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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

140TH MEETING

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TUESDAY,

MARCH 25, 2003

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ROCKVILLE, MARYLAND

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The Advisory Committee met at the Nuclear Regulatory Commission, Two White Flint North, Room T2B3, 11545 Rockville Pike, at 10:00 a.m., George M. Hornberger, Chairman, presiding.

COMMITTEE MEMBERS PRESENT:

GEORGE M. HORNBERGER, Chairman

RAYMOND G. WYMER, Vice Chairman

B. JOHN GARRICK, Member

MILTON N. LEVENSON, Member

MICHAEL T. RYAN, Member

ACNW STAFF PRESENT:

JOHN T. LARKINS, Executive Director, ACRS/ACNW

SHER BAHADUR, Associate Director, ACRS/ACNW

NEIL COLEMAN, ACRS Staff

HOWARD J. LARSON, Special Assistant, ACRS/ACNW

EXPERT PANEL:

DANIEL BULLEN, Iowa State University/NWTRB

ROD EWING, University of Michigan

RON LATANISION, MIT/NWTRB

MAURY MORGENSTEIN, Geosciences Management Institute, Inc.

JOE H. PAYER, Case Western Reserve University

ALSO PRESENT:

ROBERT ANDREWS, U.S. Department of Energy

ANDREW C. CAMPBELL, NRC/NMSS/DWM

DAVID W. ESH, NRC/NMSS/DWM

CHRISTOPHER J. GROSSMAN, NRC/NMSS/DWM

PETER SWIFT, Sandia National Laboratory

ABRAHAM E. VAN LUIK, U.S. Department of Energy

A-G-E-N-D-A

P R O C E E D I N G S

10:06 A.M.

DR. HORNBERGER: This is the first day of the 140th meeting of the Advisory Committee on Nuclear Waste. My name is George Hornberger, Chairman of the ACNW. The other members of the Committee present are Raymond Wymer, Vice Chairman; John Garrick, Milt Levenson; and Michael Ryan.

During today's meeting, the Committee will (1) conduct a workshop working group on the NRC and DOE performance assessments, assumptions and differences.

John Larkins is the Designated Federal Official for today's initial session.

This meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act. We have received no requests for time to make oral statements from members of the public regarding today's sessions. Should anyone wish to address the Committee, please make your wishes known to one of the Committee staff. It is requested that speakers use one of the microphones, identify themselves and speak with sufficient clarity and volume so that they can be readily heard.

Before proceeding, I would like to cover

some brief items of interest. First, this is the last ACNW meeting for our Vice Chairman, Raymond G. Wymer and we will miss him. We truly will miss him. And I say that for me personally and it's certainly true for the rest of the Committee as well. And we do wish him well.

Chairman Meserve leaves the Agency on March 31st to assume the post as President of Carnegie Institute of Washington. Chairman Meserve didn't see the point of staying on after Ray Wymer left, right?

(Laughter.)

Mike Lee and Tom Kobetz have been made permanent staff members. Ramin Assa, ACRS Staff Engineer, has accepted another position in the Agency and is leaving at the end of the month. There are several management changes within the Office of Nuclear Safety and Safeguards that have or will occur in February/March. Of particular interest to the ACNW, Don Cool will become the Senior Level Advisor for Health Physics reporting to the Director and Deputy Director, NMSS. Susan M. Frant will become the Chief Fuel Cycle Facility Branch. Larry Campbell will become the Deputy Director of the Licensing and Inspection Directorate in the Spent Fuel -- SFP. Daniel M. Gillin will become the Chief of the

Decommissioning Branch in the Division of Waste Management.

On March 10, the Atomic Safety and Licensing Board rejected the NRC Staff Opinion and ruled that there was a credible risk that fighter jets from the nearby Air Force Base could crash into the above-ground fuel storage casks at the proposed Private Fuel Storage PFS facility in Utah. The Judges said PFS could argue that the facility could withstand an F-16 collision without appreciable health and safety consequences, but it could not rule on that because the PFS application focused on low likelihood of accidents rather than a discussion of consequences.

For the benefit of the attendees at this meeting, it is noted that the 141st ACNW meeting will be -- will last two days, Tuesday and Wednesday, April 22nd and 23rd, 2003.

I also would like to welcome our distinguished Panel who has joined us at the table here and they will be introduced individually as we proceed and I certainly thank them for participating in our meeting.

So without further ado, we will move on to our working group and I will turn the meeting over to John Garrick who will lead this session.

DR. GARRICK: Thanks, George. The Advisory Committee on Nuclear Waste uses these kind of working group sessions for many reasons, but the most important reason is that it allows us to dig a little deeper into some of the technical issues associated with what we are doing and it nurtures our knowledge basis considerably in the process.

Given that the performance assessment is such a vital part of the eventual license application, because it's the basis for the technical decisions, it is appropriate that we pursue the technical issues associated with the performance assessment very diligently. And that's what we're going to try to do here the next couple of days.

In the prospectus that we developed for this workshop, we said that the purpose of the working group session were fourfold: first, to increase TMW's technical understanding and knowledge of the performance work that's been done to date for the Yucca Mountain repository; second, to identify areas in the analysis that may warrant increased realism; third, to understand the different approaches taken by the NRC and the Department of Energy; and fourth, to provide a reference or baseline for a follow-up working group session on performance confirmation.

There's a number of things that we want to achieve here. We've identified some specific questions. The thrust of the work shop is on the source term associated with the Yucca Mountain repository performance on the basis that unless you have the source term right, it's pretty difficult to have high expectations of the rest of the analysis.

So that's why we're going to put a lot of attention in the two days on the waste package performance and the activities that take place in the near field, because that's where the waste is mobilized and becomes in whatever form and state that it's going to become for transport.

For example, some of the questions we're very interested in is what is the basis for the water chemistry assumptions inside the waste package in the current models?

What is the realistic representation of the water pathway into the waste packages?

How can the performance assessments be used to achieve a more realistic and balanced design of engineered and natural barriers?

How should the performance assessments be used to facilitate performance confirmation?

A theme of this Committee for a long time

now has been that if we are going to do risk-informed analyses that those analyses ought to be realistic because unless they're realistic, we don't really have an appropriate reference point or game play against which to make judgments about how conservative we ought to be or the Nuclear Regulatory Commission ought to be.

So we've pushed very hard that the models ought not to be models that are just for the purpose of compliance, but models that are indeed for the purpose of telling us something about how this facility is really going to perform.

In that connection, we've also made quite an issue out of the matter of the transparency of the models. And I thought maybe what I would do is share with you two slides of something that I dealt with many years ago on what constitutes maybe a conceptual framework of transparency for a repository analysis.

This came about long before I'd read my first performance analysis and came about when I was -- had a company that made their living doing modeling and risk assessments. And one of my board members by the name of Norm Rasmussen asked me how would you lay out a model for analyzing the risk of geologic repository? And while it's changed a great deal since

that time, these are the elements. And again, both Norm and I were thinking in terms of a probabilistic performance assessment at a time when performance assessments were indeed not probabilistic.

The first thing that occurred to me is that the analysis ought to be modularized in such a way that you can decompose it into a visible expression of what the driving contributors to the performance are or to the risk. So I had the vision of a set of initial conditions that indeed would be probabilistic. You could imagine that being a different set of climatology conditions and you could imagine doing this for different discrete time intervals to accommodate the time dependence. But the idea would be to have as the first model what I chose to call the infiltration model. That is to say that would get us to the point of different water compositions that would become, that would be the output and would become the input for the next module of the model which here I've chosen to call the near field module or the source term module.

So the concept here is that you would have a variety of pinch points and out of these pinch points you would get certain performance states based on the inputs. Those performance states would be the

input to the next module and once, of course, that input exists, it doesn't matter what happened previously to that module. You can work that module in any fashion you desire.

So the idea is to have such a module for the near field, for the unsaturated zone under the waste package and then, of course, the saturated zone and then finally the biosphere.

