's question about stakeholder involvement after you get hits.

At U.S. Ecology we had angle borings put in and soil samples taken and we got some surprises down at 60 feet. We got plutonium and uranium that wasn't expected in our modeling.

Precautionary note. Make sure you take enough soil to do a reanalysis. And make sure you have a good chain of custody. We didn't have either of those.

Bottom line, we went back, recalibrated our model, did two different models, and one of the things that we found that we might have made a mistake on was we -- our model started at the day the cover was put on and we had open trenches for 50 years before that.

So, I think that's a lesson learned. But we did a second phase angle borings, didn't get any hits. And, to this day, this fact is brought up that the first time we got hits -- and I think what's real problematic is how many angle borings do you have to put in a site before you've proven a point?

>>MR. HOLTZ: Hi, I'm Bob Holtz (phn) from the University of Mississippi. And the comment that I have kind of goes back in the discussion a little bit. I had my hand up and wasn't noticed and I'm hard to not notice.

But, anyway, I wanted to address the issue of the use of monitoring data in predictive models. And one of the things that I haven't heard brought up today is the idea of data worth.

Eight, nine, ten years ago I published some work where I looked at how small measurement errors in the estimate -- in estimates of unsaturated hydraulic properties could propagate through geostatistical models and, ultimately, stochastic models for flow and transport.

And what we see is that -- is that measurement errors can lead to a spatial bias. And these can be trivial errors, things that, you know, you know, when we make measurements we like to think, well, if we're in a order of magnitude, we are doing good, right?

But, you know, we're talking errors of 5, 10, 15, 20 percent. When propagated through a geostatistical process and then ultimately used in stochastic models for flow and transport prediction, in those stochastic models you could end up with literally orders of magnitude error in your stochastic model predictions.

So one of the things that I haven't heard addressed here, and I haven't heard it addressed in very many places at all, is, you know, so we're going to take a bunch of data, we're going to use it in these models to help inform these models and then we're going to use those models to make a set of predictions.

What we need to do is figure out how uncertainty or error in those measurements can propagate through that entire system.

And what's important to recognize is that if you have measurement errors or inversion model errors, you're measuring these properties it is -- that these are not your standard kind of white noise error that people typically, you know, when they're considering measurement, they're -- people typically assume that they've got some white noise in there, mean to zero error with some variance.

And, gee, when they use it in their process everything is fine. But because all of these processes are non-linear, you can start out with something that's almost a white noise kind of error, but it will lead to bias.

And that's just a thought that I think we need to remember, you know, we can collect all this data, but it may not have a lot of value to us when it comes time to make predictions.

>>SPEAKER: I can almost feel the sensitivity analysis modeler to my left getting ready to answer that question, so I'm going to answer it for you, all right?

>>SPEAKER: (Low audio.)

>>MR. TAUXE: And this brings up another topic, I mean, it's a good point is, in your measurements in this case, how does that propagate through?

But, another very important aspect of that is distinguishing the natural variability in your system and from the uncertainty in measurements and that sort of thing.

And the -- and what you want to do is reduce your uncertainty part of it, the epistemic uncertainty. But the natural variability, you will never be able to reduce, but you want to get a good handle on and learn how to scale and do all that sort of stuff with it.

>>SPEAKER: One of my points is that you cannot characterize the natural variability used in measurements. All you can get is an idea of where things are higher and where things are lower, you're not going to be able to nail down the width of the distribution or the shape of the distribution.

You need other information to be able to inform that decision. So you may be able to get the spatial pattern, things over here are low, things over here are high, but what you can't do is put a mean to it, you don't really know what the shape of the distribution is itself.

And so, what you're going to have to do in order to use, say point data, or point measurements, is you're going to have to have information that integrates at a larger scale because that enables you to start to, through calibration kinds of processes or other kinds of processes, to be able to try and tie down the end points on that distribution and its general shape.But, you're not going to be able to do it with data alone.

>>SPEAKER: That's a good point, thanks.

>>MR. ESH: My comment was a few topics ago now, but it was related to something Craig asked with respect to monitoring and double containment design. And I think it was on the second bullet of the questions for the panel here.

But basically how long can you monitor for? So, you may be able to put in a double containment design that gives you a lot of information about leakage in your facility, if you're not going to be monitoring your facility forever, though -- I mean, it's -- I think this was the issue of the value of the information.

So I would hope that we can get to the point where we can make facilities that are going to perform in our life time, time scales with some degree of confidence.

But in our line of work we sometimes have to go much, much longer. So, is the optimum design a resistive design for the long term. Certainly for the short term, when we have high activity materials, I think it's a no-brainer that the resistive designs are the optimum designs for those problems.

But what I would argue is that people should think about what may be the optimum design for the long term, and it may not be the resistive design which you see the types of things you saw in your research.

Mother Nature does not want to let you keep a resistive design unless it's been engineered to be thermodynamically or thermodynamically geologically compatible, whatever sort of science or field you'd call that, but happy where you put it.

And I don't know whether these resistive systems are going to -- you're going to be able to maintain them to be happy where you've made them.

>>SPEAKER: Do we have any comments from the telephone audience? Good. We're at our time. Tom and Hans, do you have --

>>MR. NICHOLSON: Thank you very much, that was a fantastic discussion, started slowly, but

really developed well.

What we're going to do now is take lunch, but before we do that I need to announce a change to the agenda.

Our session this afternoon is going to be on modeling. I guess we'll have a discussion about monitoring during that.

The first talk will be by John Tauxe. The second talk will be by Roger Seitz, the third one by Craig Benson, the fourth by Anderson Ward, the fifth one by Terry McLendon, sitting in the back there, and the final talk will be by Bill Kustas and Martha Anderson.

For lunch, please go out the back, make sure you take all your laptops, anything valuable please take with you, go up the back steps and they'll lead you up to the cafeteria or the sandwich place. We're going to reconvene at 1:25.

Thank you.

>>MR. NICHOLSON: This afternoon, we're going to be talking about modeling, modeling performance and experiences in modeling.

The talk will start fairly soon. And we're going to take a break after our third talk and then we'll have two -- three additional talks, we'll have a break and then we'll have a panel discussion. And we'll ask the speakers and the panelists to sit up front after the second break.

I'd like to introduce my co-chair, his name is David Esh, he's a senior systems performance analyst in the Division of Waste Management and Environmental Protection of the Nuclear Regulatory Commission.

He has over 15 years experience in performance assessment of radioactive waste disposal.

David Esh has a Ph.D. in environmental engineering from Pennsylvania State University at University Park.

And he has a bachelor's degrees from Lebanon Valley College in Annville, PA. Is that correct, Dave?

>>MR. ESH: Yeah.

>>MR. NICHOLSON: Yeah. So, Dave, take it

from there.

>>MR. TAUXE: They lost my bio.

>>MR. ESH: We lost John's bio and he didn't trust me to ad lib, so he's going to do his own bio. Okay, well, people were throwing letters up so I added the letters.

>>MR. TAUXE: I worked with Neptune & Company, which is an environmental decision analysis support firm in Los Alamos, New Mexico and other places. And I've been with them about 12 years.

I have a -- I guess I'm a performance assessment modeler, among other things, that's my main bread and butter at Neptune. And been doing that since about 1994, when I started at Oak Ridge National Laboratory.

I have a bachelor's in earth science and then went to the dark side and got a master's and Ph.D. in civil engineering at an institution well represented here at the table, University of Texas at Austin.

Whatever is that at Texas, I don't know. My wife's an aggie, so I have to be careful. And we were all more or less in the School of Engineering there. And so, I don't know, that may be enough here.

But in the last several years I've been involved in developing probabilistic performance assessments, largely for DOE and other clients now. And have been promoting that and to some degree of success, I might say, which has been very nice.

But enough of that. I guess I'll just go ahead and get started.

So, this is -- okay, development of integrated probabilistic model of radiological fate and transport in a engineered cover. Sort of a long title and it's more about the development than about the model or about how to -- how to do development.

And actually, in performance assessments I've developed in the past, they haven't concentrated so much on complex covered physics codes. I haven't really dealt with a lot of complex covers before.

But in the one that I'm working on now we have a complex engineered cover that will -- that we'll be interested in for a very long time. And so, it's challenging our -- challenging my cover modeling ideas and introducing new ones. And this workshop is great for that and I hope to add a little something to it.

Now, as a performance assessment person, I am not an expert in any particular one of all the fields that have been discussed, though hydrogeology is my background. And as a -- someone involved in PA, you have to sort of be a jack of all trades and know enough about the different fields to get along, and then know who to go to when you need the detailed information.

So there's the outline and we'll dive in. So why do we do this? Why do we have covers on the landfills? And I think actually, something that nobody has really brought up is their aesthetic value.

Engineers, especially, like something that looks nice and neat and clean and that -- the public likes it, too. And that's an undervalued perhaps or at least unstated reason. And similar aesthetic values is keeping waste from blowing around. But we also want to keep people out and make it clear that that's not a place to be, though, apparently, that's had mixed success, from what I've heard earlier.

And, generally, we want to keep water out. Although they do keep water in sometimes, inadvertently. And keeping the wastes and the contamination in is the ultimate goal.

So do they do these things?

Well, traditionally, cover modeling -- it's grown out of the -- I guess, out of engineering disciplines and hydrologies specifically. Which is one shortcoming, really, in the long term, I think. And they've traditionally ignored uncertainty in the design and focused on the design rather than their long, long-term performance.

And it's -- discreet models of specific processes have often been employed, which is most of what we've been talking here. And I'm going to go through each of these.

This looks almost exactly like Craig's cartoon of a waste facility, the classic one. And the goal has always been containment. And that's usually been focusing on water, which is the, you know, the blue line there.

And this -- this talk -- the focus of this is on the cover. There's an awful lot to say about other things; the waste, the liner, the surrounding environment, the general, you know, part of the world you're in. And in the realm of performance assessment, aside from all that, there's the whole human activity business, the demographics, the receptors, the behaviors and all that sort of stuff that we're not getting into at all here, but often can be the most important part of a performance assessment.

So, this is how -- this is my little cartoon about all of what's going on in the cover. Even if it's a simple model layer, you've got a lot of processes going on inside it.

And this one here has, you know, different layers in it. And so, obviously, we think about water going in, sometimes there's water going out.

If it's excessively dry at the surface, sometimes you have water actually moving up, not down.

Water partitions, well, something we haven't talked about a lot is contaminant transport in these things. But, from a performance assessment aspect, contaminant transport is very important. Arguably, it's the main reason we do all this.

So there's partitioning into the soils, there's diffusion in the water phase, there's diffusion in the air phase, you know, people concerned about radon or mercury, tritium, iodine, all sorts of things.

Savannah River, they've even got tin on the list, which I always found surprising. There's air, water partitioning. And, let's see, we got -- so there's -- we've got plants going on, and there's uptake of contaminants and translocation inside the plant and then the plant dies and leaves things in different places.

We've got animal burrowing going on in the cover and that brings stuff up to the surface and it also brings things back down.

So there's a big churning activity going on on the part of the animals. Atmospheric exchanges. I haven't heard much about that at all so far, but there's suspension and deposition into the atmosphere.

And, of course, on top of all this there's radioactive decay and ingrowth, if you're dealing with radiological sites.

And on top of all of that is erosion of the whole pile and how that influences things. So all of these things and more are going on, I don't need this to be an exhaustive list, but it covers most of what I'm concerned about.

So where should we go with future covering? Well, future covered modeling, I'll hammer on this a lot. Integrating all the processes, I think is critical.

Depending on the time frame you're interested in, degradation and changes in the cover are important. There's been a lot of discussion about that. And the ranking of the significance of processes going on in your cover is something I touched on here before.

And we would like to advance cover monitoring design. And I would take the opportunity to advance my favorite design here, is finish the cover off at grade and you don't have to worry about erosion.

It doesn't work in all cases. Sometimes you're just too close to the water table and you have to be to build a big pile of things. But -- and the liners are not always desirable, though they are often prescribed.

Okay, I was asked to talk about modeling needs and approaches and different platforms and the questions for this session, so I will touch on some of those.

The -- there's lots of physical, chemical, biological processes going on that have to be accounted for. And there are going to be data needs and the uncertainty around those data, an assessment of our state of knowledge that gets reflected in the uncertainty that goes in.

And I think all models, nearly all models, could use a lot of improvement in usability and transparency. So -- for immigration of processes.

Well, I put most of these up before, in the bullet, you know, hydraulics, biological stuff. All these processes, how do we integrate them in and what -- and we were going to get into data needs here, so -- for the hydrology, for the water part, I think most people are quite -- in this room are quite familiar with this -- sorry, just after lunch.

There's the material, properties and textures and the force in functions, you know, the precipitation and all that and hydraulic conductivity, saturation, curves and things, and diffusion parameters -- don't forget diffusion -- and tortuosity and fun things, because we're in the unsaturated zone, which, of course, is notoriously difficult.

And you get into all sorts of non-linear difficult stuff and -- so the hydrology, although there's lots of attention to it, is still a big challenge.

For air transport, the kind of information you need is the hydrology because in an unsaturated system you've got the water in there and air makes up the difference in the porous space.

Maybe we've got barometric pumping, I heard somebody mention that. Air, water, partition, coefficient, Henry's Law things, with various radionuclides and if you've gotten -- if you're -- you have NAPL in there as well, then that's even more fun, you got three phases.

More on diffusivities for radon. There's radon emanation factors from the waste. We've often found those to be extremely significant in determining the amount of radon coming out of a site.

There's all the geochemistry stuff. Traditionally, people have used KDs and solubilities, unlimited stuff with that. But I think we really -- I think the case is very clear, in at least my experience, that we need much more geochemical models integrated and built in with what else we're doing.

Some of those models exist, there's FREAK and -- I forget some of the others, but there's geochemical work could be integrated better. And then what's really missing in an awful lot of this is the biotic transport. And people often focus on plants and animals as -- for ecological risk issues. What's the risk to the plants or to the animals or to people eating the plants and animals and all that.

And they kind of ignore the fact that the plants and animals are actually transport vectors themselves.

So -- we've integrated the biotic transport into our models. And what you need to do that is the density of the plants and their productivity and the depth and the shape of the root systems.

And something that's not on here is the

concentration ratios, the uptake factors for different species, uptake different.

Chemicals and different radionuclides at different rates and it becomes very complex, and there's really not much data to support most of that.

There is for some crops, but not for native plants, which is what we're really talking about when we get into long-term transport. And then there's the critters and burrowing animals can really move an awful lot of material.

And in the long run they will completely homogenize your cap and destroy all that lovely engineering that went into it.

So it's nice to know what the burrows are doing, where they're getting stuff from, how fast they're moving materials.

In terms of degradation, well, we've talked a lot about this, there's the biotubation and other stuff, hydraulic properties in the materials as they change.

So as you're modeling stuff your materials are changing, so the material properties are changing, so hydrology is going to be changing. And there's all this feedback between all those things. And in millennial time frames they're becoming more of a concern lately.

There's other extreme events that could happen that might be -- one might need to take into account. And then erosion, and I was just talking with Garry about data needs for that, or simple models for erosion. And I'll just let you read that. Most of that has been discussed already here too.

Radioactivity: Well, this is one thing where there's actually not a whole lot of uncertainty and half lives for particular decayed chains and things.

But it's a little more complicated than it seems because you need to pick your decay chains that you're going to model so you're not spending a lot of time modeling stuff that has short half lives in seconds and minutes.

But you still need to consider those in dose and contributions to dose.

So, then, getting into uncertainty. And that's often been very uncomfortable for modelers because everybody likes to feel very certain about what they're doing. But really we can't be if we're going to be intellectually honest.

And so, here's some of the topics I'm going to cover quickly on this. Well, why do we care about uncertainty? We know that our knowledge is incomplete.

And so the question is how do we work that into a model? And, as you can see at the bottom there's -- you know, you can generate one answer, and it's typically done. But when you look at a whole bunch of answers and incorporate the uncertainty, you can get quite a variety of results.

So here is an example of doing a deterministic versus a probabilistic assessment, and I have another one coming up too.

As a decision-maker, looking at the graph on the left you might at first say, well, clearly we're okay because the result is below the dash line. That's some regulatory line in the sand, right? But you really don't know what are the chances of your being wrong? You don't know the context.

And if you show the others stuff on the right then you get an idea of the context. And I won't go through the pros and cons, I think that will sort of be implicit as I go through it.

But the pro is you can make better informed decisions if you have some idea of the uncertainty around your problem.

And when it comes down to a particular parameter, porosity it's very simple out of that NUREG 69.48 that is about designing monitoring systems for performance assessment.

You might pick a value -- well, if you knew nothing about porosity except that it has to be between zero and one, you can pick this distribution here.

Well, we usually know something, and you look it up in any basic textbook it will tell you porosity is .3. You can start with that. Well, .3 still could be between zero and one.

So, you know, there's a triangular that he could start with. And as you go down you get more and more sophisticated. You can actually build your model with the triangular and see if it's important or not. If it is, you might go and get some data about porosity and then from that you can build a distribution and you could refine that distribution if it continues to be an important parameter.

Here is an example of a nice, safe-looking, deterministic result. But if you throw them all out -- oh, and this, so this result would be generated using mean values from all your input. But if you actually look at the full result, the mean value of all the results is above the line.

So there's a surprise for the decision-maker. He thought the deterministic thing was nice, but, in fact, was being misled because he was not paying attention to uncertainty.

Transparency, usability. I think in the

interest of time I will just leave it at the bottom. A model that no one uses is useless, so you really need to make models usable. It is nice if the public can get ahold of them, can actually use them.

Model approaches and platforms. You got to integrate, you got to integrate all the different processes. And -- well, I'll just step into this. That was one of my favorite slides I spent some time working on.

So you got all these processes going on and you get to convert them into mathematical models. So you take your processes, convert them into mathematical models, build them into the computer model.

Now, there are process models, like all the things we've been talking about, HELP and UNSAT-H, and these are little icons for process models.

You can take the results from a bunch of those and try to build them in to some kind of result that -- it's difficult to integrate what's going on if these things are all done in isolation.

So, my favorite approach is to use a system model.This is my little cartoon for that, that builds in the processes into it and they're all coupled together.

You can't always do that, sometimes we need to have information from a process model.

So here's an example. We run some process model and you generate a response surface or a transfer function or whatever you want to call it, you could look up numbers, given certain inputs, what's an output that comes from that and then integrate that into your system model.

That has been done with great success.Or you can have your system model call the process model, say at each time stem goes out and says tell me what the answer would be for this and you can get the answer back.

So you can link them up in all these different ways and sort of make a hybrid model with these other things.