Then the uptake which would be the other slide that I have and the only slides that I have would be outputs such as this and this is not to say that this isn't what we're getting, but it is only to say that when the Committee is challenged as to what we mean by transparency, these concepts have some of the elements of what we mean, namely that we can decompose these outputs into these various scenarios and to these various modules to understand at the module level what the important contributors to the risk are, at the scenario level what the important contributors to the risk are and then at even the lower levels such as the features, events and processes.

And again, we are talking about possibly doing this for the nominal case and perhaps treating the events such as the episodic events like

earthquakes, igneous events, meteorites and whatever separately and that lower right hand curve which is a frequency of exceedence curve is a convenient way to represent episodic events. It's known by various names. It's known as the risk curve. It's known as the frequency of exceedance curve. It's known as the complementary cumulative distribution curve. But it's a very precise manifestation of what is mean by risk when you have it and the concept shown here is the concept to capture the essence of uncertainty where probability is the parameter and the curves indicate the probability of the frequency of certain health effects occurring and so forth.

I thought I would just show this as a way or as a structure because when we review and did our vertical slice of the performance assessment, we thought very much along these lines, trying to backtrack from the results into the contributor categories such as modules, scenarios, features, events and processes.

One of the things I noticed in the independent review, the international independent review was they made the point that the international community does not emphasize probabilistic approaches to the extent that is being emphasized in the Yucca

Mountain, but in almost the very next paragraph they said one of the most critical requirements for the performance assessment is the uncertainty analysis. And I had a little trouble with that because to me the language of uncertainty is probability, if that probability is connected to the evidence and uncertainty is the issue associated with this project.

So anyway, I just wanted to set the stage a little bit for some of the things that we're kind of looking for here and now we can hear from a real expert and we're pleased to have him here, Joe Payer. Joe is a Professor of Materials Science and Engineering and Director of the Yeager Center for Electrochemical Sciences at Case Western Reserve University. He has expertise in materials performance and reliability, emphasizing corrosion and control methods. He's a Fellow of the ASM International, a Fellow and past president of the -- I think that's the National Association of Corrosion Engineers, is it not, International and recipient of the ASTM Sam Tour Award for contributions to corrosion test methods. He's been a very high profile performer in some major economic studies that have been done in the U.S. One is the 2002 report on "Corrosion Costs and Preventive Studies." And the other is the report that was

performed in 1978 on the determination of the economic effect of corrosion in the U.S. These are pretty profound studies. He was a member of the TSPA-VA, viability assessment peer review panel that was formed to provide the Department of Energy with a formal independent critique of the 1999 report. In addition, he chaired DOE's Waste Package Materials Performance Peer Review Panel and currently Joe is serving part-time on a DOE Science and Technology Review Panel in support of DOE's Director, Office of Civilian and Radioactive Waste Management.

We've heard from Dr. Payer before and he was judged as the guy that could help kick this workshop off and put the issue of how you build a corrosion model in perspective. We're delighted to have you, Joe.

DR. PAYER: Thank you very much, John. I thank the Committee for inviting us and me personally to this. I look forward to it.

Let me do some disclaimers here first. It's my goal with this presentation is to give an overview starting with what some of the conditions are at Yucca Mountain. A lot of this are things that many of you around the table obviously have dealt with before, but I think it's worthwhile to remind us what

some of the conditions are at Yucca Mountain. We do a lot of testing in beakers, fully immersed, because that's the way to do those tests. We do a lot of short-term testing, even when we test for a number of years and try to apply that to 10,000 years.

The other important message that is sort of a theme underneath this is when we talk about a corrosion process or an alteration product of spent fuel, that type of thing, we tend to take whatever the experimental information is or the modeling information at that given time and there's some kinetics or rate of reaction that's going on there and we just intuitively or by mistake say okay, well, that's what's going to go on for 10,000 years or 100,000 years.

And I think it's important for us to recognize and come back to what conditions pertain at the repository at 500 years or at 5,000 years or at 50,000 years because the conditions change over that time period. So some of these processes raise their importance and others of them fall back.

As John mentioned in the introduction here, I come from a materials science background. I did my thesis work at Ohio State University a few years ago, several years ago, in the area of

corrosion, electrochemistry and basically I spent my career in the field of corrosion, materials selection, failure analysis, determining how things will behave if you don't do anything and what if you take various criteria. So that's the bias that I come to from this.

Having said that then my primary expertise has been on the types of processes that will penetrate the package, the corrosion processes, okay? What I will say about the performance of the waste form and radionuclide release type processes are based on having sat through many sessions like this and being able to hear Rod Ewing and David Shoesmith and others who have worked very closely in this field and I'm trying to capture what they say.

So Rod certainly will have an opportunity to put the right spin on it if I miss the perspective here.

Next slide, please?

(Slide change.)

DR. PAYER: We're going to talk about the conditions at Yucca Mountain just to provide some background and perspective and then the three important aspects of this, I believe, or the way I break this up and John, I agree very much with the way

you try to modularize this overall process. It's important to know the overall outcome of these things, but I think we need competence and strive for understanding at each of the different modules.

And three of the modules I'd like to talk to you about are what's the compositions of the water, the composition of the water that's on the metal surfaces and waste package barrier layers. What's the composition of the water entering the waste packages and then what happens to it once it's in the package and releases.

So we're going to spend a little bit of time here talking about some of the issues of the composition of water. Corrosion is clearly identified as the primary determiner of waste package delay time. It's the most likely, the most probable process, degradation process that will determine when packages get penetrations and what the form and distribution of those penetrations will be.

I want to spend some time talking about the waste form degradation and radionuclide mobilization and I think that gets to the essence of this idea of the source term. That's what we're trying to control is generated and that's where -- identifies what the form of that release will be.

Next slide.

(Slide change.)

DR. PAYER: So a little bit about the Yucca Mountain conditions.

Next slide.

(Slide change.)

DR. PAYER: Start at the top level. What do we want a repository to do? There's two things that we're interested in here and one is, first and foremost, we'd like to completely isolate the waste in the radionuclides. Secondly, when they are released and the form in which they're released, we'd like to retard that egress of radionuclides from penetrated packages.

Next slide.

(Slide change.)

DR. PAYER: One of the things that makes this very difficult and that particular thing, identifying what's the failure mode, penetration of waste packages, what are the different degradation modes, stress corrosion, mechanical damage, embrittlement, that could cause those; when will they occur, what's the likelihood they'll occur, what would they look like? That's at the core of what materials scientists do that work in this field, in this area of

degradation process.

What's special about this application is the extremely long time frame we're talking about. Okay? And we're interested in regulatory periods of 10,000 years, but that's not enough. People are asking what happens even to much longer times than that.

But again, to reiterate a point I made in the introduction here, I think it's important to consider the conditions and remind ourselves of the conditions and analyze what's going on in the package and with radionuclides at different time frames. And I just suggest that as we step around here, these could be some of the time frames of interest.

Next slide.

(Slide change.)

DR. PAYER: Why is localized corrosion a major issue for waste packages in Yucca Mountain repository? Several groups have looked at this from very early days on through and it's been revalidated and revisited. But long-lived waste packages are essential for long term isolation.

Localized corrosion, pitting, crevice corrosion, stress corrosion cracking are the most likely degradation modes that can occur in these

environments and with materials that are being looked at. So basing materials selection and design on high crevice corrosion resistance is a prudent and a well-accepted way to go about this. It makes sense.

The general issues in corrosion science and engineering and materials science in electrochemistry, we know a lot about localized corrosion processes. We understand the breakdown of passive films in many ways. These are not new concepts to us. Having said that, it's a moving science. Okay? We're understanding more about these all the time, but there is a very solid firm science base upon which for the concepts certainly.

The trick is, the challenge is to determine, apply this corrosion science and understanding and extend it to the conditions that occur at Yucca Mountain.

Next slide.

(Slide change.)

DR. PAYER: Some of the important parameters in the water chemistry, the environment, any corrosion process and the corrosion rate, the rate of damage and degradation or if any damage and degradation are going to occur is dependent upon two things. It's dependent upon a corrosion resistance of

the material, how tough is this material, how strong is this material and the environment to which you expose it.

And so in dealing with these problems, if you say how corrosive is the condition at Yucca Mountain, the next question is to what? To a ceramic, to a nickel-chrome alloy, to a titanium alloy, to carbon steel? We've got to think about the material in that environment.

If you ask how corrosion resistant is titanium, Alloy 22, carbon steel, fiberglass, the question is in what? And any environment, any material, there are environments where it will act more like Alka Seltzer than a structural material. It will be attacked, certainly in these time frames.

So the question is how do you define where those environments are and how do you determine the materials' corrosion resistance in those environments and what you're striving for is not to have those two environments, those two fields cross over.

And so what do we want to know about the environment? We want to know the temperature and the time of wetness. It's well accepted that dry metals, without the presence of an aqueous phase, a water phase are not going to corrode at an appreciable rate

in this environment. So dry, we don't have to worry about. All right?

However, when we say time of wetness, we don't have to fully immerse. We don't have to put the waste package in a swimming pool. If there's a condensed layer of several model layers of moisture -- I lived in Houston in 1983 and there was a thin layer of moisture on everybody everywhere all the time sort of thing.

(Laughter.)

That's sufficient moisture. That's a sufficient aqueous environment to support electrochemical dissolution. Anodes, cathodes and all those things. They just occur in that very thin moisture layer.

The acidity and alkalinity, the pH of the environment is the way we measure that, is a very important property for the stability of passive films, the corrosion rate and so forth.

The oxidizing and reducing power of the environment, we refer to the Eh, the potential, the oxidizing potential of the environment. We go from very reducing environments that do not have a great propensity to form, to take materials into solution, to highly oxidizing environments and by oxidizing,

certainly oxygen is an oxidizing material, but there are other oxidants. Ferric ion, cupric ion, and others will increase the oxidizing power.

Having said that, there are detrimental species for the stability of these passive film and high on the list are chloride ions, reduced sulfur species and there can be other ionic materials in the environment that can affect the stability and corrosion resistance. There's some beneficial species that will make the stability of the passive films more likely and things of those sorts are nitrates and silicates. And then there can also be more complicated types of things.

The other thing to consider here and it's important is that in almost all cases we're dealing with aqueous solutions, wet environments that have multiple species in them. Seldom will be working with a pure or a sulphate only environment or a chloride only environment. We're going to be dealing in almost all cases with chloride, plus nitrate, plus sulfates plus this long menu and that's important. That can change the behavior.

Next slide.

(Slide change.)

DR. PAYER: The ambient waters at Yucca

Mountain are essentially innocuous. The materials. We're talking about neutral sodium bicarbonate type waters with very low amounts, parts per millon of dissolved solids and mixed salts and there's quite a menu of those an. ions and cad. ions and salts that are available, but they're quite dilute.

It's an aerated environment. The Mountain is open to air, so it's oxygenated. It's with air. There's a higher partial pressure of carbon dioxide in the atmosphere. That's the ambient condition out there. Those environments, both the gas and the liquid phase, are modulated or changed by the thermal period by evaporation, concentration. So if you start with a very low concentration of salts and you blow the water off, you evaporate the water off, it becomes more and more concentrated. So one of the real challenges here is to determine what solution do we wind up as this becomes more and more concentrated.

The modulations of these waters and I'm going to talk about waters in a general sense, the environment and water. The modulation, the changes that can occur to that on the metal surface or when that thin film of water or droplets of water are in contact with the waste form can be very significant and I would say they overwhelm the changes that can

occur out in the rock. There are changes that can occur in hot rock and exchange of this sort, but when that water sits on a metal surface, if corrosion starts, that environment can be modulated much greater. And certainly water sitting on the waste form can be modulated much more by the corrosion products and the interaction of the electrochemical reactions than what occurs out in the surface.

Next slide.

(Slide change.)

DR. PAYER: For the waste form mobilization, degradation and the radionuclide, we're discussing primarily the behavior of the uranium oxide matrix of the spent fuel. It's very important that that spent fuel matrix is exposed to oxidizing or reducing conditions, this Eh condition. Under reducing conditions, the dissolution rate, the corrosion rate, if you would, of the uranium matrix, is quite low.

But under oxidizing conditions, the rates are much higher. so it's very important what the local potential is.

The amounts of water in composition going into, on and from these processes, these materials, are very important and those droplets of water, those

thin films of water, the amount of water, limited water that's there are going to undergo significant changes due to the corrosion, the oxidation reduction processes, the precipitation of salts and minerals, the dissolution of salts and minerals.

The interaction with the degraded waste form produces alteration products and corrosion products. There's also a lot of materials and I'll show some pictures later, there's other materials inside the waste packages. We've got a significant amount of steel. We've got some aluminum. We've got zirconium clad. There's other materials there that are all going to be potentially reacting in this stew that we're boiling up.

Interactions with the invert and the drift support materials need to be considered and what's principal to this whole thing, this tells us what these things are, what are the transport processes while it's in there and out.

Next slide.

(Slide change.)

DR. PAYER: This suggests that the waste package design and operating mode has gone under evolution and this just shows back when the thought was there would be small packages, holes dropped in

down here. We've gone through the concept of a very hot repository where intentionally the entire area would be heated up at fairly high temperatures and keep the packages dry for long periods of time. We've now moved to somewhat even a hot scenario now is backed off considerably from what this was. And the concept is to keep it so these dry out -- that's what the red zone is saying, the portion of the rock that's been dried out so they don't overlap from drip to drip and there's also consideration and a lot of talk going about having what's being referred to as a low temperature repository. And the idea there is you wouldn't get any dry rock around here. You would never exceed boiling at the drift wall. Okay?

Next slide.

(Slide change.)

DR. PAYER: One of the things to keep in mind is this design has evolved over a number of years. It will continue to evolve. Okay? We have to go to license applications and the process and we have to go through various processes. But it's very unrealistic to think -- and these are just random numbers I've picked, but the 108th package, the 1000th package, the 10,000th package, I can guarantee it's almost certainly not going to look like package number

one. Okay? Why not? Because we evolve, we're talking about over many years here, the performance can get better, the competence can get better and things can become less expensive, if they can be justified along the way.

Next slide.

(Slide change.)

DR. PAYER: Just a series of slides here to get us all on hopefully the same ground work. The natural system out there is a series of layers of geologic formations. And the repository is placed at about 300 meters below the rock. It's about another 300 meters to the saturated water table and what that says, the importance of that is that the repository sits in an unsaturated zone. It's porous rock. The rocks are partially filled with water. It's at atmospheric pressure which is an important consideration here. There's no processes by which we can go to 10 atmospheres of over pressure or more as you could if you were inside a metal package or an impermeable barrier and generating gases. You could go up to a much higher process.

High relative humidity, unless we've driven those waters off and the ambient waters are dilute and they're neutral.

Next slide.

(Slide change.)

DR. PAYER: The water flow through this mountain is the critical issue. And the climatology, the amount of infiltration will determine how much water comes down through the unsaturated zone above the repository. At the repository level, that water can react with and interact with waste package materials, drift materials. That will determine eventually the penetration of the waste packages. The water inside the waste packages, after it goes through the cladding or if there's clad failures, will come in contact with the fuel and that's where the radionuclide mobilization release starts. There can be interactions of waters at that location, the waters move out of that area through the invert material and on down to the saturated zone.

And so it's very important -- you ask why we spend so much time thinking about waters and all that. Water is at first the material or the instrument by which we're going to penetrate the packages. It's going to be the material or the instrument by which we mobilize and release radionuclides and it's going to be the median, the instrument by which those radionuclides are moved

through.

Next slide.

(Slide change.)

DR. PAYER: I just picked this and many of the slides, almost all the slides I've taken here have been blatantly just cut out of project type reports because they have much better cartoons can I can draw, certainly. And I want to acknowledge that. On many of them there's a little -- I don't know if you can read them or not, but there's a little thing here someone might want to trace back and find out where they came from, but these are all public documents.

This is just a slide that was interesting because it brings home the fact that we're talking about corrosion and degradation and radionuclide mobilization on a wide range of scales and sometimes we're talking on a mountain scale where the measurement of interest is 10 or 100 meters. Other times in a drip scale we're talking about processes and phenomenon that go on over centimeters and meter types of scales and we go all the way down to talking about the stability of passive films or the development of very thin layers on spent fuel that are measured in nanometers or micrometers. And we have to be able to walk through that sort of time frame from

time to time or that dimensional scale.