I still prefer making models as simple as you can and building them into an integrated system model. But sometimes you have to have be able to do that.

Then modeling platforms. This is something else that we were asked to look into. Well, they're the process models that I talked about. The discretized, multi-dimensional. They might be finite-difference, finite-element, other types often called "numerical" modeling.

And I think we're familiar with those sorts of things. And ground water would be something like mod flow or -- and the system level models, which are sort of -- compartment models are sort of system level models. And that's clearly my preference.

They also may be numerical on innards because they're solving all these differential equations. Now, what would be the ideal modeling platform. This is another question we had. And I would like it to be a system model in its core, but could allow for a customized functionality.

So if I need to build in some -- a little bit of code on the side, I could do that and bring it in. And if it is something way too complicated that somebody else has already done, that's out there, then it would be nice to be able to call it and run it and bring that in.

It needs to enforce physical constraints, conservation of mass, conservation -- hey, what happened to five?

Conservation of mass, conservation of energy.Be aware -- dimensionally aware and it's nice if it can enforce units, this is good for QA and that sort of thing.

If you can incorporate documentation directly into the model, the text or figures, things like that, that's highly useful or even links to websites on the outside or a PDF.

Here's where I got this number, and it came from table 2 in this document, you hit the icon, there's the document, go look it up, great for QA. And great for building confidence in your model.

It's nice to be able to build user interfaces, simple data import and export, and all these nice features. Tracing of information flow in the model so you can look at something and see what influences that parameter and what that parameter influences, being able to take advantage of distributed computing using other computers to do the work as it puts things together, be fully probabilistic.

Some of you might recognize that so far this is actually a pretty good description of modeling platform called GoldSim.

I wasn't sure if I was supposed to mention it by name in the paper so I didn't, but -- there's more and there's some things that GoldSim doesn't do, it's not free, it's not open source.

It only runs under Windows, which burned me yesterday. And they're working on it being modular, but it's still not open source.

I would like to see it so that it could a community effort. In fact, the DOE effort could be focused more toward something like this than toward some monstrous process model like it is now.

And, of course, if it were universally accepted and computationally efficient that would all be great. But, we can dream, as I say. So, that's the end of that.

And I came in I under my time, which I didn't think I was going to.

>>MR. ESH: Okay. Roger didn't trust me either to ad lib his bio.

So we have next we have Roger Seitz from Savannah River National Lab. He's currently an advisory scientist there. He has over 25 years experience in performance assessment for disposal and clean up, including 15 years for the IEA.

He's is currently providing technical and policy support to DOE Environmental Management, IEA and multiple DOE sites. His background is in mathematics and hydrology with an emphasis on fate and transport modeling.

He has worked on PA-related research and applied projects for low-level waste, mixed low-level waste, high level waste and DND across the United States and in ten different countries.

Roger.

>>MR. SEITZ: Thank you, David. I wanted to let you know that I am in the modeling camp, but I can tell you that in 25 years of modeling you learn very quickly in reviews that you need data and they pay very close attention to the data.

So I don't want to understate how important the data is. One thing that -- I want to -- this is going a bit higher level presentation, trying to -- looking at some practical thoughts. I think we all realize there's a lot of uncertainties in this whole business of trying to predict performance of disposal facility.

And the big challenge in my mind is how do we manage those uncertainties?

And what I'm going to talk about in this presentation is how we can use modeling and monitoring to manage those uncertainties.

A few key points. When we're thinking about designing disposal facilities, there's, of course, a lot of technical considerations.

But don't forget, there's other

considerations as well. And the more you get stakeholders involved in the process -- you need to pay attention to their views.

Barriers, which barrier is important? What modeling approaches, how much detail should you use for different aspects of modeling, that's all going to be waste form, it's going to be site-specific, facility-specific at a given site. Because of that we need to have modeling -- flexible modeling approaches.

And when we're thinking about modeling, I like to emphasize that what we're trying to do is identify what's important in the system and really demonstrate a better understanding of how the system behaves.

So I look at it in terms of a learning process versus predicting. And we get often caught up in this idea that we're trying to predict these numbers, we're trying to predict exactly what's going to happen. When, in reality, probably the biggest value of the model is to try to help us understand what's important and use that information to build confidence that we're making a good decision.

Given the time frames that we have to worry about and all these uncertainties, modeling alone isn't the answer. Monitoring and modeling together are not the answer. There's many different things that we can use to help manage these uncertainties and build confidence that we are making the right decisions.

I wanted to touch on the concepts of design based and performance based facilities. And we look at a traditional -- on the left you have a more traditional disposal facility that's going to have your liner collection systems and it will have a standard cap on top.

And the conventional view there -- and it's evolved over time, but the conventional view is you design it as it's supposed to be designed, it's going to perform.

From long-term perspective, I'm kind of left with the thought, well, what happens when it fails?

And that part of it the question isn't always answered. You've seen this picture before. In the DOE system we try to look at it in a more of a performance based approach, although we do have a number of design based facilities as well.

In the performance based view you're trying to look at specific wastes, specific facility designs, take advantage of different mixes of barriers to arrive at the performance that you want. And I'd like to emphasize there's any number of different barriers you can think about.

There's covers, liners, waste forms, vaults and the natural system itself. I wanted to sum -- here's a few of the questions that were posed for the session and my next few slides are going to try to touch on these.

We have questions like when should numerical modeling of engineered barriers be performed? What are the criteria to determine the level of detail? I would add and where do we need that detail? Where should we be applying more detail? Over what time periods? How should ecological and climate changes be considered? I'm not going to talk too much about the codes aspect of it.

I'd like to put up a quote from Albert Einstein. "Everything should be made as simple as possible, but not simpler."

And generally, in the modeling world, the regulatory perspective we try to move towards the simple models. But the nice thing about this quote is, sure, we try to be simple where we can, but not too simple.

You've got to make sure that by being simple you're not missing something. And that's where all the research, all this backup information, the more detailed models build your -- the underpinning for the decisions that you're making. In answer to all these questions, there's one standard performance assessment answer, this is an inside joke, but it depends. How long do you model?

All these things depend on the specific system that you're looking at. Depends on the waste that's being disposed, the waste forms that you're using, the local climate, which pathway you're concerned about radon, are you concerned about leachate? What data are available? We can develop the greatest models in the world, but if you can't get the data to support it, how useful can it be.

And I would argue that it still can be useful, but in terms of making your regulatory argument, you get into problems if you can't defend what you have done. So a couple of things to focus on.

When we think of waste being disposed, waste forms. If we're looking at things like reactor vessels, tanks, you're going to have different considerations in terms of lifetimes than you would have if you're looking at containers that may fail and cause subsidence.

So that's just some examples of things that you can run into. Data availability, I think I already hit on that.

From the nontechnical perspective or pseudo technical perspective, I wanted to bring up a couple other things. So talking about closing massive canyon facilities on DOE sites.They actually did an assessment of how much material you would need to put a cover on that.

And the estimate for these facilities was roughly twice the amount of material that it took to build Hoover Dam. And if you're looking for a borrow pit to collect all this material, it would be about the size of a football field, three-quarters of a mile deep.

So material is a significant concern. We can design the greatest caps in the world -- we can design the greatest caps in the world, but you still have to have the materials to be able to build them. So optimization becomes an issue. Boy, this is a challenge. How well do I remember what -- the other picture that you can't see on there is of the low-level waste disposal fac -- one slide ahead.

Okay. Yeah, can I ask the chair for an additional pen?

>>SPEAKER: John gave you a couple of extra

minutes, so we'll let you have them.

>>MR. SEITZ: Okay. Yeah, just don't give me the red color.

>>SPEAKER: You're an engineer, you should be able to do the conversion from seconds to minutes. But John failed that test.

>>MR. SEITZ: I can't even see what's written on there. All I see is red, bad. Isn't technology wonderful?

Okay, another example, from a nontechnical perspective, I was doing some work at the low-level waste facility in the UK and the arrow there is pointing to the local residents. And that's -- a side note, one thing you'll find in some of the European facilities, they tend towards very elaborate barriers and designs, but a lot of that is related to the fact that people live right next to those facilities.

In this case, though, the interesting thought is what the people in that local community care about is, they didn't want to have a big mountain right next to their village after they close the facility.

So that's another case where when you're considering the barrier design, you've got to consider, okay, how do we optimize it so it's not going to create this big mountain that's in there looking out over the ocean?

Okay, more specifically, in terms of modeling needs and level of detail, I really like to emphasize the idea of a graded and iterative approach.

This is something that's proven to be efficient and effective for conducting these kinds of analyses. And when I say that, what we're talking about is starting simple, starting with the information you have graded. So we start with what we have, run through calculations, try and begin to get a feel for what's important, collect more information, this kind of feeds to Craig's question this morning.

We recognize that it's an evolving process. So we start simple, collect more information, go back redo the models, identify and continually focus in.

So what you're trying to do is focus your efforts on those things that really matter and don't spend a lot of time on things that don't matter for the overall solution.

Some key points in there, we're trying to identify important features. This is that learning aspect that I mentioned earlier. Available data. Availability of data. Defensibility of data. You got to keep that in mind all the way through.

Cost of collecting data. If you're choosing between where to do we apply our detail, that's another factor that you may need to consider.

And, in a grand sense, from the higher level perspective, don't lose sight of the forest through the trees.

I'll use an example here. We can get caught up in a lot of details on specific processes occurring that may affect the local infiltration rate and things, when at the end of day the real problem may be a fairly significant structural failure that will overwhelm any other consideration.

This -- actually in this case it's a -- it's kind of a bad thing to see, but it's a good thing from the perspective, we want to see these failures early, we want to see this kind of settling early before we put the final cover on.

One way to deal with these kinds of uncertainties in performance, at an arid -- semi-arid site like Idaho, you can look at a range of infiltration rate, it's a fairly broad range of infiltration rates and you think of it from the perspective there's any number of things that cause infiltration to increase.

So we'll look at this broad range. What we have here is a figure with results, even looking at very broad ranges of infiltration, we can show the results are well below the standard, that's a great answer to be able to get.

So in some cases you may be able to take a more broader view and look at the modeling that way. One thing I want to emphasis here, which follows on from John, what's shown on this figure is a combination of probabilistic results, the gray shading.

And two deterministic runs, one with a cover, one without any cover at all are built in within that range.

So we call this a hybrid modeling approach where we're using deterministic, more detailed simulations, looking at what-ifs, one-off sensitivities. But we're also trying to run a more simplified view in a fully probabilistic mode.

What we're trying to do is gain all the information that we can, we want to learn as much as we can about what's important.

In terms of level of detail, another approach to level of detail is what's been done at Savannah River. And I guess it's no coincidence that at a dry site you can be a little less descriptive of the processes. There's a little more room for error because there's less water.

At a wet site they needed to get into more detail, you needed to consider specific behavior of different layers in the cover, failure times of different layers in the cover.

And in this case, the cover design actually evolved because of concerns regarding clay layers, that we've heard about. And so now it's got an HDPE layer underlined by a GCL.

Where the real mechanistic failure modeling came in here is looking at that HDPE layer, looking at how it fails over time, it degrades, it's assumed to gain hole -- get holes in it eventually and that creates a pathway for tree roots, which then creates a pathway for the cover to eventually fail.

So that's an example of a more mechanistic view.

Time frames. This is a really -- this has been a topic of discussion for a long time frame.

And climate and ecological changes. I'll touch on those just a little bit in the next couple of slides.

One thing, when we start talking about time frames tens of thousands of years, hundreds of thousands of years from now, we really need to keep in mind what's going to be going on globally in the world over those time frames, as well.

And what I found -- a nice illustration of the ice sheet that was over northern parts of Washington State roughly 15,000 years ago.

So this kind of dramatic change, when we start talking about those time frames we're looking at these kinds of things happening. When this ice sheet failed the flood came through, you see the yellow -- I lost my cursor -- but that kind of yellow area down through the state boundaries there, it would have wiped out a good part of Portland.

So we're talking walls of water, very high walls of water. So these are the kind of things to keep in mind when we start looking at how much -- how meaningful are our calculations over these different time frames.

Hundred of years, we've got more information, we feel more comfortable with our predictions, when we get thousands of years, you are getting into more speculation, more uncertainties. Tens of thousands years we're really getting into extreme cases.

I really like that recommendation that the International Commission Group on radiation protection came up with. Where they talk about what we should be trying to do is quantitative analyses on the order of a thousand to ten thousand years, beyond, that qualitative.The problem with that is what is qualitative?

And that's where the discussion are going now, at least within our -- when we're thinking in terms of DOE, what do we mean by a qualitative calculation?

Two examples, in terms of time frames and how they influence modeling. In this case what I've done is overlaying some soils that -- in our areas just -- if you have soils, rubble, uncontainerized waste that's disposed of, the time frame you're concerned about for the cover is going to be short term.

You're going to be -- you need to deal with water right away. But if we look at a tank or something like that, some reinforced structure, a very robust container, the performance of the cover isn't going to be as critical over those early times.

So just kind of an illustration that different times, different emphasis.

Liners: If you have -- once again, if you have soils where you're deliberately spraying water on it to -- as part of your compaction process the liner is pretty important in that case because are you creating leachate, you're actively creating leachate.

If you have a reactor vessel, which is an extreme, but if you have a container that's very robust, the performance of the liner with respect to that waste form isn't going to be as critical as it would be for uncontainerized waste.

I tend to be in a camp that says a container can be a relatively good substitute for a liner. And some people could argue that it's better than a liner because a container can keep water off the waste, as well, during operation. There is arguments both ways.

We saw this study that's being done in Hanford with the barrier there. And I -- that's just some -- I don't do a lot with the ecological side, but I think this is a good example.

One way to deal with this kind of thing is over a -- when you're doing your modeling the first thing we tend to do, okay, let's look at a wide range of conditions. Does infil -- how important is infiltration for our specific problem?

This is an example of something that can be done to show you, well, what influence can a fire or can changes in ecology have on the problem. But for a specific problem, this kind of thing may not be important if it's not sensitive to infiltration.

If you do have some potential problems with infiltration this becomes more important. But from the Einstein viewpoint, what if we're not thinking of something, what if losing the vegetation changes some other aspect of the cover?

And I guess my -- it's a real problem because there's all these different processes and what I want to encourage here is, sure, you may have a site where you can show we don't think it's important know what happens here, but I think what we've heard over the past couple of days is vegetation can be an important part of many different impacts on cover designs.

So don't -- in that respect don't lose sight of the trees for the forest. It's the opposite view.

I'll have a couple slides on monitoring here.Just some thoughts. I worked on a report for the IAEA on the monitoring for low-level waste disposal facilities. And in addition to the general things that we typically think of in monitoring, there were two things that we intentionally introduced into that document, and this is going on ten years ago now.

During operation confirmation of as-built properties and materials.

Post closure confirming modeling assumptions. And this is getting into these ideas of performance monitoring, what alternatives can we look at addition to the monitoring concentrations at a compliance point.

So this is a concept that's been out there for a while and it's still maturing, how we actually do that.

So we need to think a little more broadly in terms of what we consider monitoring, especially when we're looking these types of robust facilities where we really don't expect to see releases for an extended period of time. And we're more interested in how the barriers are evolving over time.

First thing I like to emphasize is let's try link it to indicators that look convenient, based on what we've done in modeling.

And this is -- I can't give you specific examples here. But this is a real challenge for the people working on the detailed process models.

What kind of convenient indicators can we find that would be reliable indicators that's something is changing in your model.

NRC, when they're looking at DOE tank closures, in their monitoring role -- this is a step even further out, they're focusing on confirming as-built properties.

And the nice thing about that, in terms of monitoring is, it's objective information, it's measurable right now.

So in terms of building confidence in your assessment, these type of things really do help to build confidence.

I've talked about the performance assessment maintenance process yesterday, where we're going back in -- as we identify important things, as we get comments from peer reviewers, comments from the NRC, we go back in and do specific experiments, field studies, demonstrations, any number of different types of activities you can use to build confidence.

Now, I showed this one yesterday, it's just a sample that was taken out of a waste form, mostly for chemical property.

And the bottom one -- at one of our disposal facilities the corrosion of activated metals was one pathway of concern, a release mechanism of concern.

So what was done in that case is, they set up coupons of a number of different metals in multiple sets, at a given facility, and they've been retrieving them over the past, I guess, almost 12 years now.

And they've retrieved three or four sets of those coupons over that time. To get objective evidence, what kind of corrosion are we actually seeing.

Some specific monitoring considerations, if we're thinking about planning a monitoring program, I'd like to say let's use our performance assessment to prioritize what we're looking at.

That applies first to the compliance aspects, which radionuclides, which contaminates are we expecting to be an indicator of early migration.

But, also from the performance aspect, as I mentioned on previous slide, what types of processes, what kind of indicators can we find that would be a very robust thing to consider? This is the point I was trying to make this morning.

And it's really hard for -- we do a lot of monitoring, we have a lot of vadose zone monitoring at DOE sites. But the -- I don't know if I came across well, but what I'm trying to say is when we're thinking about all these new, unique monitoring approaches, research into new sensors, just be careful that -- it's a very public environment now, more so than it has been in my -- in the 25 years I've been involved.

Any time we're doing monitoring and reporting to the public, any little thing that's different than you might have expected is going to get a lot of attention.

And in the research world I've heard people talking about experiments that have been done, there's always little things that are going on.

You're seeing something that's not expected. I'm trying to -- it's something that I'm really work -- struggling with because what we need to do is find a way to separate this from compliance monitoring and get people out of this idea that it's a pass -- this type of monitoring is pass/fail.

When we're doing performance monitoring it's more a matter of -- we're trying to better improve our understanding, we're trying to do the right thing. We want to try and learn as much as we can about the system.

But it becomes real problematic if we're going to shoot ourselves in the foot any time there's something that's a little bit different. Another aspect of monitoring, and I think this came up earlier as well, the limitations associated with point values.

I remember the slide this morning of the cross-section of soil with the dye in it.

Depending on where you put your well you could have a completely different conclusion about the extent of migration.

So, how many wells is enough? I certainly don't think putting one monitoring port in is a good idea because if you get a hit, what does that mean? Is it an indicator of extensive problem or is it a localized problem where there may have been a feature that created a pathway for local migration.

Certainly, if you do get a hit it means you're going to probably be drilling some more. So maybe it's better to drill more to start with. So in term -- and this last bullet is just making the same point.

We're -- when we do performance monitoring put it in context we're trying to improve our understanding. And I really don't -- I think we need to be very careful that's it's not perceived as a pass/fail kind of situation. I think we're doing -- we're trying to do the right thing, but if it gets perceived as pass/fail, it's going to really be a problem.