Next slide.

(Slide change.)

DR. PAYER: This is just a photograph of a drift showing the steel invert support. The drift, various types of packages, holding spent fuel rods from PWRs. There's other co-disposal fuel BWR reactors. This shows the drip shield, titanium drip shield concept. It's in here. So this is the integrity of these and the release of radionuclides within these are what are of interest.

Next slide.

(Slide change.)

DR. PAYER: This is a busy slide, but this is a cross section and one of the things I just want to point out as we're talking about a lot of different materials here. We're talking about a titanium alloy drip shield. We're talking about a waste package that has an outer layer of a highly corrosion resistant material, Alloy 22 which is a nickel-chrome molybdenum alloy, highly corrosion resistant in a wide range of environments, will corrode in very aggressive environments. And the trick is, where's the boundary?

The inner layer for structural integrity and structural strength of material is a 316 stainless

steel and then inside that, we've got the fuel rods and those sorts of things. That just shows a diagram of that.

There's a lot of detail in here. Okay? There's a lot of materials and this just goes through some of the materials. The package will be backflushed, filled with helium when it's put in place. There's steel in this structure. There's zirconium cladding in this structure. There's spent fuel in the structure and how those interact could be an issue.

Next slide.

(Slide change.)

DR. PAYER: This just shows the various types of waste form. There's commercial spent fuel. There's materials from other sources. These will be put in similar package, not identical, but similar packages. That defines the inventory, the menu of materials that go in and then by fission and reaction processes, radioactive decay, we can get through a whole series of materials of interest. These are the radionuclides of interest that we're trying to control and hold back and go. And they go from the fission products, things like cesium and iodine to all of the actinide and lanthinide series here.

The other interesting thing about this is the half life of several of these materials are measured in 10^3, 10^4, very longevity. Some of them drop off in a matter of years, and hundreds of years. Others are going to be around for tens of thousands, hundreds of thousands of years.

Next slide.

(Slide change.)

DR. PAYER: One of the ways, I think when we talk about source term we're talking about source of radionuclides, but it might be of interest if we remind ourselves this is also the spent fuel is the thermal source term and so we start with heat that's generated at the fuel pellet and bundle area. That heat is then transferred to the waste package surfaces, the waste package transfers that heat to the drift wall. That heats up things locally around the drift and then you can also look at this as the mountain scale.

The heat from the spent fuel transfers to the waste package, goes to the drift wall in the rock. There are design and operational factors that can control that. The drift spacing, the package spacing, the geometry of the packages, how big are they? What's their diameter and length? What type of fuel

do you put in them and then how do you load up, how much do you load in the packages. So there's some control of this thermal course term.

Next slide.

(Slide change.)

DR. PAYER: And this just shows an example of -- this is some modeling. If you've got a hot package here and this is a hot package, this is looking at the degree of saturation of water and it just shows that you can get a dry out zone where the rock is heated above the boiling point. You push the water back away and then at some point you get back to ambient, basically saturated moisture, 100 percent relative humidity. And depending upon the thermal source term here, the size and shape -- the size of these can be either near the package. For a cool package, you wouldn't have any complete dry out zone. And so that's a controllable thing.

This looks at some of the modeling, again on a mountain scale now. We're looking at elevation here in each of these ticks, each two ticks is 200 meters. What this says this looks at the temperature, short time is 500 years and up to 2,000 years. The important thing here is the above boiling. Here's the boiling point. That dry out is localized around 5

meters, 10 meters, that sort of distance of the repository. You heat the repository up above and below it, but you get this thermal cycle, this cycle that goes out and then comes back after thousands, tens of thousands of years.

Next slide.

(Slide change.)

DR. PAYER: This is just an example of some data on what's the temperature of the waste package surface, outer surface of the waste package as a function of time. It's on a log scale. This is a hundred years, a thousand years, ten thousand years. And in looking at the response for the hot cycle, when the repository is closed, ventilation stops, the waste package surface heats up. This suggests in this particular example, it heats up to 160 to 180 degrees and in over a long period of time it cools down.

If you go to a lower temperature type of operation, and this has a ventilation period of 300 years to keep the packages cool, you get a heat up. Here it's controlled so it doesn't heat up above the boiling point and then you get a long slow cool down. That's dependent upon where the package is and what type of package. And that's what the fans here are to suggest.

So we get a cool, a heat up period over several years and in a very long slow cool down.

Next slide.

(Slide change.)

DR. PAYER: If you take that information and you look at the relative humidity as a function of time, what's the amount of moisture that's sitting in the atmosphere around these. In the high temperature mode, during the ventilation, here's a hundred years, several hundred years. The package and the water is driven away from the atmosphere, away from the packages. Then the relative humidity as the cooling occurs, continues to increase, and then eventually after tens of thousands of years, hundred thousand years, you come back to ambient and 100 percent relative humidity.

Well, why is that important? People would suggest that if the relative humidity is below 20 percent or so, the packages are dry. There's no moisture. You don't have this thin film of moisture on it. Corrosion, degradation processes are not of interest.

Then, as the relative humidity rises, people would argue and the observation show that some place around 20, 30 percent and on up to 60 percent

depending upon the condition of the surface, it may be dry or it may be wet. If there are delta equation salts on that surface, it will form moisture sooner. If there are not those types of products on the surface, it will remain dry. So we're in an area where it may be dry and we need some more information.

Most folks would suggest that if we're up around 70 to 80 percent that the surface, even with just some particles of an inert dust material will form a condensed layer. So the point is that over this time period we can know and we can gather information about when is it dry, when does it get wet and the type of moisture on it

Next slide.

(Slide change.)

DR. PAYER: This is a busy slide, but it just says at what time would the waste package, looking at those scenarios, those terms I have you, at what time would the package be at 120 centigrade, the outer surface? And for a high temperature operating mode, they would be at that, at some time around 500 years. After a thousand years, they would be cooled to 100 degrees. After 3,080, 10,060 and then moving its way back to ambient.

The lower temperature curves I've showed

you never get above the 100, 120. They're at about 80 at closure for about a 1,000 years and then at 5,000, they're at 60. So again, it's important to keep in mind what's the temperature, what's the relative humidity of these packages at various times.

I would suggest that the emphasis from an engineering standpoint certainly the first several years are correct. Okay? We've got to be very competent that will perform well in that particular time period.

Longer time periods are still quite important, but the conditions start becoming more of benign, the gamma radiation and radiation fields start dropping off. The fuel degrades. The temperature starts dropping and things become not as aggressive.

Next slide.

(Slide change.)

DR. PAYER: This is just a slide showing that there's a lot of chemistry, thermal coupled processes that are going on when you put hot packages into this mountain. If we get the boiling zone, we get dry out sorts of periods, there's condensation, there's interaction with the water and the rock. I again though would point out for these conversations the kind of chemical processes, electrochemical

processes that can occur at the package level can overwhelm an awful lot of information or changes that are occurring up in that level.

Next slide.

(Slide change.)

DR. PAYER: Next slide.

(Slide change.)

DR. PAYER: This is just some cartoons out of some of the project work. But essentially it shows some of the models and I'm sure we'll be hearing more about this, but there are in the TSPA, the performance assessment model, there are aspects of that that deal with water contacting the waste package. There's aspects that deal with the waste package lifetime. There's aspects that work with the release from the waste packages and then finally the radionuclide concentrations as they move out toward the biosphere.

So there are pieces of this model and as John showed earlier with his, that modules that are appropriate for looking at these various levels.

Next slide.

(Slide change.)

DR. PAYER: My thoughts on anything that would be looking at models for the source term, one of the big issues is water. Water is the accessor. It's

what will cause the penetrations, the corrosion that will allow water to get access to the fuel. Water is the mobilizer due to chemistry and access and mobilization within the package. Water is the mobilizer on getting through the cladding and penetrations in the waste package and the cladding to the fuel and mobilizing it and then water is the primary medium for the transport. So I think we've got to have realism throughout this for those types of issues.

Next slide.

(Slide change.)

DR. PAYER: What are some of the characteristics of a source term? Composition of these waters is critical. When will the penetrations occur? What are those penetrations going to look like? How many? Where are they? What's the distribution? How much water is going to enter the package through those penetrations? What will the waste form degradation meet processes? How are we going to mobilize these? What's the interaction of the radionuclides with those corrosion products, waste form alteration products and invert materials and then how are they transported out?

You can come up with your list, but my

suggestion is that it would not look -- have more detail or you could conglomerate those, but some place somebody has to talk about what our understanding of that is.

Next slide.

(Slide change.)

DR. PAYER: Water contacting waste package. Next slide.

(Slide change.)

DR. PAYER: It was mentioned that the issue here is what's the realistic range of environments at Yucca Mountain? What's the realistic range of materials susceptibility, the corrosion resistance of Alloy 22 and titanium? And what you're looking for is where is that level of overlap? What's the likelihood of overlap? What's going to occur in that area of overlap and in an ideal world you'd have no overlap at all. Okay? You like to separate those boundaries so that realistic environments you'd see no damage.

In order for this damage to occur, there has to be water. The water has to remain there while the degradation is going on. There has to be a corrosive water. It has to be in this range of environments not out here in the non-aggressive

environments, but it has to be in this range here. The material has to be susceptible so that the material has to be in this area, not out in here. And those conditions have to persist, if it's on again/off again type of a situation for a long time, long enough to create a penetration.

Next slide.

(Slide change.)

DR. PAYER: We're interested in water on the package, water on the waste form and water coming out of the waste form. The water is going to be in a couple of different forms: condensation of moist layers and dust layers or so forth or on surfaces; drippage and seepage into the drift from the environment.

Next slide.

(Slide change.)

DR. PAYER: This is just a handful of slides that I put together just to -- not that it's any detail -- but to give the feeling that we have a science base for understanding and predicting behavior in these types of materials and one of the useful treatments in the water chemistry issue are either this particular or things that take a dilute solution and predict, as you concentrate that, as you drive the

water out of that solution, what are you going to have left in the beaker? What are you going to have left in the drop on the waste package surface or the thin film?

And what it says is you start with a dilute mixture and you reach several of these, what are referred to as chemical divides and so if you come down this way, depending upon in this series, depending upon the relative amount of calcium in the dilute water, versus carbonate species in a dilute water, if there's an excess of calcium, you will go this path. And then there are several divides that you go through. Starting up here, if you've got excess carbonate and lower amounts of calcium when you get to this fork in the road, you'll start coming down this way.

What that says then is there are ways to deal with water chemistry ways, geochemistry ways, solution chemistry that will tell you what the family of types of brines you might wind up with. So there is a logical and procedure for dealing with that.

Next slide.

(Slide change.)

DR. PAYER: The issue of deliquescence of various salts that are on the surface. This shows the

relative humidity versus temperature and at what point would you get an aqueous phase forming if you had sodium nitrate crystals sitting on the package; if you had sodium chloride on the package; if you had magnesium chloride sitting on the surface. At what relative humidity would you start to form moisture? This is data. It's readily -- it's a data set that's available to help us look at that.

One of the important aspects of that though is that mixtures of salts -- this shows a sodium chloride, a sodium nitrate, a sodium chloride, mixtures of those salts can have a lower deliquescence point than either of the pure substances. So again, we've got to come back and remind ourselves of what's going on when we've got multiple constituents.

This is just a slide that shows silica solubility. Silica is readily available, SIO2, out at Yucca Mountain. At the bottom of this is pH, I believe, can you move that up a bit?

This shows the pH and what it shows at high pH, silica is very soluble, even at lower pHs. These are parts per million at different temperatures of silica that would be in the solution. This is a cartoon out of corrosion literature, a book by Morris Fontana, but it shows what happens when we've got a

crevice material where there's a restricted geometry solution could get back in there. Due to the chemical and electrochemical processes back in the crevice, the solution that's back in the crevice or underneath a deposit can become significantly different in composition than the bulk environment. And there can be build up of species in here. It can become more acidic. There are many processes that are pretty well understood that occur underneath deposits or in metal to metal contact.

Next slide.

(Slide change.)

DR. PAYER: Two slides on corrosion.

Next slide.

(Slide change.)

DR. PAYER: The water composition in Yucca Mountain naturally occurring. It's the major source of water and ionic species, dissolved minerals. It's the aqueous environment on the metal surfaces and on the spent fuel that we're interested in.

These packages will not be fully immersed in water. The full immersion on the metal surfaces is highly unlikely. The two likely conditions are condensed water from the air, water seeping and dripping on to those metal surfaces, deposits forming

on those metal surfaces. But it's unlikely that we'll see fully immersed conditions.

Next slide.

(Slide change.)

DR. PAYER: Nickel-based alloys and titanium are the primary materials of construction we're interested in. These materials have excellent corrosion resistance. They, however, are susceptible to corrosion in extremely aggressive environments. And the question is do those environments have a chance of occurring over reasonable amounts of time at Yucca Mountain or not? And two of the major considerations within this are fabrication processes, the welding. How the packages are fabricated can have a significant effect on this and also the temperature effects on these materials.

Next slide.

(Slide change.)

DR. PAYER: This is just a reminder of that temperature during the ventilation period and prior to closure. The temperatures are kept low. When it's closed, the temperatures rise and then there's a long slow cool down period. These are rising in this slide up to a -- and this is with backfill. So if there's backfill over it in this

scenario, temperatures will get quite hot without the backfill in this particular scenario we got up in this range. If you cool those, if you ventilate those for longer periods of time, up to 300 years for example, and then close, you can keep the package surfaces at lower temperatures.

Important performance factors, waste package temperature, the form and composition of the water and then the interaction with the clad and internal temperature.

Next slide.

(Slide change.)

MR. KIEFFER: This is just a montage of slides on localized corrosion. The top one are a series of nickel-chrome molybdenum alloys and it shows that those alloys -- these are all in the same environment after a given test. The materials that are less corrosion resistant can go very significant attack. Notice it's localized attack, these dark spots are pits, into the metal surface and the more corrosion resistance materials in these experiments, Alloy 22, Alloy C-4 and titanium basically show no level of attack at all.

The difference between the Alloy 22 behavior and the Alloy 825 behavior in this particular

case, the Alloy 22 has more chrome, more nickel, more molybdenum. It has a more stable passive film.

We know a lot about the chemistry and treatment of localized corrosion processes and that corrosion science provides a basis for understanding these behaviors. We can measure the polarization behavior, the potential versus log current of these and we get these polarization curves that you see here, and that gives us a rationale for determining the corrosion resistance of the material. We can compare the corrosion potential to the potential at which damage occurs at and above and we can determine the expected corrosion behavior. And this just shows that this is the corrosion potential across here. This is the protection potential and the rationale is if this corrosion potential never gets more positive than the potential at which damage occurs, then we would expect long term passive behavior.

Next slide.

(Slide change.)

DR. PAYER: That's in terms of potential. Potential is not the easiest thing to measure on an operating waste package. One of the things that would be easier to measure would be temperature an there are temperature analogs to those critical potentials. And

the idea is we can determine the temperature at which aqueous corrosion occurs. We can determine the temperature at which crevice corrosion occurred. If the temperature for moisture formation is below the temperature at which crevice corrosion occurs, there's no temperature. There's no vulnerability.

If the temperature of aqueous corrosion is greater than where the temperature of crevice corrosion could occur, then that temperature difference defines a range of vulnerability. It doesn't mean corrosion is going to occur in there, but corrosion could occur in there.

The trick of this is these temperatures are environment sensitive. And so as the environment changes, those temperatures change. If you have the temperature ranges of vulnerability, you could go back to those plots of temperature versus time and you could determine kinds of vulnerability for the waste packages.

Next slide.

(Slide change.)

DR. PAYER: This just shows passive film formation. We're talking about very thin films. These films are measured in nanometers and so forth. If these films remain stable, if the passivity

persists, then it's very likely the packages could last longer than 10,000 years without any penetration. That's the trick.