A couple of examples I want to show. From a performance monitoring perspective this the Santra Lemance (phn) in France. And we talked about the settlement indicators, they have them there, there at Fernald.

For example -- okay, we've shown a deflection of 6 inches at two indicators, when you report that to the public.

What does this mean? Without doing a -- does that mean there's a major problem? Have you told them that we're expecting to see a certain amount of deflection up front or are they just getting information, saying uh-oh, it's sagging, we have a major problem.

Talk to the stakeholders up front, explain the purpose for what you're doing. This is why probabilistic analysis is great. Probabilistic analysis reflects things in terms of ranges. And that's exactly what you need to do if you're trying to compare monitoring results with modeling.

You've got to have those ranges of possible results in. Last slide, managing uncertainties, I'll just touch quickly on.

Internationally there's a concept called a safety case. And this is getting at the idea that we tend to focus on the performance assessment uncertainty analysis, but what the safety case does is it opens it up to all these other different things that we're doing to try and demonstrate that things are performing as expected.I like this quote. "The purpose of computing his insight not numbers."

We are really trying to learn how these systems behave in addition to the prediction. We have a radioactive waste management basis in the DOE system.

Stakeholder involvement in this is critical. The more we involve stakeholders in our DOE activities, the better it's become, they get a better appreciation for the challenges that we face. They also get a better appreciation for all the different things that are being done to try to do the right thing.

Okay, performance assessments and risk

assessments certainly can improve increased capabilities for more detailed modeling. I don't want to -- I do lean toward the simple models, they're easier to explain, but we do need the basis for those simple models.

When you think about level of detail for modeling, graded and integrative approach. Try to start simple, focus on the things that matter, don't waste a lot of time looking at things that don't matter.

Maintain perspective for the time frames that you're modeling. What's going on more globally in the plan? How are we going to report results to the public?

Talk to the public before you implement new monitoring approaches. Involve them, help them to understand what you're trying to learn using these new tools. And just the idea, we've got to have an integrated approach, not just models, not just monitoring, use a variety of different tools to manage the uncertainties.

Thank you.

>>MR. ESH: Next we have Craig Benson. He was introduced earlier, he said that I could ad lib this. I have the bio now.

>>MR. BENSON: I didn't say that.

>>MR. ESH: So that's what I'll do. He has a lot of initials after his name. He's a distinguished good engineer, apparently. He has some degrees from Texas A&M, the aggies.

>>MR. BENSON: You're really ad libbing now.

>>MR. ESH: I think the only thing on this bio that I didn't hear earlier is, maybe it was said that he's a member of the Management Board of DOE's Consortium for Risk Evaluation and Stakeholder Participation.

But as -- Craig has done some work for us, and it's been very good work and very much appreciated, so I think this fits him well, this part of our session.

As you'll notice, we're transitioning from performance assessment, higher level practical observation in-between, and then more detailed process modeling towards -- after the break.So that's where we are now. Okay, Craig.

>>MR. BENSON: And I'm a Longhorn. No aggies up here, all right. I think John and I went to school together, John Tauxe. I got to defend engineers a little bit, John.

You came up here and you said that you got, like a geology degree, and then you went into the dark side. But many of us said you finally saw the light.

And Dave was talking about engineers yesterday, and two minute timing intervals on the schedule, and he's the only with the stopwatch up here timing the speakers. I don't quite know what's going on.

I was a modeler when I was in graduate school, actually, we had a similar supervising professor in grad school. John and I did a lot of mathematics and a lot of modeling.

The more modeling I did, the less I wanted to see data because data always let me know whether -- what I was doing was correct.

And I think what we'll see today is that, at least from what I have to say, some things we do well and some things not so well. So one of the things that we're often involved with -- I'm going to talk about just modeling a part of this.

And I think Roger really talked really nicely about this bigger picture of modeling. And this just part of it, modeling that cover over the containment system. And I'm going to talk about some of our capabilities in that regard. And in the near term, I think that -- let me shed some lights on what we can do over the longer term.

When we talk about covers for waste containment, we often want to look at what -- how much drips out the bottom, with the intent of knowing what the boundary condition is that goes into the underlying waste, like Kent had talked about earlier today, understanding that.

And when we look at being able to model these systems, the one on the left was our earthen and synthetic combinations where we got deposit barriers and drainage layers.

Our ability to model those is really murky, I would say, right now, we're are not very good at that.I think we can probably -- I can tell you off the back of an envelope, as well as I could predict those flux rates from those right now.

Our capabilities are better for all earthen systems, because I think we understand the physics to those better, we're dealing with systems that are a little bit better behaved. And so most of my presentation will talk about earthen covers and not earthen covers combined with just synthetics. This slide has been up, I think, three or four times, but I think it's an instructive one. Bill showed it earlier. And this is what we're trying to predict.

This is essentially the hydrologic dynamics of a cover system. And it is dynamic. It's very seasonally, as we saw -- and I'm going to find the radiation bullet again over here. Hopefully, I don't like turn it off. There it is.

So these are kind of seasonal fluctuations, what we talked about earlier. Most of the hydraulic -- most of these systems are hydrologies driven seasonally, not a particular event, not on an annual basis, but on seasonal events.

And wet seasons tend to be more significant than dry seasons or wet winters tend to be more significant than drier winters, they tend to be seasonally based. They're very cyclic in nature. In a cyclic seasonal time series, we tend to get cyclic -- or periodic pulses of percolation at the bottom.

You see one here and then the next year we hardly have any. And then some more later on due to these kind of seasonal fluctuations. And what I question is whether we can capture this type of detail in our models and how much detail can we capture? You know, can we predict this?

This is what we measure, can we predict this, and I think that's the question, to what degree can we predict it with the type of information we have.

Well, I start off with a conceptual model, some of you may have seen this slide before, I use it a lot, because I think this is where we always start with thinking about what the basic processes are.We've got a reservoir for storing water, that's our soil profile. It may be one layer, it may be two, it may be multiple layers.

We've got some forcing functions of precipitation and the energy from the sun, and perhaps convection due to atmospheric air currents moving over the surface, and that's going to drive a series of fluxes at the surface boundary.

Precipitation applying on to the cover causing some infiltration in, but also evaporation and transpiration from these engineering plants that I put on here, Jody, these are engineering plants, all right. These little sticks of green stuff, all right. And ultimately, get some flux out the bottom, some percolation.

And what's that normally driven by, we take this conceptual model and then we put it into a numerical model that does these type of predictions over here.

It will predict water content as a function of depth and then we'll use other types of constitutive relationships relating pressure to water, conductivity to water content and predict the fluxes of interest from our basic conceptual model, put in that mathematical model that can make those predictions.

And this is the basic governing PDE. I saw -- I think it was Andy Ward's presentation, I think I was the only one that really liked it when and I liked it when you had those PDEs in one of your slides, you had like four -- a couple of PDEs, and I thought that was pretty cool. Most people, it puts them to sleep.

But this is at the core of most of these models is a numerical model. And numerical algorithm based on some partial differential equation that describes the physics and perhaps couples in the biology and the chemistry in certain cases.

This is largely a physio model, physical mathematical representation with a very simple biological component, the sink term for root water uptake on the right-hand side.

But we solve these equations, that's what we get to determine these fluxes, what's coming out the top in terms of evaporation and transpiration, what seeps out the bottom, what runs off.

You know, at the top barrier -- that's the basic idea. And of course like everything, the devil is in the details, how we actually implement this. And one of the things that you'll find, you can go on the internet now and -- when I first started working on this you would actually go to, like, the hydrology website at PNL and you could get one code in.

Now you can buy six of these codes, Windows based codes, on the web, you know, you download them today and start modeling, if you want to. But one of the things is they all do the different processes slightly differently.

For example, they handle atmospheric boundaries, which is kind of where everything starts, where the water moves into the cover, where it interacts with the precipitation and the other energy sources at the surface.

How we manage these flux boundaries, essentially, movement of water through, and then this transpiration of water back up from the root zone and back up to the atmosphere.

So these interactions occurring at the top tend to be very important, how we capture those boundaries can be important. The transpiration one, we talk a lot about plants, plants being important, plants being a driver for water removal, and what we find, if we look at most of our models -- and I'll talk about this as we go forward a little bit -- a relatively simple representation of the biological system in most of the cover models that we use today.

One of the reasons for that, they weren't developed by ecologists, they were developed by engineers and soil physicists to draw plants in with sticks and then -- sink terms.

But some of them are more sophisticated, they might have somewhat of a mechanistic approach for transpiration where we have some water -- soil resistance for water flow and then some resistance within the plant structure itself. And then some evaporation mechanisms off the leaves and into the atmosphere.

Most of our models aren't that sophisticated, they'll use a semi-empirical approach, which I'll show in a minute. Regardless of whether we use this kind of constitutive approach or mechanistic approach or semi-empirical one, again, the devil is in the details.

Parameterizing the models is where things get difficult, what he would put in as input. And I think in some of our vegetation models that -- from my perspective, and I've done a good bit of modeling is this area, this is one of the areas where our data that we have available is weak.

This is a semi-empirical approach as opposed to kind of simulating what goes on within that plant, that kind of mass transfer and the -- since the mechanisms control all the water sometimes we'll just use a very simple mechanist -- semi-empirical approach in lieu of the mechanisms.

What we'll have is plant limiting function and essentially just say depending on what the pressures are within the root zone, we'll take the maximum of potential transpiration and we'll just take some fraction of it and transpire it.

And we'll define that fraction of actual transpiration to potential transpiration of the maximum amount using this plant limiting function. That little box type function.

It doesn't work too bad, actually, but again the difficulty is getting in these different parameters and enter a biases point and a limiting point.

The limited point is probably a little easier for us to get at then the other two points, particularly this one gets a little ambiguous where there's limiting case is that kind of defines where we have plenty of water to transpire and where things get limited and we start to get reductions in transpiration.

Many of these semi-empirical models that you do is they'll just assume that the water is removed in, proportionally, the root density. So if I got more roots at a shallow depth, more water is removed at that depth.

Then at greater depths, then we'll use something like this root density function to describe that density of roots then to make an inference that we can use that to describe the relative distribution of transpiration throughout the root zone. It's very simple representation of plant water removal.

And in some cases, plants will do a lot more removal at depth and then less at the surface, depending on their particular essentially climate in which they live in the subsurface and their physiologies. So this is a fairly simple approach.

Models that you can find that will do these things, I mention there's a host of these. You can get all of these on the web right now, if you wanted to, you could get them anywhere from free for the UNSAT-H or LEACHM model up to about 6,000 bucks for SV flux or VADOSE/W, HYDRUS is probably somewhere in-between them.

And as I show on right, there's just some notes over here, they use different means of describing some of these interactions with the atmosphere, empirical, mechanistic and sometimes a mix of both. But you can find these models on the web.

And, actually, in practice, a lot of these models, you know, somebody will pick a model that they -- that they've invested in and use it over and over again, I think that's a reasonable practice.

But the questions are: How good is one model relative to another and are any of the predictions realistic?

Well, I think that latter question is a significant one, because one of the things that I find as I look and practice -- and I would use practice in a very broad sense that includes low-level waste, but also solid waste and circular type projects that -- you know, that one of the things that I find is that the model predictions tend to look very realistic.

And this is an example of one, I just plotted up here from output -- and I'm not exactly sure which model this is. Could have been any of them.

We'll give you some pretty realistic output. You can see here, this soil water storage group here in red. Yeah, it's got all the jigs and jags that you'd expect from a natural hydrologic process. It looks pretty real.

And then if it looks real, well, it must be right. Right? It looks pretty real. You know, then, these other fluxes look okay, you know that the ET is a little smoother than the precipitation process because we have a damper within the soil profile.

And it lags like you'd expect, right? We get a little lag, water kind of soaks in, and later on, a little later in the season we'll get more evaporation, transpiration, we'll get kind of sludge. We see episodic runoff events, like Andy talked about, where they're not smoothly varying, but tend to be more episodic, like we see here in purple.

And then these more smoothly varying percolation events that we see in a lot of our data, as well, they tend to be seasonal but they tend to have some smoothness to them. So it looks pretty real, but I think the key thing is that they're just model predictions.

And in the end, they're abstractions, they're not facts. And I find -- and more so in the solid waste industry, sometimes these things get taken as facts. If the model predicts this, then, therefore it is. And we need to be careful about that, because things that look real and are pretty sophisticated -- have pretty sophisticated -- Windows interfaces, aren't necessarily real.

Well, let's look a little bit about model accuracy. You know, what we want, in terms of model accuracy probably depends a lot on the setting. I think Roger's comments were very well put. It depends, right? That's a classic academic answer to everything, right? It depends give us $10 million and we'll tell you what the answer is ten years from now.

But it is true, it depends on the setting. And then you may have a certain level of uncertainty may be okay, in one case, and a much finer level of uncertainty may -- or acceptable level of uncertainty might be important in another case.

In a lot of the problems I worked with though, we're often interested in predicting percolation rates in this kind of 1 to 10 millimeter per year range as a design goal or acceptable goal. And this is a pretty small number, actually, it's a pretty small flux.

And the question is how well can we do that and how reliable it is. We really have pretty limited validation of our models and our ability to determine whether that level of prediction is valid for the models that we use.

And comparing them to field data is probably the best way to do that. You know, we really need to compare detailed observations to our model predictions to get a sense of how good we are.

One of the things I think is important, and I had this in my last bullet, is really model validation versus calibration.

And I think this is part of that loop that Roger was talking about, which I kind of inferred to this morning, which I think is important, because we always need to be thinking about and validating our models, and asking whether we got the mechanisms right, the procedures right.

And that's different from calibration. Calibration, we're often adjusting the parameters to get output that looks like what we observed in the field.

And we know, at least in my work, that we can calibrate something today and it won't predict well tomorrow or in ten years.

So our calibrations tend to be only for that point in time -- ten minutes, that's a fast stopwatch you got.

>>SPEAKER: (Low audio.)

>>SPEAKER: You need to calibrate it.

>>MR. BENSON: It's a calibrated -- it's only good for that point in time. It expands as it

goes forward.

But what we know is that calibration, it tends to be very limited in terms of its use.

Validation, things that are mechanistically correct are better, in terms of making long-term predictions. And so, we need field data to do validations.

Bill talked about these, and I'll just talk a little bit about some field data from one of the sites in Western Montana, this is in Polson, a sub-unit site with a capillary barrier.

And this is the type of data we got from this site. This is actually a great -- I think we had less than a millimeter of percolation over five years in this climate.

And you can see that these two lines here, the precip and the evaporation lines are running right next to each other. You know, all the water that's going in is essentially going back out. And so, this is a pretty simple one, hopefully we can predict this pretty well.

Again, We see the seasonality down here in the soil water storage profile. So I used four different models here, actually three different in this particular example. Took the same input to all of them. These are all commercially available models that you can pick today and use the same input for all of them and made predictions of our output.

And I think a couple things that you -- if you look at this in detail you would find that one thing is that every model gives a different prediction, and some are better than others, but none of them are quite right.

And I think that got back to that earlier statement some -- all models are wrong, just some are better than others or something to that effect. Some are useful. I think the one that we're often interested in, this box at the bottom, percolation versus time and at least all these models were per -- were conservative, they're over-predicting the percolation rate of the flux into the waste, which is positive.

And perhaps, there was a note earlier that usually we couldn't go more than a factor of ten. Well, maybe that's okay in this case, we are within a factor of ten it looks -- except for the LEACHM model, that's a little bit higher.

But the HYDRUS and the UNSAT-H in the field data are not too far off. But all the models give us a different aspect or a different prediction. There's a number of factors that give rise to this, the way they manage boundary conditions, for example, UNSAT-H has some defaults that it uses for the upper boundary for managing the intensity of precipitation.

And depending on how we change that we'll get different predictions. If we use the default, we'll get this green line here, 10 millimeters per hour. That's pretty high intensity.

On the other hand, if I use my field measure value at .68 or kind of an average intensity we see in the field, we get something quite a bit lower. It's allowing more water to get in.

So the boundary is important there. The lower boundary we predict is equally as important, sometimes it's a little ambiguous what that lower boundary is because we don't have a cover that just sits by itself, we have a cover that's coupled into a waste form and then coupled into maybe a liner, maybe a vadose zone. That gets a little ambiguous as well.

So you we get -- put different boundaries in at the bottom, you'll get different answers as well. Hydraulic properties, other inputs, which are -- can be difficult to characterize.

We can -- here if we use kind of the mean values from our site characterization, we get a prediction that's down here, for this particular example. If we have some scaling in it, five times or ten times, we get closer.

All right, so that might be due to some pedogenic effects. But the point is if we input our mean values from our site characterization, that might not represent what we see in the field. Partly, that may be just due to uncertainty.

If we had done an uncertainty analysis and got an envelope of answers, perhaps it would encompass that.

Other things. Constitutive model for unsaturated hydraulic properties. Something hardly anybody ever thinks about. Do I show you Brooks-Corey or should I show you the van Genuchten. And if I you use van Genuchten model, should I put in synthetic air entry pressure or not. What should be the core action term?

Most people are probably thinking "what is this guy talking about?"

Well, these are kind of basic modeling questions to make these predictions. Changing any one of those three I just mentioned you'll get different answers.

Took the same data and parameterized the van Genuchten model and parameterized the Brooks-Corey model and made predictions. Everything else is the same. I get two different curves, I get -- here is my runoff curve with van Genuchten.

Well, that's quite a bit of runoff and it's lot higher than what we measured in the field. If I use the Brooks-Corey model. Geez, it's pretty darn good. Everything else is the same. All I've done is use a slightly different constitutive data model that I fit to the data describing unsaturated hydraulic properties. The subtle difference which can make an important impact on the predictions.

It all has to do with what's -- in this particular case it's kind of subtleties right around saturation which is governing the infiltration process. And that affects what we predict out the bottom as well, we get somewhat different predictions.

300 seconds, good. That's five minutes. I did that in my head. All right. Pretty good.

Vegetation, I want to say a few things about plants. One of the things that we find when we run these models, that if we have plants or don't have plants, we get very different results.

And that's what I showed you in this graph, it's actually a graft for, you know, for parametric simulations we did. But we predicted percolation from a -- the covers of different thickness for a given location here in Sacramento.

And we ran the kind of wettest year on record, five times in a row just for -- as a base case or worst case type of analysis. And we plotted up the percolation rate as a function of thickness of the cover. So a thicker cover we should get less percolation. And we see that -- if we have a vegetative cover, we see that actually drops off pretty quickly.

If we have a non-vegetative cover it's much more slowly because we are not very efficient at extracting that water at depth. But big difference between no vegetation and vegetation, so the vegetation should be important, right, it should be an important part of this model.

Okay, let's put in -- let's put in -- let's vary some of the vegetation parameters then that are within the model and see if it makes much difference.

For example, let's take -- the models use LAI or leaf area index partition PEAK here, potential evapotranspiration into evaporation and transpiration components. So shuttling it between the soil and the plants. And we expect as the LAI varied and we shuttle those different components of water removal that we get potentially very different results. No vegetation. We get this curve of percolation as a function thickness. No vegetation, we're going to get a lot more percolation.

But we vary this kind of fundamental characteristic in the model about how we manage PE and PT, and we get virtually the same results.

All right, let's change the root length density functions. The shape of that function I showed earlier where -- how we distribute water throughout the roots then. We use three different -- very different root length density functions and we get essentially the same curve here. All right, and we can do that for a variety of other factors. We can change coverage and -- my point here is that, well, this is kind of an important part of the model and yet it's pretty simple, all right. And I think -- one of the things that John mentioned earlier is you can look at parts of the model that influence the predictions and others that don't, and you could that part and you can say, well, maybe I'll just focus on the things that influence it.

But, at the same time, I think you have to be a little careful too that one of the reasons that something may not influence the output is because the way it's coded in or mechanistically built into the model is insufficient.

I would argue that our models for plants are probably too simple.

So, takeaway messages. A couple of things when we look at hydrology of final covers they tend to be driven by seasonality. There's a lot of discussion about the events or kind of analyze them, but then usually it's seasons that drive our hydrologic processes and covers.

We really need to account for seasonality in our models -- it requires that we usually use daily data at least to make predictions.

Boundary conditions are important. You need to make sure that they're -- they simulate what we have in the field with a reasonable degree of realism. Change the boundary conditions, you'll get different results.

Of course, you'd expect that if you -- I remember back to solving those PDEs in college when you took math 319. Change the boundary conditions, get a different solution. Very sensitive, the hydraulic properties we use as input.

You know, we really want to be as realistic with the hydraulic properties as we can. The vegetation properties don't seem to have as much of an influence. And I wouldn't argue that's because the vegetation isn't important, I would argue that's probably because our models are pretty -- fairly simple.

Now, we probably ought to work on that. That's something that we ought to feedback on and develop better algorithms for that part of our models.

I would argue that Monte-Carlo simulation can be very valuable. I think, as John talked about this and as Roger did, it -- kind of describing our uncertainty, it's really good at kind characterizing that band and doing it a quantifiable way.

At the same time it doesn't account for model bias, and adherent model inconsistencies. And so, we need to make sure that we use simulation, Monte-Carlo simulation in the right way. I think, finally -- this last bullet is the most important one. Model predictions are just model predictions.

They -- and I've heard this a few times today. They're not reality, even if they look really cool and they look really realistic, they are just a prediction. And this really says that we really ought to be monitoring by function, from my perspective, that I want to monitor the elements of my system, whether it be the cover, the liner or the waste form release, whatever it may be, I want to be able to monitor that function and determine whether my predictions are reasonable, not necessarily are they accurate, but are they reasonable or conservative.

I think that's more important than monitoring for compliance, which we often do at a point off site of our facility and by the time we get that information it doesn't really allow us to make changes or alterations in our operation that would prevent an environmental degradation.

So I didn't get the last -- oh, I heard the beep on that. On the stopwatch. How many minutes?

>>SPEAKER: 25 minutes and 21 seconds.

>>MR. BENSON: Pretty good, huh? I had a little stoppage time there.

>>SPEAKER: Ten-minute break.

>>MR. ESH: So I'd like to start off now with Andy Ward from PNNL, who is going to share with us some experiences with modeling the Hanford barrier with STOMP and sparse vegetation and ET model.

>>MR. WARD: It turns out that the title in the proceeding is different than the title on my abstract. And this title is a combination of the

two.

First you look at -- a little bit at the -- okay, how do I get the -- I can use this. Okay, thanks.

So the typical engineer environment problem is a multi-dimensional problem. In most cases, at least at Hanford where waste is close to the surface, you end up with a raised cover and with a raised cover you basically need to have these protective side slopes, such as these here.

You have the barriers unique in that we have two different considerations in side slope, there's no curve design practice. You have the side slopes, but we compare to. And you've seen a little bit of the data from this morning. It has two -- the cover has a 2% slope to shed water towards the edges, the crown here slopes off 2% in either direction, it's anisotropic, it's multi-phase, because you're dealing with the -- with a flat component, there's water here, an NG component that we need to solve.

There's spacial variability, even the

installation given this is an engineered cover. When we install instruments we can see significant changes in density with space.

And over the surface of the cover and measure the hydraulic conductivity. So there's a lot of processes that we need to examine that are somewhat difficult to deal with with some of the more common models.

So what we set out to do at Hanford was to use a STOMP code, which has been used extensively for flow transport, simulations and the evaluation of different remedies to look at -- for use in barrier design. You'll see -- I'll talk a little bit about some of the differences between STOMP and the others. So the current models mostly are either 1D or 2D.

Probably just give a nice summary of those. A lot of them are isothermal coupling and somewhat semi-empirical for climate, mass and energy are naturally coupled. The -- for that reason many of these codes are inadequate for the types of problems that we were trying to solve.

You'll see shortly, I'll show you a profile from one of the sites where we're creating a barrier, which is quite anisotropic, quite heterogeneous.

Also, these are the plant components that Craig went into detail about, were developed -- the PT models were developed in the agricultural industry or the agricultural arena that assumed non-limiting water content and full canopies, lower wind speeds.

We get wind speeds upward of a 100 miles an hour on top of the Hanford barrier. That's not low wind speed. And, as I said, full canopy.

So these -- when we look at simulations with these types of assumptions we typically could not match any of the data that we have in lysimeters or similar field sites.

So we chose to use STOMP, it's a code that was developed by PNL, it's a multi-fluid, multi-phase, multi-dimensional, you can compile it for 1, 2 or 3D.

We have a sequential or problem version.

We're actually running barrier problems now with 4,000 processes. So we can simulate pretty large problems.

We can deal with multiple phases. Ice, they use for HYDRUS. So it was ideal for this type of problem, because we also use it for looking at designing different remedies and looking at flow and transport in the subsurface. So this will be ideal for looking at a barrier and then what happens after the barrier.

So, again, try to answer some of the questions. When should modeling be performed? And we thought here that since the goal is to provide a measure of coverability to prevent infiltration over long periods, some of the things we would be looking at is quantifying system behavior, assessing the data quality objectives.

We use this code quite a bit to look at designing monitoring systems, looking at which state variables we might want to measure or which surrogates my be useful. So the types of things that people have talked about this morning.

We can couple modeling with monitoring to improve identification and understanding some of the processes and identify the most sensitive state variable or surrogate, as I mentioned.

So I will start with a couple of examples where you will apply this code and see a bit more details there. But, I mentioned that we have two different sizes of configurations and one of the first things that you notice with our first attempts to model the side slope performance, the riprap side slope, was that we always were getting a lot less drain -- we were observing a lot less drainage from a riprap slope than a gravel, which was somewhat counterintuitive because the riprap is like 25 centimeters fractured rock, it's open framework, there's no plants and it threw us for a loop initially because all of our studies have been based on lysimeters without this type of system.

So, we hypothesized that it was probably due to the effect of drying and we incorporated that into the STOMP code. And, sure enough, it turns out that with wind pumping, if you basically have a warm, dry area impinging on the side slope, you actually do get some evaporation off the faces of the rock.

And this reduces the amount of drainage that we measure. And you can see here, this was an irrigated treatment -- we are not looking at risks, but certainly here, this is a gravel side slope which has a two to one profile. And the riprap, which is -- sorry, gravel is ten to one, the rock is two to one, which we're looking at here.

And it turns out that you drain about somewhere between 11 and 18 % of precipitation each year, depending on the distribution.

So this was one example where, by using monitoring data and modifying our conceptual model, we could take care of it.

Time periods for simulation, this is somewhat challenging. The Hanford barrier has a design life of 1,000 years. They initially have a three-year treatability test designed for it and we have been successful in getting money every year after that in one year increments, now at the 16th year, thanks to Kevin.

But some of the things that we need to look at in these long-term simulations would be weather, disturbance. We looked at fire, biointrusion, changes in soil properties and how you would handle these.

And some of these soils we can handle in the STOMP code, as I'll show you in a minute. We haven't attempted to deal with biointrusion or burrowing of animals yet.

But it's important in this case to demonstrate, at least what we think is important to demonstrate as acceptable performance over a range of potential conditions; elevated precipitation near surfaces. And we have looked at simulating in the field, 1000-year return storm. We burnt the surface to look at what happens in term of the water balance.

I mentioned this, this is another view of that trench this morning, that we could not simulate it with daily averages of precipitation, but if we do hourly data, precip data, we could actually get amounts of runoff.

So the criteria for detailed monitor -- modeling, this for us was very important, because you have a capillary barrier with layered thicknesses going from less than 10 centimeters up to 1.5 meters, as you can see here.

So we have something thin layers down here about 10 centimeters, up to 1.5 meters. If you follow the tradition or the requirements for your regeneration, where adjacent grid sale is at least or not more than 1.5 times the adjacent grid, you can see that the problem becomes very large.

If you try to simulate this in the field scale, it's even larger.

So we look at it as the type of system with the monofill, you can get a relatively coarse -- very little detail, a composite cover like this, you need a lot more detail. Flow transport, obviously with transport you need to take care of things that will lead to -- or minimize things that will lead to numerical dispersion.

Spatial resolution, I mentioned this earlier, but another component is the -- is the slope that you have in the system. Because of slope, you tend to have to deal with somewhat smaller disvariations, especially with the fact that STOMP started off as a finite volume or finite difference code.

It is -- we cannot do curve or linear rates, but in the early days you had to stair step, which was quite difficult if you have a 10-centimeter layer. We can rotate -- make a grid and rotate it. And then, it works pretty well.

Temporal resolution, this was something that we dealt with -- we struggled with for a long time, because there were certain inputs from the data we could average, but you could not average precipitation because of the very reason I mentioned earlier, you would miss these episodic events that cause violation in the capillary barriers or even runoff.

And, of course, computer resources, if you have 4,000 processes, you could probably do a million grid cells. If you have two, it's a different problem.

Now, this is a picture from -- a profile, an outcrop from close to the Hanford barrier.

And if you're looking at the barrier itself and then, you know, you get .1 millimeter per year percolation that goes into this type of material. Long-term performance, especially if you're looking at the performance of the whole system, it has to account for this.

We propose that you need, definitely, a mechanistic model, something that will simulate the variability saturated flow of water and air.

Using a Richard equation, we have to solve the heat equation because of the energy balance. And, obviously, it has to be multidimensional. The functional portion, which is that portion between the side slopes, we have a 2 % slope there, because that's where you need to have the lateral component.

Some of the things we can do, in terms of dealing with physical properties. We are changing properties. We have benefited from a lot of work that's going on in other areas with a STOMP code. For example, the development of the Eke-CHEM reactive transport module that we can simulate precipitation and dissolution. And we can then use the output of this to change the pore size distribution in your soil.

You can get various dissolution and precipitation will occur and it changes the pore size and you basically get a new pore size parameter, Brooks-Corey, or whether you're using -- it will depend on the water -- the water characteristic model you're using.

And these will allow you to use realistic scenarios to see what might happen in terms of water retention.

Freeze-thaw, the work we're doing with (inaudible) sequestration was also useful here. We have a fully coupled mass and energy. And, again, this affects the hydraulic properties, the saturation of the hydraulic conductivity.

Physical deterioration, burrowing and root penetration and cracking we have not tackled, and I'm another sure how this is currently modeled.

In preparation of ecological and climatological changes, Craig talked a little bit about the fact that there's some really sophisticated codes of ecological modeling and we sort of take -- we have to compromise in there, using some rather innovative approaches.

One of the things we've said, is that it can deal with this sparse canopy model, and it can deal with multiple species.

The Hanford barrier has like 17 or 18 species on it now, and we can include each of those in our equations. We have introduced this term called a plant area index that basically allows you to assign some portion of the ground coverage to a particular species, it sums to one.

And we can vary this -- these distributions can vary over time. So if there's a fire, you can actually include this in the input model.

The phenophase, basically, this is the

seasonal development of the plant. This was a -- this was somewhat challenging, and I'll show you in a minute. But we started off where we would specify the start of growth or activity of the plant particular to each year, and it would end at a given time, depending on the plant species.

We later found that this was somewhat -- it was somewhat more rigid and we could not match some of our observation data.

So we went to this control -- we went to the degree type of format, where you're looking at the lowest temperature in the winter and you accumulate heat that the soil is using in the agriculture industry again.

And this was quite helpful in solving the problem, and I'll show you in a minute.

Our roughness length, zero-plane displacement. This is dealing with the wind velocities of controlled vibration, and this is all built into the model.

I probably can skip this. The difference between the STOMP code and the others that we use, the Shuttleworth-Wallace model. It allows us to deal with -- give a better description of the potential developed transpiration. I probably will go by this pretty quickly.

Root water uptake. This was interesting. Craig showed a rather ubiquitous explanation of decrease in root length density, which you see everywhere. And this is an actual root length density from that profile I showed you earlier. It decreases exponentially. You get an interface and capillary break and root density increases quite significantly.

And it still continues on. So this would definitely give an erroneous -- you definitely get an erroneous evapotranspiration if you were using explanation model.

So we made some modifications to the root models so that we could deal with these types of distributions.

I will not get into the detail. Input data and parameters. Craig was perfect, because he talked about all this. But there is a lot of input for this stuff. Your plant species, if you're dealing with, six to eight species, you need to define the phenophase for each one, which is this graph here, and it tells you, basically, when the plant will start growth or evapotranspiration, where it reaches a maximum and where it goes off into hibernation.

They also take into account the albedo, the plant albedo, for energy balance. So it's a pretty comprehensive model, the area index, the ground cover, plant height, root distribution.

We do not simulate the actual plant growth, but the model is set up such that we can define these parameters as a function of time and it will change over time.

And there is a lot of resistence. We actually use temperature to control the start and end of evapotranspiration. That plus the -- the degree days has allowed us to match our observations from year to year.

Input data. Some of the biotic parameters typical for us, the typical soil parameters, this is measured water retention and the mean. And it's one standard deviation.

This is a geotech style water retention properties from, I think it was a paper by (inaudible) that we actually fitted the evaluating parameters to and we can use this in the model.

Unsaturated hydraulic conductivity. As I said, is very anisotropic. We actually even developed a model where you can deal with saturation dependent anisotropy.

The L parameter or the tortuosity connectivity term were a lot of these pore -- pore-size dependent models can actually be treated as a tenser, and you get a different connectivity in each direction, and it allows you to have anisotropy.

One of the unique things in terms of barrier performance, is that we can do inverse modeling with STOMP. It's coupled with tests and we recently added the Monte-Carlo markup chain code from Jasper Vrugt. He was out in Reynold, he's now in California.

So we can actually take field data and do an inverse model, hit parameters, hydraulic parameter, plant parameters, thermal properties, whatever.

So here's an example of where we started off. This is a grass site, basically, 3.5 meters thick. The circles here is the observed storage and the lines are what we're -- these lines were our attempts to model the storage by just having a rigid description of the plant -- the start of evapotranspiration in the end.

And it turns out that we can always match the later part of it and we -- the year prior to this it was perfect.

The second year, we could never match this until we actually used the accumulated the heat degree days that -- and it turns out here, when you look at the data, the winter was somewhat -- it remain cooler for somewhat longer periods, so there was a later start to evapotranspiration, which could not be handled if you had a rigid description of that start.

And this is a simulated water balance. We don't have a measured water balance for this site, so I would assume that this is accurate and correct.

But, it sort gives the little squiggles that Craig showed, and gave a reasonable amount of evapotranspiration, based on what we know for some of the other sites.

Bridget Scanlon, in 2002, published this intercode comparison. She compared seven codes. And we basically repeated that. And the bottom section here is the STOMP performance.

When you look at HYDRUS and UNSAT-H and a bunch of the others, STOMP does pretty well in matching the drainage. What we see in here is this -- a negative, basically it's -- we were unpredicting drainage by about somewhere between 4 and 9 centimeters compared to 86 centimeters over prediction by UNSAT-H.

I'm not -- this is UNSAT-H, but there's a big difference. All these different models give a different result, as Craig showed, for storage.

We did a lot better. Craig showed that you could never match storage, but here STOMP did quite well in matching the storage that was measured at the sites.

So what I want to do now is a quick little AVI that shows -- this is actually a 3-D simulation of a field scale cover. It has a 2 % slope, but in order to get around the interface, stair step, we actually create a smooth interface and rotate the grid between 2 degrees -- 2 % rotation, and we run the simulation so you get a smooth interface.

And, basically, this is January to December of 1995. We're doing hourly time steps with hourly meteorological interim wind speeds, temperature, precipitation, relative humidity. All this is in the boundary condition.

This is a side slope of the areas at ten to one, and this is an 80-centimeter thick silt loam layer.

And let's see if it will start. So this is the simulated saturation.

So what you're seeing over here is -- remember all the data I've shown so far is you get, basically, drainage out of silt loam layers and you get most of the drainage occurring from the side slope. And this is what you're seeing.

These pulse are basically these precipitation events that passes right through this -- in fact, this is not a riprap, it's gravel. You get a wetting front moving down -- so this brings into play the questions about barrier overhang, how far do you need to extend beyond the waste zone.

You probably pass it here, but because of the slope, this is a crown here, 2 %. And what I showed in one of the storage measurements, this moral is that we tend to get a lower storage on the crown and we tend to get accumulation of moisture at this region.

In a lot of cases, this is the point of failure for barriers, both here and on the toll, where you're getting a lot of moisture collecting at the toll.

We saw some erosion in our case, but you tend to get moisture moving down and collecting in this region. And if you notice here, this region is getting bluer and bluer.

I probably should have switched it where the blue was wet and red was dry. But there's a dry front that's moving down onto the actual barrier, whereas, on the side slope you're getting this dynamic change in moisture, that is coming both from lateral movement from upstream here, down to this interface, which forms somewhat of a capillary break and then actual direct infiltration.

So, what we've seen in the field, and there's some sort of circumstantial evidence on the Hanford Barrier, this region here, all sagebrush here is like two or three times the size of the rest of the crown. So, obviously, you're getting a lot more water. And Steve can tell you about it.

So, I'm done anyway. So, in summary, what I wanted to show you is that barrier simulation, basically, the attempt to simulate these engineered covers is a multi-dimensional, multi-phase problem. Performance is controlled by these tightly coupled processes.