Why would they break down? They're going to break down either because, primarily because of chemical attack. And this just shows we have methods to go in the laboratory and measure the composition, structure and so forth of those films.

Next slide.

(Slide change.)

DR. PAYER: Stress corrosion cracking is an issue. Stress corrosion cracking is a failure mode. If you've got a mechanical stress and a corrosive environment, a particular environment, you can get very rapid failure. These are just some cartoons that this phenomenon has been dealt with empirically. You'd load up specimens, and you see if they fail or not. There is theory behind why these occur. The theory for stress corrosion cracking, again, is an evolutionary thing in corrosion science.

But there is a basis by which we understand these processes. One of the primary ways of controlling stress corrosion cracking is to use treatments that will put compressive stresses on the surface of the material. And this is just a cartoon

illustrating this.

Important factors for stress corrosion cracking are the residual stresses, primarily and of high interest that might occur around welds, what's the corrosive environment, what stability over a long time, and welds are of particular interest for this phenomena.

Next slide.

Let me skip over this. We know some things about long-term stabilities. Alloys -- again, the challenge is to determine the very long-time aging, as we look as a function of temperature, so taking information at 400, 500 degrees and higher, and projecting that out the long time.

Next slide.

The design and fabrication -- there's a lot of design details and just how these things are fabricated and put together. There's a lot of structural details around the drift, and what materials are used here, and how they're used.

And those types of things can have significant effects. The materials of construction, what's the metallurgy of those materials, what's the residual stress of those materials. And, again, when we're looking at waste package components, the welds

are critical items.

Next slide.

Some of the aspects about waste packages -- they're exposed to one long, slow cycle. There's no moving parts. It's a static exposure. We don't have cyclic loads on these things. The heat fluxes are low, and they would be dry in a higher temperature mode.

Next slide.

Materials give off heat and radiation that decrease with time. Radiation effects, after a few hundred years, on the package surfaces are not important. Thermal effects diminish after several thousands, tens of thousands of years, at the repository level.

Next slide.

You all can read that. Some comments on waste form.

Next slide.

Once you get a penetration in a waste package, depending on where it is -- and if there's seepage and dripping water that can impact on that -- the question is: how is that going to behave? And there's two different ways of dealing with this.

You can either say, okay, we're just going

to have penetrations at the top, or wherever the penetration is, the water will just start to fill the package, and it will act like a bathtub. The alternative concept would be to have a package that had a penetration at the top and a penetration in the bottom, and then it would act more where the moisture would move its way through and out of the system.

If you can't get advective flow, the flow of moisture, then the movement of moisture in and the movement of materials through that -- the radionuclides are of primary interest -- are going to go by diffusive processes as opposed to advective flow processes.

Next slide.

This is just a picture of the fuel bundle. The zirconium rods -- if there's a fracture in a rod, the moisture can go through that fracture and access the spent fuel. If it accesses the spent fuel, it can then start breaking down, dissolving that fuel, radionuclides can be mobilized, and move their way back out through those packages.

Next slide.

And this just shows a montage of photographs that say there is a science, there is a background of understanding those processes. Okay?

Not as fully as we would like to understand those. It's an area of continued corrosion -- in this case, dissolution-type study. But this is a cartoon of the grains within the fuel, and this shows the fuel cladding. So this would be a high magnification. These grains are a couple microns, tens of microns in diameter.

And the question is: what happens when moisture comes through and accesses that? Well, anything like the cesium that would be built up in this gap -- in this gap would essentially become mobilized right away, very short time.

Materials that were on the surface of these grains or in the grain boundaries, if the moisture had access to it, would be mobilized very quickly. The radionuclides that are incorporated within the structure, within the matrix, or bound within these particles, could be retarded, could be held back, could be slowed down in their release.

Well, so we'd like to know about the dissolution of this. This just shows that under oxidizing conditions, this is corrosion rate basically versus pH, under oxidizing conditions very high, reducing conditions not very high. We understand chemical interactions. This case shows some

interaction with carbonates.

The pH in the environment, the oxygen content, is critical. Again, this is corrosion rate versus pH. This just shows the radiation levels over a function of time, because radiolysis products can be important here. And this just suggests that after 100 years or so, or a few hundred years, that the gamma and the beta radiation has fallen off dramatically. And so those radiolysis effects are critical or more important early on and less important later.

Next slide.

This is just to show this pH effect on the dissolution -- the corrosion rate of those spent fuel drains. Under reducing conditions, they are fairly stable, and they would provide a significant degradation of radionuclide release.

Under oxidizing conditions, they dissolve, they corrode much more rapidly, releasing radionuclides. Those processes are fairly well understood. We can use thermodynamic calculations to look at the stability of the various films.

Important factors here are oxidizing versus reducing. We can measure that as an Eh or describe it as an Eh, and the acidity/alkalinity environment is very important. A lot of this stuff

has been taken from a review article, an excellent review article by David Shoesmith.

Next slide.

A lot of this stuff was taken from an article by Burns, Ewing and Miller, and this is Ewing sitting over here. So there is complicated mineralogy here. There's a lot of different phases that can form, okay, when we have silicates and uranites and various other materials.

We understand some of these materials and structures at the atomic level, and so we can use crystal chemistry to predict what the various tetrahedra and how those will be put together to get some of these sheet-type products or interlocked-type products.

Thermodynamics provides an excellent basis for what phases will be stable in various chemistries. And so where is the UO2 stable? Where is uranophane, and so forth, stable? Important factors here are the crystal chemistry, chemical analysis, thermodynamics.

We're interested in how the fusion products -- fission products, sorry, and actinides might be incorporated and held within these types of materials in an alteration product.

Next slide.

Transport mechanism -- this is just a cartoon of colloids forming and the radionuclides sorbing or desorbing from these products, and it may provide a mechanism by which they can be carried on and transported.

How do the radionuclides interact with the degraded fuel and the alteration products from that fuel? How do the radionuclides interact with the corrosion products, the iron oxides that are developed, and other corrosion waste package and internal materials, and how do they, then, interact with the drip and support what's in transport through that?

Next slide.

And this is just a cartoon showing that if radionuclides that are sorbed on the colloids and all of that as it moves through the fracture -- and that's a very high magnification cartoon here. But as those move through the fracture, how will those -- will those radionuclides being transported interact with the matrix, or will it stay in the fractures and move?

Next slide.

This just reminds things going on on large scales down to the microscale -- but the transport of those radionuclides to the unsaturated zone, into the

waters, and out to the biosphere.

Next slide.

So let me just finish by saying the goal of this aspect, the goal of looking at it as the source term, I would suggest would be a set of models that capture reality. And what that means is it -- they recognize the important processes and the dependencies of those processes. And they do that in terms that are relative to Yucca Mountain.

And if you, again, go back to the modules that we might want to consider and look at there is, what do we know about the water contacting waste packages? How is that captured in these performance models? What's the waste package lifetime, the types of penetrations, form of penetrations?

What's the release of radionuclides from the waste form and alteration, either the release or the incorporation of? And then, how do they mobilize and transport?

Thank you very much.

MEMBER GARRICK: Thanks very much, Joe.

I wanted to further acknowledge the distinguished panel we've put together to stimulate the discussions following each of our presentations, and most of them have been mentioned already. But we

have Rod Ewing from the University of Michigan and a very visible investigator in the source term development of not only Yucca Mountain type conditions but was very visible with respect to the waste isolation pilot plan.

We have two members of the Nuclear Waste Technical Review Board here. They are Dan Bullen and Ron Latanision from MIT. Dan is from Iowa State University.

And we're very pleased to have Maury Morgenstein from Geosciences Management Institute with us as well.

Partly due to my extended introduction, we're a little behind already. But I do want to give the panel an opportunity, at this juncture, to ask any questions that they may have. I suspect most of the questioning will come with the detailed presentations that are to follow. But nevertheless, I want to give the panel a chance to ask a couple of questions at this point.

Dan?

DR. BULLEN: Dan Bullen from the Nuclear Waste Technical Review Board.