The available tools are not always applicable, at least not for the cases that we wanted to deal with.

And STOMP is used extensively, so for us it was the perfect tool to make these modifications to.

We looked at it and, basically a soil-plant atmosphere continuum. It's physically based, full climate coupling, fully coupled mass and energy, and it's a well-suited to sparse canopies of typical arid environments and we can deal with freezing, freeze-thaw, snow accumulation, all these types of things.

Thanks.

>>MR. ESH: Thanks, Andy.

Next up we're going to have Dr. Terry McLendon.

Dr. McLendon is a plant ecologist specializing in vegetation water use, ecological modeling and vegetation dynamics. He has authored or co-authored over 100 scientific and technical publications and is the originator and co-developer of the Ecological Simulation Model.

And Dr. McLendon has worked on the design and development of water balance covers at mine sites in Arizona, Montana, Nevada, Washington and in Egypt. He received the 2009 outstanding alumnus award from the Department of Natural Resources Management at Texas Tech University for his work in plant ecology and ecological modeling.

Dr. McLendon currently serves as ecological consultant to the Los Angeles Department of Water and Power and the Southern Nevada Water Authority and on projects with the U.S. Army Corps of Engineers. And he can talk glowingly about the final seconds of the Texas game with Craig Benson.

>>DR. McLENDON: Well, what you didn't hear was the (inaudible) a while ago.

What I've been asked to talk on today is the longer term effects of vegetation change and how we might model it.

Plant succession over the long term, what effects that might have on designs.

Now -- and I'll be bringing in some of our work with EDYS and how we modeled theses systems in different areas.

But to get there, before I talk about the EDYS simulations, I'm going to need to talk a little bit about succession. And then I've got succession, I need to lead to into that with a little bit more about below-ground aspects of plant communities.

And I've been very, very pleased in this meeting. This is the first meeting like this I have ever been at where I wasn't the lone duck talking about plants.

My big worry from the get-go yesterday was I'm going to have nothing the talk about by the time y'all get through with this.

So bear with me as I go through some of this root architecture stuff. Hopefully, I'll be able to bring a little bit more in with some of my biases and try to make it not too boring for you.

To repeat what's been said several times in these meetings, most plants concentrate most of their roots where there's water and where there's nutrients. So they're going to go after those. And so, just expect that.

And so, your concentration roots tends to be in those areas. But that doesn't mean those roots can't grow through dry zones. Plants have this amazing ability -- and I'll show you some root depth numbers in a few minutes -- but plants have this amazing ability to run their roots down through the dry soil.

And question for a long time is how in the world did they do that? Because those roots tips, right behind that root tip itself, desiccates relatively fast.

What we found out now in research is that the plants have the ability to transport water up -- not only up through the roots, but also down, and re-transport, re-move that water to different parts of the plant.

So, basically, they move that water to that growing tip zone and, in essence, sweat their way through as it leaks out of the root, and make a little wet zone right around the root as it goes down through the dry soil.

And I'm going to bring the point up a little later about microbial communities and how that might affect that. So, just remember, roots will go down through dry soil if they have the capability of doing so.

And as long as there is sufficient resources, those roots will go down more until one of three things happens: They either hit their genetic limit, different species of plants -- different types of plants have different maximum rooting zones -- hit their genetic limit or they hit an impenetrable barrier and, to a plant, that may not be what we think it is.

Because, as it as been pointed out earlier in this meeting, they'll find every little crack, every little fissure. If there's anything there to exploit, they'll find it and they'll go through it.

So, but an impenetrable barrier or they're going to hit saturated soil or toxic material.

And once they hit that, obviously, they're going to stop, but otherwise, they're going to be moving downward to their genetic limit.

Here are some numbers of just -- the first set are for the ponderosa pine, from our work in Washington at the western nuclear site that Garry talked about yesterday, and these are percent of roots by depth for the ponderosa pine. It's actually cover.

The sagebrush data comes from the PNL Group at Hanford. And the blue grama data comes from Bill Albright's group at CPR out in eastern Colorado.

They're just three illustrations from three different studies of distribution of roots by depth.

If it's ponderosa pine, I go down a lot deeper than 1.8 meters, but that's just where my trenches stopped in that study.

But I bring this up to show the obvious, that the concentration of roots tends to be more towards the surface where, in general -- these are all native sites, these not on covers, native sites -- where there tends to be a higher concentration of both water and, in most systems, but not all, in most systems, higher concentration of some of the nutrients, especially nitrous from decomposition.

Typical V-shaped architecture for most plant root systems. However, other species have different ones. You can have tubular type systems where the roots are fairly evenly distributed through the upper zones, not concentrated right at the top.

You can also have root systems fairly common where you'll have a V shape in there and then a settling of this mass of roots at the bottom, where they're hitting something, like water.

Forgot who was showing the slide -- was it this morning -- of the root ball, or yesterday afternoon, of the root ball down at the bottom of the -- that's what those roots are. They're going down there and getting some water and they're spreading out.

So root ore can take different shapes, but typically has a V shape to it.

Here's some rooting depths. He just pulled out the literature -- again, I do a lot modeling of modeling, in addition to field work, and here are some numbers that we pulled out for model applications.

And these are maximum reported rooting depths in the literature. It doesn't say that plants can't grow deeper than this, and it doesn't say that all plants of this species are going to get down this deep. But -- and those numbers are in meters, not in centimeters or inches.

Some of them will go down pretty deep. Fifty three meters is a pretty stout root system. Now, I'm not saying that all species roots down to 53 meters, I'm just saying there's a report of root -- deep roots being down to 53 meters.

Greasewood, common scrub in the west, maximum reported depth that I've seen is just over 17 meters. And greasewood is considered to be gratified, it requires, supposedly, high groundwater.

High groundwater is not 17 meters.

And there's a number of other reports in the literature showing greasewood at depths of 12, 14 meters. So these numbers aren't too far off.

Just kind of give you an idea of what some maximum depths might be. For herbaceous species, top three are grasses, 6, 4, 3 meters. Bottom three are 4's, broadly herbaceous.

Alfalfa, pretty good rooting depth. See it? Be even lowly sunflower, potential depth, pretty good.

So when we're thinking about plants and changes in species composition as it goes through time, one of the things we have to consider is what's going to be that maximum rooting depth. It's going to change as the plant community changes.

Another factor we might want to consider in our concepts of what happens as plants change over time -- plant communities change over time on our cover designs, is what's the size of those roots? And it appears, again, some data comes from the western nuclear site in Washington.

And these are the maximum root diameters, average maximum root diameters from trenches that I dug. And these include both laterally running roots and vertical roots. But, in each case, it would be the width.

And again, we see the size of the roots decreasing as we go down. These are ponderosa pine. But, still, at almost 2 meters depth, 3-centimeter root is still a pretty good size root. It can punch a pretty good hole in things. Kind of give you an idea of potential sizes of roots by depth.

So trying to kind of summarize that part of it, brings us back to thinking about below-ground aspects of community change.

Roots -- most species are going to become -- most of the roots are going to be concentrated in that top 50 centimeters. But there's going to be some that are going to go down a lot deeper. And that's something that needs to be planned for in our designs.

It is going to happen.

And the other aspect is, some of those roots are going to be pretty good size that are getting down there in depth.

Okay, so what potential effect on barriers? It's been mentioned before. It's obvious. It depends.

You probably weren't looking over there, but I grinned when you said "depends," because my reputation with my clients is -- as an ecologist, is every time they ask me something, I always say, "Well, it depends. It depends."

Depends on type of vegetation. Depends on depth of barrier, density of barrier and amount and location of soil water.

So as we think about the changes in vegetation, the effects, the so what, the potential. Depends on a lot of different things.

Okay, so y'all stole this slide from me

yesterday and you've already talked about all of these things. Just bring it back up again, if there's going to be a negative impact on those barriers -- and I mostly work with clay barriers -- that it's going to be this sort of a process. It's going to be that as those roots get down there, that clay barrier is going to start to crack, from whether it starts as wetting, drying, cracking or some type of other type fissure, that root will go in there, it will start to exploit it, the root will go down, open it up more, debris goes in there, critters follow that, more and more shrink-swell over time breaks through.

So the process is an iterative process over time of more roots, more debris, more water getting down there. If you're cold enough, freeze-thaw aspects on the clay.

It's natural. Roots penetrate, dense layers. Here's an example from the literature of a fracture being down at a half a meter down. Notice the root architecture as it hits that very dense layer.

Goes down, very few roots in that layer, so the roots are going down, that mass of roots gets fairly small and the roots themselves actually get small.

Goes through. Some of roots get through. And then what happens, they expand again below and here they keep going down.

So a barrier -- a barrier, once breached, look out, they're going on through.

Fifteen, 20 years ago -- 15, 20 years ago, when I made this part of this presentation, these were the concerns and these are basically the same concerns today. What happens when those roots get down and what happens with an expansion of root system when those roots gets established in that barrier and then you have other aspects, like wind throw.

Now I can add to this, so what? And that concept has been brought up in these meetings.

Does it really matter? Does it matter? How much does it matter if the roots penetrate the barrier? Some times it matters a lot. Other times it may not matter so much.

Okay. So whether this is really that much of an issue, again, it depends on the purpose of that barrier, how critical it is, how much redundancy is in the system.

Okay. So much for boring you again with root architecture. Now let's move --

>>SPEAKER: (Low audio.)

>>DR. McLENDON: One of the major reasons we were designing the -- Garry talked about the design at Western Nuclear. And one of the things we talked about, we looked at early on was the ability of this thick sand layer to be able to heal itself, to be self-healing.

Should throw these in here. I've got some beautiful slides of wind throw up there, of trees being blown over with massive root zone and this chunk of soil with it, and this bighole that took place. So, yes, it's a major potential problem.

I'm going to come back and say I like thicker covers. This is one of the reasons. If you have a mass root up at the top and something tears that off, but you have a thick layer underneath, then you've got some protection. You don't have that many roots down -- don't worry about interrupting, that's okay.

Plant succession. The changes that take place over time.

Plant succession occurs, it occurs everywhere. It's going to happen. Again, I never believed I would hear it at a meeting like this, but I heard yesterday that if it's a battle between engineering and nature, nature's going to win.

I didn't think I'd ever hear it. That's right, nature will. And by -- and she'll also outwait us. She doesn't mind waiting a thousand or 5,000 years to make her point. But succession will occur.

And we can go out there and try to stop it and we can cut it and we can spray it and we can chop it and we can do everything, but the minute we stop, it's going to be right back coming at us.

So, simple example, one that I spent 30 years studying. Here's an example of a succession in -- to the west, pretty typical of most of the areas in the Great Basin region. Taking abandoned land, area that's been bladed off, whatever we want, a cover that hasn't been revegetated. And in most of the west, first thing that's going to come in is tumbleweed, Russian thistle. And you're going to get a real nice stand.

We have a research site in northwestern Colorado, between Rifle and Meeker, and been stating these patterns for 25 years now. Bladed it off and been watching that recovery on the sites since then.

And nice strands of Russian thistle like this, first in two years. And then that's replaced typically by cheatgrass. Once cheatgrass comes in and then, slowly, the perennial grasses come in and replace the cheatgrass. It may take a while, but they'll come in eventually.

And the rabbitbrush comes on typically to follow that. And then, sagebrush eventually replaces the rabbitbrush. Typical succession.

In northwestern Colorado, this process to get the structural changes, that is to get the sagebrush natural, not receding, natural sagebrush reestablished on that site, takes 50 to 75 years for it to dominate.

It starts coming in on our sites by year three, by year 25 it's abundant, but it takes 50 to 75 years before it becomes totally dominant on that site by natural means.

I have similar studies going on, not as long, in Owens Valley and California, and we're seeing patterns there. But even in that very dry environment, it's about 120-year pattern. So a typical succession in the west.

Wherever we are, couple of the pertinent aspects about succession is that all systems are going to tend toward a greater structure in productivity.

That is, the greatest amount of structure and the greatest amount of productivity allowed by the resources at the site, in the west, of course, typically (inaudible) precipitation. But think also below ground, just as above ground.

And in the absence of that recurring disturbance, woody plants of some type are going to replace herbaceous, count on it. It may take a while, but count on it, it's going to happen.

Here's a site that -- a study site in Colorado, the center part of the slide is a revegetated area called the pipeline installation.

Our research sites are over on the left side. The -- I'm going to show you some data now from the root architecture from this early successional community, which is this receded area right down the middle. Compared to a rabbitbrush community, which we consider to kind of a mid-successional community, over toward the left. And then, a sagebrush, material sagebrush community back out behind that.

So each early succession, middle, a rabbitbrush community and then the sagebrush on the other side of that.

And here's root coverage by depth for those three systems, the smooth brome being the early community, rabbitbrush the mid and big sagebrush later.

Notice several things, one is total root biomass increases over time. Nineteen to 38, about doubles. And you start getting some changes in the amounts at depth.

One thing I would also like to point out on this slide, the question came up -- Tom, I think you raised it, wherever you are. I think you raided it yesterday on microbial communities and how they changed with depth.

We have had three microbial studies that have gone on here. We've got some over in eastern Colorado, and then also some microbial studies in the Owens Valley, California.

They're all showing the same thing, that micro -- soil microbial communities change -- differ significantly among these communities. They differ significantly by depth. They differ significantly right next to the roots versus right away from the roots.

So, plant structure makes a big difference in the soil -- in the soil microbial communities.

Okay. Again, I'll pass this one pretty fast, we've already talked about it. Different functions of vegetative covers.

And so, when we look at vegetation change, how does it affect the vegetative covers through these three -- these four processes?

One other thing to point out before I leave this is, remember that different types of plants function differently for stability aspects.

Grasses have very fibrous root systems. I'll show you the slide in a few minutes. Tend to stabilize that upper surface very well, but they don't grow as deep, so they tend to allow sloughing.

On the other hand, woody plants have deep root systems, but they don't stabilize the surface as much. So you're going to have different erosional or slippage patterns, depending on the type of vegetation you have.

So, effective cover designs need to take into account, changes over time. One thing to remember about my presentation is, things don't remain the same. They are going to change over time. And we need to at least be planning for that and see if that really matters.

Okay, so how do we -- oh, no. Boy, am I in trouble.

To plan for that, how do we model that? And I was going show you some stuff on the EDYS model. The model we use -- I thought that was through. You see, I'm not an engineer.

I just look at the first number and go.

EDYS is the model we've been using for a while on a lot of different sites, from very arid zones, Yakima, Washington and Owens Valley, California to rain forests of Indonesia.

And a number of validation studies -- and I agree wholeheartedly with the difference between calibration and validation. There's a big difference.

These are validations studies that we've done where we actually go out and apply the models of the system and you go out and collect data and you test the model numbers against the field numbers. So, pretty good credentials for the model.

EDYS is set up -- it's a three-dimensional model, it's a dynamic model, it's a mechanistic model. So we actually try to model how plants and systems grow and function, rather than just make the assumptions of transitions.

It's -- we can operate on multi-scales. The model is set up so that we can -- if we have cells that can by grouped into the landscape. Landscapes can be any size we want to make them.

The largest we've done so far on a fine scale has been 300, 400,000 acres, it's Owens Valley. We've modeled Seminole Creek Watershed in Baylor County in Texas and Clover Creek Watershed outside of Salt Lake.

We've done a coarse model where we've linked Seminole Creek to the San Antonio River drainage, all the way down the Gulf of Mexico. It was about a million acres.

So it can be large. On the other hand, the smallest application I've made was where the landscape was one square meter. And that was a project for the quarter where we wanted to look at changes in soil microbial dynamics. So our cell size in that was a square centimeter, and the landscaping was a square meter.

So, we're flexible and do spatial scales and the model setup so that we actually model the dynamics of each of the species that are entered into that application for the model, and the model keeps track not only of the species themselves as a whole, but changes in stem, leaf, roots, roots by depth, root size, nutrient content, contaminant content, by each of those parts, and all of that changes every day.

So we have date and timestamps. We can make them hourly if we want. And it would keep track of the roots by depth.

And so in the model the plants are growing and changing day-by-day. They're impacted by different stressors. And that affects the composition, and we look at those changes over time.

This was going to be my five-minute slide, so better skip over this one pretty quick. But, another nice thing about EDYS, we're able to model dynamics of the plants, root growth changes over depth, amount in each of the layers, water uptake at each of the layers, and the impact of the different types of vegetation, grasses versus woody plants on surface properties, like erosion, interception, et cetera.

Here's just a slide of an example for vegetation change on the revegged site at a mine site in Montana, Mineral Hill. Just illustrating some changes over time.

We modeled a -- long-term studies. And the question that's come up repeatedly is what do you do for the precipitation data over long periods of time?

And we've taken several approaches. One is, we try to find the longest data set for the precip that we can get for an area, or build one from a nearby station.

So we like to get 100 years data and when we get something that we repeat it ten times to get a hundred -- a thousand-year run. Or, we can take patterns that we see -- I got that one. We got patterns that we see, and use that information into the model.

For instance, in modeling, we worked there in San Antonio, there's a definite cycle effect, periodic cycle, in the precip. So that's 150 years -- almost 150 years' data there.

We seem a similar pattern out in California.

So if we see those, we can modify data sites.

One other way we've done it, again, for the western nuclear site and Dolan site in Washington, I went and found as much paleo type data, pollen data, tree ring data, isotope data, to look at what the climate change has been in the past and what the vegetation was, and found a pretty good record for about 8,000 years for that area.

I took that 8,000 years, translated what that would be for vegetation and then precipped it to support that vegetation, and then assumed that for a thousand-year run, there wouldn't be any more change than there had been in the last 8,000 years.

So there's different ways we can approach precip dynamics for the long term.

Here is just some EDYS output for changes in roots biomass by depth. The red is first year of -- after receiving that site at Mineral Hill and the tenth one is the projections of root depth over ten years. And you can see it's already down in the tailings.

We're also able, in the model, to model stressors. In this case we're looking -- this is drainage at the gold mine site and looking at drainage coming out of the bottom of the pile they have to treat.

We let the area burn, in this case, twice, and looked at the impact of drainage. So we look at stressor impacts, what effect they may have, both on the endpoint variable, in this case, drainage, or the dynamics of the vegetation.

I can give you 30 seconds back.

Base point to make is that succession,

changes over time, definitely need to be accounted for in our designs. And we've done a lot of work in looking at modeling of these systems from the plant community, above ground, down to the bottom of the soil, and there's major changes that place. They need to be accounted for in designs.

Thank you.

All right, our last speaker for this afternoon's session, before our panel gets together, is Bill Kustas, who was introduced earlier. And I'll let him say a few more words about himself, if he wants to.

He's going to talk to us about applications of thermal remote sensing for multi-scale monitoring of evapotranspirations.

>>MR. KUSTAS: I think this will tie nicely with the talks, especially, just before me that was describing a modeling technique and integrating the plant physiological aspects and the water balance aspects to the problem.

Everything okay?

>>SPEAKER: (Low audio.)

>>MR. KUSTAS: Oh, the little red dot? Oh, sure. Why not?

>>SPEAKER: (Low audio.)

>>MR. KUSTAS: Can we make the dot bigger? Anyway, being the last, I'll try and make a joke or two to keep you awake.

But, anyway, I'd like to acknowledge Martha Anderson, who is also from our lab, Hydrology Remote Sensing Lab. And we've been collaborating with Christopher Hain, who's now actually with Noah at Silver Spring, and John Mecikalski from the University of Alabama in Huntsville.

So this summarizes somewhere in the talks this afternoon on developing a model that treats the full process here of water balance and sort of the active root zone.

Of course, with these four types of models and for any sort of predictive mode, you need this type of modeling approach. But then it requires a number of parameters that we've spent -- we've heard a lot about, you know, rooting structure, canopy structure and soil properties, which can be -- can be available at sort of ceratin spatial scales, but when you start dealing with the landscape, becomes more difficult to define.

The approach we're -- we've been taking is to develop a scheme that can complement what goes on in these four type of models. With a remote sensing approach, which we are defining as sort of an inverse modeling approach. And what it does is it views the land surface with an effective surface temperature which is comprised of some sort of soil substrate temperature, and that of the vegetation.

And with these two pieces of information on radiative input, we can get some idea of the water loss required to keep both that soil and vegetation at those observed temperatures.

So, in other words, it's a way of implicitly determining what's happening in the root zone substrate condition here, by looking at how the soil and vegetation temperature changes over time.

This particular approach, called here the atmosphere land exchange inverse or ALEXI model, is first operated at the -- sort of what we call the regional scale.

It uses geostationary satellite observations, which you can get every 15 minutes from the GOES Satellite system that you see on the Weather Channel, for example.

The advantage of using the GOES data is that -- of course, it's temporal -- you have a high temporal resolution. What's lacking, of course, is that you have coarse spatial resolution at five or so kilometers.

What this also allows us to do is link the surface temperature or rated change in temperature over time, with the boundary layer evolution. And there were several talks today talking about how there's an importance of linking the climate with the land surface and the impact that has on evapotranspiration and other fluxes.

But by doing this at the scale, we link the atmospheric boundary layer process with the land surface temperature change.

It also -- by using this rated temperature change over time, it minimizes some of the atmostpheric effects on the derived land surface temperature. Because with remote sensing there's, of course, especially from the visible through the thermal, there's atmospheric effects on that remote sensing signal, so there needs to be atmospheric correction applied to the data, but this minimizes the uncertainty related to that.

The other important input is knowing the leaf area index of vegetation, type and structure of the land surface, which we can get from satellite such as MODIS that's out there providing operational products related to the -- to those vegetation characteristics.

The other aspect of the model is embedded within it is a disaggregation scheme, which we call DisALEXI, over here to the right. What that allows to us do is, by taking the blending high temperature that's produced by the model, so it's implicitly derived through the linkage of the land surface or the atmospheric boundary layer, it provides an atmospheric driver that can then use higher resolution information, either from an aircraft or, in this case, a landsat imagery and disaggregate this 5-kilometer scale flux estimate to whatever resolution can be provided by a higher resolution sensor.

Okay, in this case it's going to be landsat. In the future there's a hyperion sensor that has both hyperspectral and thermal that will hopefully be launched in the future.

And with this type of information, then we can go between the regional or landscape scale down to the smaller scale, down to the field and plot scale.

Currently, this is kind of a list of thermal imaging systems that are available.

You have, as I mentioned, 15-minute temporal resolution, but coarser. You have daily time scale for MODIS currently. And then there are future satellites that will be -- I lost my red dot. Anyway, down to moderate scales. And then at the finer scale, as I mentioned, landsat. Hopefully, there will be some other satellite sensors. And, of course, there's aircraft sensors that can be used, when available.

The issue of resolution, I think, in this slide, demonstrates how important it is to have that higher resolution information.

This is data collected over the San Pedro River in Arizona.

Now, the GOES can give us some hourly information about what coarsely is going on, in terms of evapotranspiration. And even at the one kilometer we get some more signature where there is variability of evapotranspiration, but it isn't until we get down to the 30-meter or 100-meter resolution do we start to define where the water sources are. In this case, the riparian zone -- riparian area along the San Pedro River basin shown here.

Of course, there's an issue here, you go from hourly time scale to daily to, potentially, monthly time scale with landsat.

So we lose -- while we gain in spatial, we lose in temporal.

So one of the efforts we've been trying to do is develop a means of trying to link what goes on at these coarser scale. Higher temporal resolution with a -- higher temporal resolution with lower or coarser temporal scale of the observations.

Here's another example again where it becomes important about the temporal resolution or the spatial resolution of the data.

What this thermal-based technique can do is provide information. In this case it's irrigation going on in a region in Arizona. That's very well picked out by the thermal signature.

As you get the coarser resolutions, like MODIS, at one kilometer, you see an indication of higher ET rates. In this case, there's a fraction of potential ET.

But the point is that it's at these higher resolutions that you can really start to distinguish activities at the land surface. And I should say that a lot of land surface models that are currently run in weather prediction models don't actually have this type of information available to them because they don't use this thermal information to determine where irrigation is occurring.

And that's a big problem, because, obviously, irrigation is a major water user. And in our water resource management decisions, is critical to know where this is being used.

So, here I'm going to summarize for you what we're trying do with high resolution interpolation scene.

In this case you have a landsat scene. This is in a Florida region in 2002, where you have a landsat scene on this day, 3/28, and then another landsat scene several days later.

One way of attempting to do this is by conserving the actual to potential ET over the course of this time period to sort of get some idea of then mimicking what's happening at the land surface at higher resolution.

The problem is that going -- assuming that that ratio is consistent over the time frame, neglects changes in water storage and other aspects.

Another technique we were also using was developed at NASA, it's called a spatial temporal adaptive reflexives fusion model, which I will describe in a minute here. But it provides another means of trying to -- trying to merge what happens at higher resolution, at very distant temporal scales, and tries to fill in, gap fill-in the information.

Now, the STARFM module that I don't have time to describe here, we looked at two possible approaches; one is to use this technique that -- to use it with the actual temperature data. But, what actually probably is more useful is to use it with the ET daily that we get whenever we do have high resolution data available.

This minimizes independence on the acquisition time. And we use an evaporated fraction technique which relates to the actual evaporation to the available energy net radiation minus soil heat flux to try to integrate that over a daily time scale.

So, by having this technique, STARFM, with ET day, what we're able to do is sort of provide a bridge between these high resolution observations.

And here is an example, again in Florida, where the ALEXI model can been run at continental scales with GOES data. With MODIS, on a daily basis, we could focus in on there, and a regional basis.

And then, with landsat, we produce these high resolution output with this ALEXI, down to the scale where we're looking at individual fields and looking at different waterways and other asporogenic influences on the evapotranspiration and surface energy balance.

So this sort of fusion technique that I was just briefly describing attempts to do this with MODIS data.

So we take information that we can get at a continental scale, more routinely with 15-minute data, and apply it to the MODIS regional scale data, and now we create this daily integrated map of daily ET, because MODIS is, again, has higher temporal resolution, we're more able to gap fill that data.

Then, at landsat, we may have an image at the higher resolution, separated by several days before we have another image for -- due to cloud cover. And by connecting this STARFM to these two cases where we can do the actual correlation between coarser to higher resolution data, we can then use this technique to apply to the integrated or values that are integrated in between these two higher resolution observation datas to create sort of a simulated set of high resolution maps of ET.

This is where -- this is where it becomes important because we can now start looking at the resolutions that would be necessary for the types of architecture and areas that are concerned here today.

Here is an example of applying this technique. So at the top here is the MODIS-derived, DisALEXI product of ET here at the top.

The middle here is this landsat for these particular days where we actually had landsat images collected. So this is running with the actual landsat. And then, this is the attempt at using this STARFM to derive landsat image created with this technique.

And so the difference between these two, between the actual and the sort of simulated, is shown here. And the air statistics are shown here at the bottom.

So what you can see is that, with this technique we see some real good potential.

There's the relative error in trying to integrate between actual landsat scenes, as shown somewhere to be between 10 or 15 %, which is quite good.

So we can see that there's a real potential here for trying to link the coarser resolution information, but higher temporal resolution, with the higher resolution spatially available data, but not often available due to cloud cover.

Here's another area where we're also looking at applying this technique, it's in Bushland, Texas.

If you've ever been out in Bushland, Texas, you'll be amazed at the irrigation that goes on in a region that has very limited water conditions.

But, you know, this is one of the regions where there is a lot of emphasis being put on improving irrigation efficiencies because of the Ogallala aquifers being, you know, tapped and decreasing rapidly over time. And with this type of spatial information, again, it's at the high resolution that we can start seeing where irrigation is occurring and get a handle on how much water is being lost based on these current practices.

We are also starting to expand beyond the U.S. and looking at different regions of the globe where, obviously, water issues play a big role in the water rights between different countries.

Here in the middle east, there's a major concern about the Nile River and water being diverted from the Nile into irrigation of crops.

This is data created from the meteosat, that's the geostationary satellite that covers Africa and part of Europe.

We're starting to apply the model to these regions and working with NASA to help them estimates water use along the Nile. So these are, again, regional created monthly maps of midday evapotranspiration and then, you know, using MODIS and then, eventually, landsat, we hope to be able to provide very useful information, as far as where in the Nile basin is water being withdrawn for irrigation.

Maybe it's not as relevant in the U.S, but certainly in other countries where there is very limited ground information, these types of techniques I think will play a major role in helping to understand how water is being utilized in these water-limited regions.

Also, I would like to again reiterate my initial slide where I showed the two techniques, the forward modeling technique, which we've seen several discussions about today, and the inverse modeling technique that I just described using remote sensing data.

I think there's a -- there's real potential for a compliment of these two techniques, particularly when you talk about trying do validation of some of the forward modeling techniques. Often there aren't observations available.

And what we can still try to do is utilize different modeling approaches to look at whether we get consistency between models and whether patterns of water loss, which eventually lead to water budget and water storage variations, and then, ultimately, to predictions of percolation rates, whether there's consistency in these patterns.

And I think these techniques offer that potential.

So, conclusions. One is that the -- we believe this MODIS satellite daily ET fusion appears to be a feasible way of trying to create these high resolution products over time, on a daily basis.

There seems to be consistency in these products. What's important, you know, is making -- ensuring that both the leaf area index and vegetation cover is integrated over time, along with these modeling approaches that I described today.

There is a caveat, that is that it's important that we have these two higher resolution images at some point, so that we can bridge sort of the STARFM approach meets these sort of two endpoints to sort of integrate between scenes.

So it's important that we have that. The other -- the final thing I would like to point out is that I think, you know, as we develop these models with more complexity, we also need to be able to have models that can work from the top down and try to produce, at a disaggregated level, output that we can start comparing with these various models, over time, to see whether we get consistency.

I think that's another way of both modeling and monitoring might improve predictions in the future.

Thank you.

>>MR. ESH: All right. Looks like we are at a break time. Probably a ten-minute break time. Yeah. NRC has provided fresh tap water and moderately enjoyable air in the atrium for you during the break.

Please be back in ten minutes and we'll get our panel going.

>>MR. ESH: All right, we're going to start our panel on modeling.

We have a lot of questions to cover. We have a lot of expert modelers, experienced people, to talk about it.

One thing we wanted to do was, we figured this is the end of day two and you might be getting a little tired and need something to pay attention a little more, so we're going to take Donahue approach, which is, I'm going to wear the Donahue glasses and I will run through the audience and ask a controversial question.

>>MR. NICHOLSON: Okay, I'd like introduce the panelists, and our first panelist is Ming Zhu. He has a Ph.D. and he's a professional engineer currently at the site support program manager for the Hanford and Idaho sites, while leading groundwater and performance assessment work within DOE's EM's Office of Large Site Supports. Between 2009 and April 2010, he established and managed the Advanced Simulation Capability for Environmental Management, ASCEM program.

Prior to joining DOE, he has had -- he had 24 years of experience in environmental remediation, nuclear waste disposal and water resource development, including managing natural systems work on the Yucca mountain project.

Dr. Ming holds a Ph.D. in mineral engineering from the University of California, Berkley. Is a registered civil engineer in California and was elected fellow by the ASCE in 2009.

And Dr. Ming has a few slides he would like to go over and provide us with his thoughts on modeling experience.

Dr. Ming.

>>DR. MING: Thank you, Tom.

Well, you have so many talks, so I make this very brief, just to summarize my thoughts on the topic.

Actually, to give you a little bit of my background, because of my involvement in the EM work, I got to attend workshops like this a lot lately.

Before -- actually, before my involvement -- I should point out Craig just left the room -- he led a significant review effort, independent technical review effort of DOE and EM's landfill and other unit disposal facility performance assessment work between 2007 and 2008.

Between 2008 and 2009, there was another review led by the National Academy of Sciences of our entire technology development program.

And in the middle of 2009 there was an Office of Science -- the DOE Office of Science led a workshop to examine the so-called complex systems in the subsurface site that provided some of the insights that I would like to share with you also.

And subsequent to that, in January, this past January, we kicked off this ASCEM effort that Tom just mentioned, to develop -- integrate two sets -- we have two sets to address. A lot of the problems that we have talked about and some more.

And in June -- in mid-June this year, there was another workshop organized by our Office of Fossil Energy and also Office of Energy Efficiency, to look into the common themes in the research area for subsurface systems, involving characterization, predicted capabilities and particularly with an aim to support cover storage, ** and thermal imagery development.

And also, I had the pleasure to attend a IAEA-led consultants group meeting, very small group meeting to discuss the use -- the general topic of use of simplified versus detailed mathematical models in environmental remediation works with the goal to generate a publication next year.

And the topic -- some of the topics they are particularly interested in are very similar to what is covered with this workshop. I actually shared some ideas with Tom before the meeting, and Tom suggested that, you know, the proceedings from this workshop could be information that we could consider to cite as references for that publication.

So, my reflection from all the interactions that I have been participating in in the last year or so, I want to summarize just maybe a few bullets and maybe this could be my talking points for discussions, if the group is interested.

I think that it has become very clear to a lot of us who are working in industry-related areas, that there is a need for a integrated modeling approach, building upon, you know, what has been done in the last few decades, to really study the hydrogeological, geochemical, geomechanical, even thermal processes, in detail.

What has suffered a little bit in gaining the public acceptance and also stakeholders' acceptance or some of our performance assessment work, is we have not -- honestly not paid much attention to truly understanding the system behavior for some complex systems.

And, for example, just -- you know, so I think this audience is fully aware that -- that, you know, that widespread use of simplified, constant KD, you know, to project long-term performance of some years is just not well supported.

The technical basis for those kind of approaches need to be reexamined.

And along that front, actually, YEN has launched two initiatives. In addition to ASCEM -- actually, as part of ASCEM, perhaps, to field into ASCEM, there is the Cementitious Barrier Partnership program that is looking to detail a couple of processes, particularly for the cementitious materials.

And ASCEM itself, we're hoping in about five years, will generate some results that will have widespread applications.

And in terms of the practices, we heard from

Roger yesterday about what YEN is doing internally under the DOE 435.1 for low-level -- self-regulated low-level waste program.

But, I think it's also becoming widely recognized now that the cleanup criteria at -- and perhaps along that line, assessment duration, whether it's 500 years or 1,000 years, need to be -- in my view, need to be tied to the low-level risk that could be site specific.

And, frankly, for when we were talking -- had the IEAE meeting in Vienna -- about the criteria or the recommendation for setting up the criteria to development in the states, in developing countries, some of the thoughts were, uniform number may not really apply to, you know, all countries.

And, certainly, I think another vulnerability in our existing work is a lack of two sets, to some degree, and definitely not a widespread practice of doing facility clarifications in the system.

And again, ASCEM was trying to develop

some -- you know, some numerical schemes to help people to better quantify, particularly conceptual -- conceptualization, different conceptualization, which is a weak spot in some of our past work. Given in -- you know, in high level waste programs, like Yucca Mountain, where we're not able to fully quantify the conceptual models.

And because of those needs, I will recommend for NRC and folks also coming from EPA to consider the adoption of flexible regulatory framework, so that when the development work is going on, you know, the framework can be -- can accommodate some of the modifications that would become necessary.

But that, I can give you just a thought. For example, when ASCEM or codes like ASCEM become available, perhaps it's a time to reexamine, you know, the rules and regulations well, those advanced two sets can be made best use of in the applications.

And lastly, I would also make a kind of self speech for selfish reasons, because Tom and I both sit also in the steering committee for the multimedia environmental modeling group, ICME.

And we're trying -- in the last few months, trying to set up a working group called Integrated Monitoring and Modeling, which I think is accurate by quite a few presentations from this workshop.

I think there may be some synergy that could be realized by teaming up together.

I'm actually trying to recruit a colleague from our ALEXI management program to, you know, represent the monitoring expertise and you're co-chairing that group with me.

So in that area I think there is a lot that could be done. But, at a high level, I think some of the issues that could be of interest to look at is, not only to use the integrated two sets, like ASCEM to better analyze the data sets, but also, perhaps, using the multiple lines of more defensive measurements.

You know, you have widespread concentration measurements on the sites, but you also have, you know, low resolution and maybe sporadic geophysical measurements. You have maybe tracer, you know, test data, isotope data.

You have, you know, other type of really biological measurements. All of those will provide hints about how each of those system or part of the system really behave.

By putting them all together in the integrated process may give you a much better understanding of how the pieces are really putting together -- the pieces of the puzzle are putting together, trying to get a better understanding of how the system really behaves. So those are some of the thoughts.

And, in addition, we all recognize some of the sites, particularly some of the long-standing or more challenging DOE sites, having sited for a couple of decades now, at least.

And there are tons of data collected and some, you know, actions were taken and monitories ongoing. And it may be high time right now to take a closer look at those monitoring data, because you have the five-year, ten-year review, to see how those data really compare to the previous modeling predictions. And that's an aspect of the model foundation that we can take as a little hint.

Those are my thoughts. Thank you.

>>SPEAKER: Thank you very much, Dr. Ming. And join us at the end of table.