Joe, that was an outstanding presentation and a good summary overview. But I have a couple of

key questions for you, and I would be off mark if I didn't mention high temperature versus low temperature performance. So I wanted to come back to a couple of statements that you made.

When you made your presentation of high temperature versus low temperature, it looked like a majority of the time the temperature curves overlapped. So basically, past about a thousand years, everything sort of looks the same. Is that a fair statement?

DR. PAYER: That's my understanding.

DR. BULLEN: What kind of changes would you expect in a high temperature environment versus a low temperature environment with respect to the corrosion activities? Is there a possibility for a more aggressive environment in a high temperature mode than you would expect in a lower temperature mode, or vice versa? I guess I'd like your expert opinion on those lines.

DR. PAYER: I think certainly you could produce environments in the high temperature mode that you would not see in a low temperature mode. So that's a scenario.

DR. BULLEN: Right.

DR. PAYER: I think that's possible.

DR. BULLEN: And I guess along those lines, your comment about the key element of the source term model is realism. And so when you get to the realistic interpretation of the source term, with respect to evolution of the environment, one of the statements that you made right toward the end -- and I wrote it down as your Figure Number 42 -- was that you thought it was going to be dry in the high temperature environment.

And I guess with all of the comments that were made about deliquescence temperatures and the types of, you know, sort of almost desiccating environments that you see, what sort of moisture contact would you expect to see in that high temperature environment? And I guess I'm questioning whether or not it really would be dry.

DR. PAYER: I think you would drive water away from the drip. So you're not going to have seepage and dripping at those temperatures.

DR. BULLEN: Okay.

DR. PAYER: And I think the degree of deliquescence that you would see would depend on what's -- you know, what's on the packages.

DR. BULLEN: Okay. So you're talking about drying away from the drip, not dry on the thin

film of the waste package if there were deliquescent salts present.

DR. PAYER: Well, I think, again, you have to get into some of the specifics. But I think you'll have dry packages in a high temperature operating mode, depending on what temperature you're at and how you decide what's on the packages.

DR. BULLEN: Okay.

DR. PAYER: I mean, I don't -- there's going to be -- the processes are correct. Okay?

DR. BULLEN: Right.

DR. PAYER: And so then, you know, what are the dust compositions? What are the compositions that are on there? And how do they behave and mixed salts and things of that sort?

DR. BULLEN: Okay. I guess the last question I have is you talked about the overlap of environments, where you had corrosion and where you had the environment. And the less overlap you have, the more improved performance you might be. Is there more or less overlap with a high temperature or a low temperature operating mode? Or can you say?

DR. PAYER: You've got a whole agenda here. The --

DR. BULLEN: I'm sorry.

(Laughter.)

DR. PAYER: I'm not going to vote on high temperature versus low temperature.

DR. BULLEN: I understand that.

DR. PAYER: I showed a whole bunch of chemistry and all those types of things. As the temperature goes up, the environments that will cause alloy 22 and titanium to corrode increases. There's no question about that.

And so the question is: what's the likelihood of those environments?

DR. BULLEN: Right.

DR. PAYER: And how do you get into it? But, clearly, that increases with temperature.

DR. BULLEN: Okay. Thank you.

MEMBER GARRICK: Yes. Maury?

DR. MORGENSTEIN: Maury, GMI. To follow up on one of Dan's points, do you feel it might be possible to wet a canister or a drip shield in a very high temperature mode if you are driving water from above the repository through a large fracture system?

DR. PAYER: Well, the quick comment is that I have not looked at that particular scenario in enough detail. Also, I think the intent of my presentation here was to identify what the processes

of interest are --

MEMBER GARRICK: Yes.

DR. PAYER: -- and not what Payer thinks, although I'd be happy to share what Payer thinks. You know? But I'm not sure if --

(Laughter.)

MEMBER GARRICK: Well, I think we're going to get into that kind of detail as we listen to the speakers on specific topics.

DR. PAYER: But clearly, I mean, those kinds of issues are exactly at the heart of it. You know, will you get --

MEMBER GARRICK: Yes.

DR. PAYER: -- deliquescence? Where will the water be? I mean, so I -- I mean, those are --

MEMBER GARRICK: Yes.

DR. PAYER: -- critical issues.

MEMBER GARRICK: Any other quick questions before we proceed?

Okay. I think I'll ask the committee to hold until we get deeper into the presentations. I believe our next speaker is Abe Van Luik from DOE, whom we've heard from many, many times. And I'll just ask Abe to kind of introduce himself, given that DOE is constantly reorganizing.

(Laughter.)

DR. VAN LUIK: I am Abe Van Luik. I work as a Senior Policy Advisor to the Office of License Application and Safety. Joe Ziegler is my boss.

And the reason for this talk is that you are going to hear some rather detailed talks from the other DOE speakers on technical subjects, and they wanted you to know that whatever their scope of work is is our fault at DOE.

(Laughter.)

So if we can go on to the next vu-graph. I want to talk a little bit about what NRC requires of us, what our approach is to realism and conservatism (momentary equipment failure) -- requirements for the performance assessment used to generate compliance with the post-closure performance objectives. We have to pay attention to what they specify.

The Yucca Mountain Review Plan -- yes?

Oh, okay. High tech is not my forte.

The Yucca Mountain Review Plan, Rev 2, specifies the approach that will be used by the NRC to judge the adequacy of our performance assessment in terms of meeting these requirements.

I'm not telling you anything you don't know at this point.

Next.

I really don't want to read this to you, but reasonable expectation is a very interesting section in 63.304. And if we can go to the next one, you'll see what I think is important from that. To me, what 63.304 says is that DOE should evaluate uncertainties. There's no question about that.

We should include parameters of importance even if they're not precisely known. And we should evaluate the full range of distributions but be reasonable. The goal of these evaluations is to determine likely performance, not unlikely performance, for the distributions.

Next slide.

This is another one -- 63.303. And you'll notice that I go through the regulations backward. That's a personality defect.

(Laughter.)

But, to me, it seemed to tell a more coherent story to do it this way.

If we go to 63.303, the implementation of Subpart L, we have some statements here that you can read for yourself. And on the next page you'll see what I took away from this page.

Next page.

The mean dose is to be evaluated using the full range of distributions as discussed in 63.303. So these are basically our guidelines on how to proceed with the performance assessment.

Next.

Now, if we go to 342, limits on performance assessment, there is a lot of good words in here about the limitations of performance assessment per se. And if we go to the next page, these are the things that I pulled out of there that I think are relevant for this talk.

Performance assessments need not consider very unlikely features, events, or processes. And this is going back to -- we're looking for the likely performance of the system. The assessments for human intrusion and groundwater protection need not consider unlikely features, events, and processes. Those two subaspects of performance assessment are to look at the most likely performance of the system.

Okay. Now, if we go to 63.114, requirements for performance assessment, here again is a statement of requirements on the work that we are doing. And the way that we work with our contractors, whom you will hear some of the details of what they've actually done, is we take these kinds of requirements

and put them in direction letters to them and say, "Follow these requirements."

Next.

We decided to cite the entire 63.114 set of requirements. And what I pull out of these requirements is that we must provide the basis for the models that we selected for the features, events, and processes evaluated and excluded. We must provide the basis -- whoa, I'm almost lost there -- provide a basis for data used and for derived parameter ranges, and provide a basis for judging adequacy of the modeling.

And I think all of those requirements before are to make sure that we know that the NRC is not interested in just bottom-line numbers. They want to know the scientific basis for those numbers and the calculations leading to them.

Now, if we look at the Yucca Mountain Review Plan criteria, these are basically the directions the NRC is giving to its staff on how to conduct the review of our license application. In there it says that a conservative approach can be used to decrease the need to collect information and to justify a simplified modeling approach.

However, it puts us on notice.

Conservatism in one process may not mean conservatism in the dose projection. They have determined -- and I think we all know -- that conservatism in one process may, in fact, because of the linkage of processes, lead to a non-intuitive dose projection.

And wherever we claim conservatism, we need to show a technical basis. They will not take our word for it.

Next.