The other person who has not spoken yet, who's a member of our panel, is Dr. Robert M. Holtz. He's an associate professor of geology and geological engineering at the University of Mississippi at Oxford.

He has a BS in geological engineering from the South Dakota Technical Institute and an MS in geology from the University of Texas at El Paso, and a Ph.D. in hydrology from New Mexico Tech in Socorro.

Dr. Holtz owns -- has over 26 years applied research experience related to nuclear waste disposal, with a focus on flow and transfer processes in pores and fracture media. And I would like to add, it's not in his bio, but he has been the past chair of the Unsaturated Zone

Committee of the American Geophysical Union and has done great work there.

Now, in talking with Dr. Holtz, he has done a lot of work at the new low level radioactive waste site being proposed in Texas.

And one thing that caught my interest was that he thinks that he has both field evidence and modeling results that demonstrate there hasn't been any significant recharge to that area since the cretaceous period. So I said, that's fantastic. I said, you should use the old Sinclair dinosaur as your logo.

I'd like him to try to explain what he means when he says that there has been no significant recharge since the cretaceous period. And what lines of evidence has with regard to both field observations, as well as modeling.

Dr. Holtz?

>>MR. HOLTZ: Well, Tom just dropped this one on me.Significant recharge, I would say that this group of rocks has likely never been completely saturated, that would be a better way of putting

it.

You know, I'm not going to get into an argument about what significant recharge might mean. But, I've been involved in the WCS site out in Andrews County, Texas now for about three, four years, and most of my work there has been focused on hydrogeologic site characterization activities, some modeling, some geostatistics efforts.

And it's through some of our site characterization activities that, you know, I've grown to appreciate what an interesting site that particular location is.

We -- you know, a little bit of background. The facility is designed to be constructed in Triassic red bedrocks.

These rocks are predominately old, they're ancient -- they're paleosols, ancient verticils (phn), in fact. There are swelling clays present within the materials. And those are some of the materials that are used in the landfill covers, because there are swelling clay is present.

Anyway, we've taken 12 cores out at that site, 4-inch cores, where we used both -- we drilled them with air and we drilled them with air water mist. We used dew point potentiometer, as well as filter paper techniques to measure water potential or capillary pressure in the cores.

And later on, adjacent to those boreholes, we drilled a separate set of holes. Joel Hubbell was working on that with me and we installed advanced tensiometers in some zones. We installed heat dissipation sensors, thermocouple site pyrometers, vapor ports and the like.

And one of -- you know, our observations were that in the course -- first of all, our two techniques lined up very well, as far as giving us data, the filter paper technique and the WP4 dew point tensiometer showed very good agreement with the data.

And what we saw is in these cores, depending on which core you were looking at, you would see average capillary pressure of, let's say 2 megapascals or 3 megapascals, and sometimes it would go up as high has as 10, 15 megapascals.

And in some cases it would get down low. But we really saw unsat -- what you would interpret as unsaturated conditions in these rocks.

Later on when we put in the bore holes what we observed was initially it takes a long time for things to go in the equilibrium with a bore hole. It can take, literally in some cases, up to a year and a half to -- for these instruments to come into equilibrium with the bore hole.

And what we observed was that there was a -- the capillary pressure dropped to values that may be say, you know, five-tenths of megapascals. Now, we use two different techniques.

A thermocouple site pyrometer, as well as heat dissipation sensors, thermocouple site pyrometers have a lot of problems, they die quickly, and so forth. But in general, when they were working they gave us pretty good agreement.

So we think that we got good data there. And so we got this problem where we got core data that gives us one set of potentials and we've got instruments in the ground that give us another set of potentials.

And we've got no reason to disbelieve either one of those sets of data.

You know, We done calculations looking at, you know, should this -- should the cores expand, could that give us the kinds of things that we would be seeing. And, you know, it turns out that falls down into the detection limit that the device, that kind of expansion.

So we've done -- we've done some verification of our data. And the only sort of conclusion that one can come to is that the capillary pressure at depth insitu is really affected by a compressed air phase.

So it's a compressed and pressurized air phase, so that when you drill a hole in it and put instruments in there, what happens is the air phase now goes into equilibrium with theatmospheric pressure, which is atmospheric pressure.

For those of you that don't remember the definition of capillary pressure, it's the pressure in the non-wetting phase minus the pressure in the wetting phase, if I decrease that pressure in the wetting phase I'm going to see a drop -- I mean in the non -- if I decrease that pressure in the non-wetting phase I'm going to see a drop in the capillary pressure.

And so, that's what we think is going on out there. We've been developing some new invasion percolation models. Based on some models that I had developed earlier, which was based on work that Bob Glass had done years and years ago. And we've been using those invasion percolation models to simulate this air entrapment and compression process.

Now, this group of rocks really has only had one time in its history where it was covered up with water, and that was during a minor transgression during the cretaceous period, it may have lasted a million years or so.

And from the geologic evidence at the site the water depths were not much. But, currently, what we are attempting to, simulate, and we're having some pretty good results with, but we're not completely finished with the model, is -- what we're simulating using this invasion percolation approach that allows for capillary forces, (inaudible) forces and air compression, and it's fully 3-D.

We're able to replicate what we observed in this case. We put 100 meters of water on there. The capillary forces in this particular group of rocks are strong.

Average air entry pressures are a megapascal, they range from as low as .02 megapascals to up to greater than 50 megapascals, capillary forces are strong. Basically, you drive -- you create a wide wetting front that drives the air downward, compresses it into local regions where you have larger cores.

And then, you know, we've done some calculations with respect to diffusion, to look at things defuse out of this.

Our first sets of calculations suggest that after a million years 87 percent of the mass of the gas phase remains, after ten million years you have 35 percent.

Then, if you remove that C away, the gas expands back out and you end up with a distribution of moisture that is similar to what we have observed in our cores.

So one could argue that even throwing a -- in this particular instance, even throwing a cretaceous seaway over the top of this, we were not able to fully saturate this group of rocks. Namely because, you know, to start with they were unsaturated. There were soil deposits in a semi arid environment.

>>SPEAKER: Thank you very much.

>>MR. HOLTZ: If you have questions, you can grab me after this.

>>SPEAKER: The other person on our panel is Garry Willgoose, and we listened to him yesterday talk about lane form evolution. He's with the University of Newcastle in Australia and -- there's Garry.

Okay, Garry, would you like to comment on this interaction? We've heard some examples already during the panel discussion, but earlier the relationship between field observations and monitoring, geophysical methods, direct (inaudible) measurements and modeling and how those two should interplay.

What are your thoughts?

>>MR. WILLGOOSE: I guess -- I come from a group of researchers that are very interested in what's referred to as (low audio) estimation. And essentially what this is about is you run a model, Monte-Carlo, like we've heard about today, and then you start to look at what do you want to know about this model.

So you start to identify what are the outcomes of that model that are critical. You look at the standard deviations and the variances on the predictions from model. And then you start to look at the inputs or data collection that you might be able to do and try to quantify what's the best type of data that would actually reduce the (low audio) that you have on the model.

And by that way, you actually design optimal -- essentially optimal data collection. But the key thing about that is that it's not a matter of collecting all sorts of data or collecting everything that you can think of.

You actually use the model to essentially focus what sort of data collection you need to do. And you actually can quantify essentially the improvement you can get out of that by doing this.

That is all subject, of course, to the, model actually being any good in the first place.

So, you know, we take that as sort of a given. But one of the big advantages of this is that it's actually -- we find when we're talking to clients, it's actually really good way to actually sell to the clients the value of collecting data because they can start to see, essentially, how this is going improve the reliability of the estimation of failure or performance or whatever.

And in that way you actually see, essentially, the use of models and the data in a really natural sort of environment where they both going on.

I mean, we always talk about that we got to collect more data, we've go to get better models and it's a partnership and all that sort of thing, we've talked about that for many years. But this actually provides you with a methodology of actually how you go about that.

>>SPEAKER: Thank you.

One of things we've been hearing during our discussions both today and yesterday, is DOE work order 435.1 and we've also heard about EPA criteria 40 CFR 192, Loren.

And the question is: Should that new criteria include modeling? And if they were to include modeling, what are the criteria to determine the detail of modeling, for example, should the actual processes changing a GCL be modeled.

Craig what is your opinion?

>>MR. BENSON: Well, let me -- and before we do, that let me rephrase a little bit. Or at

least put some context to that question.

>>SPEAKER: So I think during our session and throughout the workshop, we've heard people talk about if you can all build an influence diagram in your head. They've talked about the diagonal.

Okay, so we've heard about hydrology, we've heard about erosion, we've heard about ecology of plants, we've heard about disruptive processes, et cetera.

And I think this question that we're posing is for regulatory decision-making, is it enough to be able to address that diagonal?

Is that going to allow you to make effective decisions and effective long-term predictions or do you need consider the off diagonal terms, and which ones are they?

We've heard some people talk about some of them usually -- and usually we don't hear that at all, but we've definitely heard some researchers talk about some them.

I know just in Terry McLendon's talk he mentioned how the -- I think it was in yours too

-- he talked about the plants effecting erosion, that's a good example of an off diagonal combination.

So that's just some context for the questions.

>>SPEAKER: Craig, do you want to address that?

>>MR. BENSON: It's a pretty big question. I wish I wasn't the first person to talk on it. Well, I guess, I'll step back and ask -- get into that a little more generally.

Well, I'll give the it depends answer. That's the easy out. But it -- well -- but it does though, because it depends on what level of detail you need for a particular problem. I mean, if you needed to understand what mechanisms were driving alterations in a barrier. For example, you might need to build a fairly sophisticated model.

But if you understood that those mechanisms under -- occur under certain circumstances that are fairly well defined, then you might create a simpler model that represents the outcomes of those mechanisms and the time sequence in which they occur.

So it depends on kind of the level of knowledge and the detail you need to look at the particular problem that you're trying to solve. And so I guess that's the way I would put it, that there isn't a simple answer to that, it depends on the particular setting.

I think in some cases you can use broader based aggregated models once you understand the mechanisms and where they apply.

>>SPEAKER: I'd like to respond to that somewhat, too.

Now, you originally couched the question in terms of the regulations. There's also 10 CFR 61. And all of these are generally based on the concept of reasonable assurance, at least 10 CFR 61and DOE order 435 use that term reasonable assurance.

And I'm actually not very familiar with 40 CFR 192, but 191 is inherently a probabilistic sort of metric. And these others, by throwing in that term reasonable assurance, they are sort of hinting at the idea of a probabilistic analysis or at least, how do you get to reasonable assurance? What is it?

They don't really define it, unfortunately. So it's sort of the big-wig words in the regulation as reasonable assurance. That means then that some decision-maker has to decide what's reasonable.

And how assured they are. And so, that sort of gets into the idea of, well, are you happy with 95th percentile passing, but 5 percent not, or something like that.

And so, it is suggesting a probabilistic approach. And then, as I mentioned before, if you do that, then -- well, you said are there perhaps changes that might be put into the regulation to require certain levels of detail or something like that. And I would be very resistent to getting too prescriptive about anything like that. Perhaps one could provide a lot in guidance that would help define what reasonable assurance is and how you might get there.

There is guidance out there already, the performance assessment methodology is a good starting point for a lot of that.

And then, as Garry was saying and Craig too, that the model itself can provide guidance on what's important in the model and what to go after in certain details. But, it's a very site specific and even contaminate specific and time specific thing.

If you're interested in extremely long term, you will be interested in different parts of the model than if you're interested in the very short term. And so -- yeah, there's no way to answer that in a specific way, except there are approaches that do work, and I recommend maybe -- as in the performance assessment methodology.

>>SPEAKER: See, what I would add -- what I would add, John, is that I believe the regulations, at least many that I'm familiar with, they try to provide the requirements that you need

dealing with the terms on the diagonal. And what my part of the question or addition to the question was, in what particular problems or areas is it the combination of two things or three things on off diagonal terms that can have big effects?

Maybe -- I would hope that we don't have too many of those in the short term because we've been studying these things for some period of time now, and we've learned about them and hopefully we got most of the first order of things.

But what's the panel's opinion about the off diagonal terms and whether they can have a big effect, especially for these long-term predictions because these are -- this is the area where we're evolving to and trying to -- considering as we are revising regulations and guidance. So how do we deal with those off diagonals?

>>SPEAKER: Okay, I just thought I was going to add a quick thing.

>>SPEAKER: Okay, I just want to -- I support the idea that you really need to dive in, look at

the information that you have, start doing some analysis to identify what's important.

I think that's a natural part of the process. And if you can start getting a feel for what gross behavioral aspects of the problem, appear to be most important, based on what you're doing at that time, then, you can start narrowing it down and start getting into these what ifs and start building a branch of what are some of the off diagonals that could affect that specific piece.

But I wanted to -- another -- there's two ways to look at this, we can try to push back towards the simple and ignoring off diagonals. But if you get into optimization, if we get into situations where we're trying to make shorter covers for material requirements or any other types of considerations, then you may need to get into some of these more detailed.

So from a regulatory compliance you may not need it, but if you want to start justifying a more optimized design, that may force you to start looking into the more detailed aspects.

>>SPEAKER: By Dave putting on those Phil Donahue glasses, I feel I can ask this question now. I noticed during the presentation they were very general, like on modeling and so forth. And Craig Benson, I think it was him, he said the models -- the codes model that do exist now, they're not very good.

They are -- you know, they can do a little bit but they are not very specific or so.

And Tom was asking when should numerical modeling of engineer's barriers be performed, or at least that was part of his question.

Now, I'm wondering -- it sounds like we're just talking about engineered barriers here. And not the whole -- the unsaturated (low audio). I'm just wondering, it sounds like we're kind of at the beginning, I'm going to ask just the general question. Is it worth pursuing?

I mean, we don't seem to be very far -- or my question would be: What do we hope to gain out of doing better numerical modeling of engineered barriers, of covers?

Because, so far, I don't -- like I said, the topics were very general.

And so it's kind of a devil's advocate type of question, but what do we hope to gain by putting a lot of effort into doing modeling of engineered covers, because they are rather small systems compared to other things and not needed that complicated?

>>SPEAKER: Maybe I'll just steal that down. Yeah, I guess -- one thing I didn't mean to imply from my presentation that our models aren't good or we can't do things with them.

I just think we need to understand their limitations. At times there's a tendency to trust the models because they're sophisticated and they've got of input and they're -- got a neat package.

That what you get out of them must be right, and that's not true. There's always an abstraction. We have some pretty good models.

And I think, like what Andy showed was some of the really high end things, that we can really do some really good predictive work.

You know, I -- one of the things I think that we can do is -- and given the advances we had in computational power and our understanding of different elements and systems now, is to put together more aggregated models that look at the entire package instead of a cover model.

And really need a system that looked at the containment, a model looked at the containment system and how a couples with the vadose zone below. And then perhaps groundwater.

So I think, you know, if we were going to create the next generation of models, that's the way I would like at things, that we ought be creating more comprehensive models. And at the same time, working at some of the deficiencies in the elements, but create things that allow us to look at the whole picture.

>>SPEAKER: But that would be a recommendation to carry forward to Section 6.

>>SPEAKER: That would be a good recommendation. And that actually fits in with, I

think, some of the things that Kent was saying, and I don't know if Kent is still here. But also with some of the initiatives in DOE right now to develop some more comprehensive modeling capabilities.

And at the same time you've got to work on some of the deficiencies and some of what we know now. But I think that's where we ought to be going.

>>SPEAKER: How did each of you know, those of you that do modeling on the panel, how do you decide whether your model is complete -- whether your model is complete enough?

>>MR. WILLGOOSE: I was going to make a more specific comment, but that's -- that actually sort of touches it. We've exercised their brain quite considerably the last ten years or so of what the next step is for SIBERIA. For instance, you know, it's got a bunch of things in there.

What you find when you create this, essentially coupled models, let's take for instance vegetation as an example, is that the vegetation -- if vegetation doesn't respond to everything else then you can just apply it in there.

But if it responds in dynamically to the changing environment around it, then you have to actually create a coupling of those two things. And what you invariably find is the magic of, the surprise that has come out of the coupling, not actually out of the core model you put in.

So you end up finding that there are things that you don't understand about having coupled together. The way you look at the vegetation independently from the erosion or from soils you don't see because they don't really show the sort of dynamics of the experimental scale, which you've done before. And we've been continually surprised by the behaviors we see.

But I guess to -- specifically -- one of the things -- one of the things that we are currently doing -- I guess I've not heard of GoldSim until today, is actually creating essentially a framework where we can couple all those models and we can (low audio) not so much -- we want to avoid a situation where you build in a specific model.

But you allow people to couple in whatever model they happen to be comfortable with. And the danger of that is essentially the coupling itself may be the weakest link. But at least it means that you're building upon your existing knowledge base, whatever that happens to be, it may be stronger or weak.

But, I mean, certainly with the length of evolution, you asked specifically about what model might be off diagonal (inaudible).

It's quite clear, at least for a simple cover, that the evolution of the materials on the surface, the breakdown and almost the creation of the soil from the rock barrier is an important thing.

And the vegetation response to that because of the water holding capacity and the geochemistry that's going on in there.

So, at an absolute minimum, we think that there needs to be a couple erosion, vegetation and soil development model at an absolute minimum. So you've essentially got the coupling of those three.

Now, that, I have to say, is extremely challenging. I mean, to go back 20 years ago, we were running SIBERIA, just the erosion component of this, on the Pittsburgh Civic Center. We never get enough CPU time, the slowest compatible model, which we developed over the last ten years ago, ten years ago we were running on a slow computer and we couldn't get enough time for that. Now, we've managed to break that down.

Now, the coupling of the vegetation, I'm sure it's going to require similar sort of demands, from that point of view. So I think computing time as much as anything else is probably the limitation.

>>SPEAKER: I personally experienced that limitation at one time where I set a problem to run and I came back overnight and it had simulated .13 seconds of the problem. And this is where I was in the Craig Benson, maybe I should be doing

an experiment. Or Bill Albright, I think, said that.

>>SPEAKER: Other panel members, completeness of your modeling, how you think about that?

>>SPEAKER: I'd just like to comment on the focus on uncertainty. You know, I think Monte-Carlo approaches and coupling of models together is a great idea.

It offers the potential to help us quantify to some extent the uncertainty in the decisions that we have to make.

One of the things that's really critical there is that we have to make sure that the models that are coupled together are well parameterized. And that they capture the essential physics to the problem that's at hand. If they don't, we run the risk that, you know, instead of having a realistic uncertainty window like this, we have something that's like this.

And so, you know, we have to -- have to, you know, we've got to be careful not to get too carried away by coupling together an erosion model, a plant model. You know, I've never seen a soil development model that would be predicting changes in, say, moisture characteristic barrier behavior or relative permeability behavior and things like that, that have ever been validated. So all of those are great research ideas, but when it gets down to practical application, I think we need to draw a line.

And that line, you know, we need to recognize that those effects are there and do what we can. But we shouldn't be out there just, you know, hey, we got a new model, let's just tie all of these things together and run them all and see what happen. And, you know, I gave that example earlier about errors that are introduced from measuring things.

In that particular case, what I had done was I had simulated measurements using a tension infiltrometer, a really simple device for measuring unsaturated hydraulic conductivity and slow parameter for the relative permeability.

I had simple errors in there. And it

actually led -- you know, orders of magnitude errors in stochastic model predictions as compared to reality.

And in this particular case, I knew what reality was. We had very simple -- very simple models. In real life we don't know what reality is. We don't know necessarily what the physics are.

And I think a number of our speakers today gave great examples of that, you know, for 10, 20 years people didn't want to believe that gravity driven fingering was important and the focus flow occurred in the unsaturated zone.

So, you know, there's a lot of physics that could be missing in some of these models. And, you know, we need to be very careful.

>>SPEAKER: Along those lines I think you mentioned and previously, in a couple of talks, that people identified data needs.

And I think we have a question up here about data needs. But -- so generically what are the primary data needs, maybe in your area of specialty or more generically, for those you trying to simulate these problems, where is there kind of a gap in information where there could be a benefit to collect some more information?

Can you just walk through it, John?

>>MR. TAUXE: Well, I wanted to answer some of the other questions.

>>SPEAKER: You can answer the other questions too. Sure, go ahead.

>>MR. TAUXE: Quickly, your off diagonal terms, you got to get there by doing a global sensitivity analysis. A one good time sensitivity analysis is never going to show you the coupled impacts of things.

The other one is when do you know if your modeling is done? Remember, why we're doing this. This is all, at least from my perspective, this is in the decision context, to try to make some decisions about sites and what to do with them. If the decision-maker can make a decision that's defensible and is based on stuff, then you're done with the model.

If we're just looking at cover and specific models, modelers would just keep going forever. I'd love to, you know, but in the decision context you're done when the decision can be made.

As far as data needs, I don't know,I'm still learning about covers. And I keep thinking about this in the whole performance assessment context.

And the big gaps in the performance assessment have to do with human behavior and future demographics and things like that. And I expect that in that big scheme of things covers are going to play a much more minor role in determining overall risk, which is necessary to make the decisions than other big parts of the model.

So I'll leave that there. I know we're restricted to covers and if we're going to talk about that, I will leave that to other folks. But there are a whole other things that need to be coupled with it, if it's hard coupling in vegetation, it's even harder to start coupling in those conversion factors, it's human behavior, exposure pathways and all that sort of stuff becomes even more complicated.

I wanted to not answer your question either. I want to got back to this bigger model question.

>>SPEAKER: My questions are pretty clear, aren't they?

>>SPEAKER: That's the beauty of us having a microphone, you know, we get to say whatever we want.

Now, I think -- at one point I think we do need to be careful when we aggregate models. We want to aggregate models where we're pretty confident we have a lot of validation behind them. Certainly, we don't want to stick anything in there, that would be a mistake.

But on the other hand, there's a lot of models. I mean, UNSAT-H, that's at least 20-years-old. And Kerry Rowe has done work on liner transport models for at least 20 years. And these are pretty well validating codes that we can start putting together to look at systems.

And -- but also recognizing that there's some things that we're not going be able to do and we may have no piece-wise in some of that information when you talk about data needs and things that I would like to see. And one of things that I look at in models when I want to make longer term predictions is how things evolve over time and how I can build in mechanisms and parameterize those mechanisms to be able to allow, for example, soil pedogenic processes.

How can we build that into the model so that it's not something where we're I'm -- every 20 years I'm changing the parameters to reflect something new. But to be able to actually build in the processes. I think that would be a great thing to be able to do.

I think with vegetation as well, to be able to simulate the evolution of vegetation and perhaps in some Terry's models we're able to do that already, and I just don't know that.
So I think being able to build in some of these evolutionary processes and being able to parameterize those would be a great next step.

>>SPEAKER: Terry, if we wanted to take your models and connect them to SIBERIA or an UNSAT-H type of model or both, or STOMP, what would be your data needs to do that?

What would -- in an ecological plant evolution succession area, what would be the information needs where you feel you're lacking right now? Or do you think you have adequate information, it's a matter of -- it's more an integration effort?

>>MR. ROWE: That goes back to a -- related to the question of when is the model finished. Okay, in all our applications of this, and we made them from Indonesia to Maine, we've been able to operate it satisfactorily, in every case, with existing data.

Now, we can improve it with better data. So it's a question of could we link data to some of these other models now and get improved results from what's available now from a combined package? Yes. Do we need anything more to do that? No. If we had a additional data could, we do a more efficient job or get a better prediction? Yes.

So it's more of a question of improvement rather than being able to do it now. As in everything else, the more specific data you have, site-specific, species-specific, soil-specific, the better.

The longer the period of precipitation record that you have, the better.

So, the more complete characterization spatially of your soil profile, the better. But you can't do it all.

So at what point do you say, good enough? So start right away? That also helps us identify where you get the best bang for your buck, the sensitivity analysis.

And where do you really need to collect more data for a specific application? Where are you lacking? So we have all the pieces now, it's just a matter of putting them together.

>>SPEAKER: Roger, I saw your hand.

>>MR. SEITZ: I'll give you one -- I can answer a couple of the questions. But I'll give

you one specific answer for data needs.

I think what we found in our cover modeling in Savannah River is the timing and, I guess, the length of time, the time when it's initiated when HDPE layer begins to fail and would allow root penetration throughout, turned out to be really important.

In terms of when have you done enough modeling? One thing that we try to do in performance assessment world, you talk about multiple lines of bringing.

We try to run multiple models. We want to use different models for the same problem to give it -- that helps build confidence, because every model has its bias.

And so by looking at least two different approaches -- and it's amazing often a very simple model will inform a detailed model. And, likewise, a detailed model would inform a simple model.

One last -- on the data topic, one thing -- a challenge that I feel for the research community is we know that there are benefits from the more complex models, but how do we optimize this relationship between the data requirements and our ability to do these complex models?

If we can develop some approach -- some real creative thinking on how we can populate those models defensively, would be very helpful.

>>DR. MING: I would just like to add a little bit to what was discussed.

I think the data needs and also the need -- going back to your earlier question. The need for detailed coupled processes models, perhaps, for the engineer barrier, depends largely on how important you're expecting the engineer barrier to perform, in terms of meeting your dosing requirements.

If it plays a bigger role, you honestly need assurance about the long-term performance. For that, you really need to look at a lot of the processes. Again, for the near term, perhaps it's only sedimentation, you know, and now mechanical degradation, as a result of -- for example, for the concrete systems, cementitious system, stress-induced cracking, that kind of thing. And which you could perhaps develop by performing some lab testing, you know, extracting on that basis.

However, if the system, engineering plays a less important role, where you have to rely on the supplement contribution from the natural systems, is a different ballgame.

In those scenarios, you know, you have to really dig it much deeper into some of the database, connective parameters that you are using to quantify those detailed biochemical processes.

So that -- in those cases, well, you know, the (inaudible) parameters, well, those could play into -- well, you know, will have to be studied in some detail.

>>MR. ESH: And since I'm here next to Andy, I know in your talk you had put a couple of question marks besides "disturbance."

Do you want to talk a little bit about disturbance and how you may or may not incorporate that in your model or what data needs you would have?

>>MR. WARD: Well, it's something that I think -- well, going back to the question of whether the model is complete. It's -- based on the data that we've collected, it appears to be a process that we need to be able to model.

At this point, we have not really tackled it. I know we've been looking in the field of geomechanics related to cracking, but it's not something we have attempted at this point.

I actually am hoping that I might learn something before I leave here as to how we might approach it.

But, certainly, in these covers we've seen a fair amount of the biointrusion. There is borrowing that consistently happens, there's cracking, even though it's a silt loam, we do see cracks form and seem to repeat formation in the same places.

And I think these are things that will affect near surface evaporation, that will affect the water balance, so at some point, we need to address it.

>>MR. ESH: Thanks. Tom?

>>MR. NICHOLSON: I just wanted to ask Bill Kustas a question. I'm very fascinated by the approach he talked about, the landsat.

Now, Bill, one of the issues is what might be disruptive to an engineered cover may not be of a long duration, may only be 24 hours or even less.

Looking at those dynamic processes, how can you capture those with both land-based monitoring coupled to remote sensing?

What are your thoughts?

>>MR. KUSTAS: Well, it's -- you know, it's clearly a problem of the temporal resolution. So, if there was ever a possibility of a constellation of satellites that have high resolution data available, it's going to be -- that's going be a hard one to deal with.

But, on a related note, something I thought about too in our discussions about the various complexities of models and what they're able to simulate, I think one issue that wasn't clear to me that -- I mean, it was touched upon in different talks, but the spatial variability that has to -- you have to deal with here, adds another, I think, level of complexity, because you may be able to model this process at a sort of plot scale, but what happens when you -- when you, you know, go beyond that to landscape scale, and how do you validate that, that landscape scale model.

There has to be some thought as to the observations you might need to do that. And I personally think that remote sensing can provide some spatial information that might be useful somewhere along the line, in terms of either the monitoring or the validation that I think needs to be looked at more closely.

>>MR. ESH: Well, we heard a little bit from a number of you about time scales and spatial scales, but Andy mentioned hourly data for some aspects of this problem, Terry said daily, but he could do hourly, if somebody needed that.

I think, Bill, you were doing 15 minutes, right, for some of your data?

Craig, I think your measurements were pretty high frequency for a lot of the ACAP stuff, right?

>>MR. BENSON: Yeah.

>>MR. ESH: And I'm guessing, Dr. Willgoose, you had some fairly high frequency data in your simulations. Although you did say performance was dominated by somewhat of the average -- the averages and is variance around the averages and not necessarily the extreme events, if I remember correctly.

>>MR. WILLGOOSE: Yeah. That's an important point, actually, is what level of resolution you want.

If you just want predictions -- in a lot of these cases you can develop, essentially, what are known as effective parameters, they are parameters that sort of characterize the short time scale or short spacial scale properties.

But they're not very good for going back and sort of doing a retrospective. And one particular case that we've been faced with is there was a major storm over one of the mine sites they had done a lot of simulations on and they want to back and say, okay, given that we normally do air resolution at about a yearly level for erosion over a thousand years, can you actually simulate what's going on during this one event that occurred over a couple of days, where they had about 700 millimeters of rainfall. It was basically a hurricane went straight over the site.

And so, you know, you have to actually look at that in a slightly different way. But, the resolution is, essentially, using effective parameters.

And the key issue of a resolution is then what do you need to do computationally -- like if we want to track all of the grading of all of the material that's eroded, we have to do that in second time steps. Which is why we needed the super computer to do that soil stuff ten years ago.

So, you know, I mean, that -- but if don't want to track it at that level of detail, you can do it at a larger time step, event scale, monthly, something like that.

So, I will say that I don't actually have a time scale that I look at. It really depends on what you want to track and what you want to get out of the simulations.

>>MR. ESH: It seems to me that because of Morris Law, our computers are getting ahead of our intellect. But maybe that's just my opinion.

>>MR. WILLGOOSE: No, I could deal with a faster computer.

>>MR. ESH: I guess people have some ideas that they could use a faster computer to apply them to.

>>MR. WILLGOOSE: Well, you start doing Monte-Carlo simulations and before you know it, I mean, we did one Monte-Carlo simulation that took 200 CPU days, because we wanted to do 100,000 simulations to completely explore the space of all the variability, and because you're looking at failures that are the frequency of maybe one in a million.

You need to do hundreds of thousands of millions of simulations to get that little tail at the end of the probability distribution.

>>MR. ESH: So, do people feel comfortable with the models and processes that they're using, on the time scales that they're using, and being able to extend them to, say, much longer time scales, computationally, I'm talking more so from here. Conceptually, there will be some questions about the validity of it, but I'm talking just in like an upscaling type question.

I know you deal with that because you have to do thousand-year simulations, but, Craig --

>>MR. WILLGOOSE: Saying that if you asked us to do 100,000 sim -- 100,000-year simulation, could we do it?

>>MR. ESH: Yeah.

>>MR. WILLGOOSE: Yeah. We're doing million-year simulations for natural landscapes, so it's not a problem.

>>MR. ESH: Yeah. I think -- for -- for your very complicated element of that diagonal that I

was talking about, where yours really deals with some of the off-diagonal terms, definitely, but not necessarily -- I guess maybe we would stress the limits of our computational ability if we started coupling, say, your model with the STOMP or with an EDYS or EDYS --

>>MR. WILLGOOSE: Well, the one thing --

>>MR. ESH: That's where we get in trouble, I think.

>>MR. WILLGOOSE: One thing I'd say, if you want to do models with really highly spatial result simulations, you're not going to be able to do Monte-Carlo simulations.

>>MR. ESH: so You lose the value of the Monte-Carlo at the expense of the spatial resolution.

>>MR. NICHOLSON: Let's ask the question a different way. Let's imagine we're all out in west Texas and we're the public and the question is going be asked: Have you looked at a variety of disruptive scenarios that may occur in the future? How would you formulate those scenarios

and look at them? And based upon either paleo-hydrologic information or knowledge about similar processes, under different climatic regimes, how would you go about formulating those scenarios, modeling them, and what would you inform the public as to your understanding?

>>MR. WILLGOOSE: Well, I guess, the example I just gave of the -- retrospective of the hurricane that went over the site is a good example.

Yeah, that wasn't, until three years ago, a scenario that had never happened, and people were interested in. Now it was a real situation. So, I guess, that's one disruptive situation that you could look at.

In terms of the paleo data, I mean, in some sense, you just use paleo history of climate, just like you would do a simulated climate for a climate simulator or climate record, in that regard.

In terms of other types of things, that really would depend on what the public wanted, essentially.

I -- we've never run into something that we haven't been able to cook up a sort of a simulation to be able to do without short of actually coupling in, you know, completely different physics.

>>MR. TAUXE: I can give an interesting example about that.

We're faced with modeling into the very distant future, with the depleted uranium problem. And, you know, if we're interested in modeling out until we reach central equilibrium with depleted uranium, that's a 2-million-year proposition.

And now we're getting into major climate changes, glacials, interglacials, there would be several of them, there could be tectonic changes almost in 2 million years. Certainly evolution could take a significant change in 2 million years.

How do you deal with these things? It quickly dissolves into a great deal of uncertainty.

The one thing we are certain about is the rate of ingrowth and decay of radioactivity, and that's about it. But we can go back -- as far as that's concerned, that's anybody's guess.

As far as climate change is concerned, you can go back into the record and look over the last -- well, however far people have gone and whatever region it is you're looking at and consult those paleoclimatologists about what might happen in the future and what the probability might be and that sort of thing. And then, depending on your site and what might happen, try to build that into your model.

>>MR. ESH: Tom, we're what 5:40. You want to take a question or two from the audience and see if there are any public ones?

>>SPEAKER: See if anyone on the phone lines has any questions?

>>MR. ESH: Is there anybody on the phone that would like to ask a question for this panel, in general?

Anybody in the audience that has a burning question that wants to get in the way of everyone and their dinner?

I'm seeing who's bold in the audience here. Anyone?

All right. Mark, okay.

>>MR. FUHRMANN: This isn't a question, this is just one more modeling thing that I think would be very beneficial for us.

And, you know, as Kerry Rowe was showing us, HDPE is apt to last a lot longer than we had anticipated previously. And right now it would be very good if we could model, through the antioxidant, the oxidation, and then couple that with the stress field that you have in the field with the reduction in terms of strength or other strength properties, to be able to go, how is it likely to degrade in terms of cracking over time? And when does that become important? Because, from his data, it may be way out before that becomes important, until we have those cracks forming. And if we can have that kind of coupled model, that would be very helpful.

>>MR. ESH: With the data to verify it or

validate it, of course, right?

Bob has a question.

>>SPEAKER: I'm going to take it one -- go to the opposite extreme of the geomembrane maybe lasting longer.

Of all of the coupling and the modeling, I haven't heard much about the waste and whether the processes in the waste that should by coupled -- going back to what we were talking about this morning with raveling, so if you get concentrated water getting down, and is that considered in any of the models and what effect that might have?

>>SPEAKER: We faced some questions about that when I was in Idaho. And we ended up specifically running simulations that exaggerated the infiltration through specific sections of the disposal facility.

So -- and that tends to be how we address it. We get these comments, these questions that come up, and it leads us to run some models and look at what the real impact could be.

>>SPEAKER: But in a model like that, then do

you physically say that there's a different mechanism now that may internally erode material in there, or is it just more of the same, that the constitutive relationship would say, can you just accelerate it or run more water through it?

>>MR. FUHRMANN: No, it's relatively simple. These kind of things are quick turnaround, you do what you can in the time you have.

>>SPEAKER: In terms of modeling capability, we have to (low audio).

>>SPEAKER: I'd like to make a statement on ET covers and UMTRA covers, in that really -- you know, you can model all you want, but in a degraded state, the cover really won't do any better than a natural analog.

And so, for example, the question is: When do we use the models? What's the importance of the models?

I think if you're looking at an ET cover, you go out to your site and you look at what's there already and say -- let's say enter, apply a region or area where there's not any focus recharge, and that's about the best you can do.

And then what you would use the model for is to perturb that condition, to look at a climatic change, or changing something that you can't do.

Maybe you don't have the right burrow source to get the same soil, so you change the soil slightly. Or maybe you don't have the grade at your test area, so you make a shallower grade or increase the grade, depending on if your site is on a hill or something like that.

But, really, you know, as Jody said, we have to look at the analogs, and we're really not doing anybody any favors, except modeling of the degraded states.

So when people say, well, you know, these things are going to change, maybe we should model the change, why bother, you know, because the waste is going to be there for a long time. And, you know, we're not dealing necessarily with just wastes that are going to biodegrade and so you might as well model further degrade and say -- state first and save yourself the trouble.

>>MR. ESH: That's a good comment. That version of a comment from you, Craig, and at least one or two other people to use your direct information sources when you can, use your modeling to test things that you can't directly observe or perturbations that you might not want to have happen at your site, test and see what that tells you, in terms of impact.

So do we have any others or are people ready to go?

All right, I'd like to thank all our panel members. We had a good discussion. And we start what time tomorrow, 8:30 again.

>>SPEAKER: Yes.

>>MR. ESH: 8:30 tomorrow.

(End of workshop)