Continuing with the Yucca Mountain Review Plan criteria, they recognize that the use of conservatism to manage uncertainty -- and this is one way to manage uncertainty -- has implications for risk-informed review. The staff is to evaluate assertions of conservatism from the perspective of overall system performance.

The staff will use any available information to risk-inform its review. It will not be totally dependent on what DOE provides. They will use their own knowledge, intuition, and basis to aid their review.

The Yucca Mountain Review Plan's review methods and acceptance criteria emphasize the staff's intent to thoroughly review potential non-conservatisms at both the subsystem and system levels.

And I think this is very important. This review plan puts us on notice that they will look into the details of everything that they feel they need to.

Next.

What we get from both the regulation and the Yucca Mountain Review Plan is that realism is desirable, but realism in every aspect is not required. We believe that adding in realism where it's practical is prudent, because it allows more meaningful safety margin evaluations. I think we've heard that loud and clear from both the TRB and the ACNW, and we agree.

Taking a more informed, less conservative approach to barrier design. It's a more straightforward communication in the case for system safety when you're talking about realism versus -- trust me, this is way conservative. It couldn't be worse than this.

And we like the idea of having an improved understanding of system performance. I think our international peer review underscored this saying, "You can show compliance with the regulation, but you also need to demonstrate that you really understand your system."

The NRC staff rightly took exception to

that saying that if -- and that's why I quoted all of the sections on the basis. The NRC wants the basis for the information. They want to show the understanding that underlies our system performance calculations.

So conservatism, in our view, has both advantages and potential disadvantages. It has real disadvantages.

As recognized in the Yucca Mountain Review Plan, conservatism may allow assurance of safety with lesser time and other resource expenditures. It's a practical approach. It can become a tradeoff issue between design and material costs and research costs, or licensing costs if you will. And conservatism tends to understate safety, and that is a disadvantage.

Next.

We would like to think that we are using an approach of pragmatic realism, and, you know, I think it's pragmatic. Pragmatic realism is one way to say that it's one step away from realism.

The ACNW and the NWTRB have made comments over the years saying that realism allows a more meaningful uncertainty and safety margin evaluation. We agree with that. I mean, we don't disagree at all.

We must say that as we did total system performance assessments with more and more realistic input data, long-term safety estimates have improved every time that we have added more realism to a component model.

Realism has improved the understanding of system performance to the level needed to demonstrate safety in the regulatory context. We think that we are basically on track with the way that we're approaching the TSPA for the license application.

Next.

Speaking of the license application, this is a very important viewgraph, because it explains what you're going to hear a little bit later from the technical talks. This is a policy talk. We're right here in the middle of FY2003 already. So if you draw an imaginary line through here, you can see that when it comes to TSPA-LA, the methods and approach have already been settled on and agreed between DOE and the contractor at the very end of fiscal year 2002.

The test feeds that feed the analysis and model reports are done basically, and the analysis and model reports will be done in a few more months, allowing the TSPA-LA to move forward. And this is one reason that because these things are not done yet, and the TSPA-LA has not been fully put into place yet, the

modeling -- the model construction will be complete early in 2004. That's later this year.

Because of that, the things that you will hear in the technical talks that come later will be based basically on what we have done to this point, but there may be changes in the TSPA-LA that will not be reflected in these talks. So that's one thing to put you on notice about.

The other thing is that we are basically well on our way to completing the TSPA-LA. And so any discussion we may have over the next few days may be able to be incorporated in some nuance of change. But when it comes to substantive changes in our approach, you know, we are too far along the way to TSPA-LA to make a complete break with some approach that we have embarked on.

So, basically, this is my talk is to tell you we agree with you, we think we're being pragmatic as far as our approach to realism, and we're well on our way towards the TSPA-LA.

We feel good about the product we're creating. We think it meets the expectations of the NRC, as communicated to us in formal documents. And the next set of talks from DOE are going to be on the technical details of the modeling.

So with that, I don't think there's another viewgraph. Well, okay, a summary. It basically says something -- this is something that I added in at the last minute. The license application will have a mix of conservative and realistic models. I think that's what I was putting you on notice about a minute ago.

But there is hope. We have a performance confirmation program to enhance confidence in key process models over time. In addition to that, we have a larger long-term test and evaluation program to add understanding and realism for the modeling. And we also have embarked this year on a science and technology program, which will go into the long-term to evaluate new science and technology for enhancing safety, efficiency, and understanding.

And I was glad that Joe Payer mentioned that waste package number 10,000 will not look the same as waste package 1, because one of their charges is to see if we can make it more efficient, safer, and cheaper at the same time. And, you know, to lock something in for 20 years of production at the first year I think is a little bit -- what would Lee Barrett call it? Technologically arrogant?

So with that, I will -- since you're out

of time, there's no time for questions, I'll sit down.

(Laughter.)

MEMBER GARRICK: Well, we're not going to let you off that easy.

DR. VAN LUIK: Okay.

MEMBER GARRICK: Rod?

DR. EWING: Abe, just a clarification. You made that point that as realism has been added to the TSPA that long-term safety estimates improved. What did you mean exactly? Does that mean the dose always drops, or uncertainty decreases?

DR. VAN LUIK: The dose doesn't always drop with every nuance of change that we have made. But if we step over time and look at the major products, for example, we did three separate TSPAs during the site recommendation period. They all pass muster when it comes to the 10,000-year requirements, but the peak doses keep stepping down.

If you look in between two of those cases, there was actually time that they turned back up. But peak doses are of interest to me, and I am very pleased that every time that we've added realism into the modeling they have come down in size. Now, whether that's a trend that continues or not would be --

DR. EWING: And the peak dose is always beyond 10,000 years.

DR. VAN LUIK: Way beyond 10,000 years.

DR. EWING: Right.

DR. VAN LUIK: It's about a half a million years now.

DR. EWING: Yes. Does that seem strange, that, you know, in a complicated system that, as you get more data and know more about the various parts, that you always get a desirable answer -- that is, the doses, the peak dose drops?

DR. VAN LUIK: Well, I think it's not strange, if you recognize that we have made a concerted effort that where there was uncertainty we manage that uncertainty by exactly what the ACNW is criticizing us for -- going in an unrealistic but conservative direction.

It kind of verifies that these major assumptions that we've made, as we get more data, especially in the waste package materials area, as we get more data, we add more realism to that model. And the waste package life extends out in time, and the failure rates slow down.

DR. EWING: So if I followed through this series of TSPAs and looked at the parameter ranges and

values generally used, I would see that from point A to point C you were more conservative in C and it became less conservative with realism?

DR. VAN LUIK: Yes. Yes, I think for certain aspects of things.

DR. EWING: Right.

DR. VAN LUIK: There were other things -- for example, the very first cut at TSPA-SR, we had not updated the climate model yet. When we updated it, the peak doses actually went up.

DR. EWING: Right. But that doesn't necessarily mean you added realism to the analysis, right?

DR. VAN LUIK: There is an argument there that what we have added is informed speculation. That's better than the speculation we had before I think.

(Laughter.)

MEMBER GARRICK: You sound like the news media now.

(Laughter.)

Any other questions? Dan?

DR. BULLEN: Dan Bullen, Nuclear Technical Waste Review Board. Just a quick question on your summary schedule. I guess maybe it's just an arrow

that you left off, but it sure looks like that the design and even the analysis and model reports are actually design -- they don't feed into TSPA at all.

DR. VAN LUIK: It's an arrow problem more than anything else.

DR. BULLEN: Okay.

DR. VAN LUIK: They didn't --

DR. BULLEN: There's an interface between design and performance, then?

(Laughter.)

DR. VAN LUIK: Yes, there is.

DR. BULLEN: Okay. Thank you.

DR. VAN LUIK: Yes, there is.

(Laughter.)

MEMBER GARRICK: Abe, is the license application date, calendar-wise, still at the end of 2004 or --

DR. VAN LUIK: At this point in time it is. It is that way on our schedule. But, actually, even as we speak, there is a frantic reassessment -- and "frantic" is a strong word -- but there is a serious reassessment of every aspect of every --

MEMBER GARRICK: But it's probably realistic.

DR. VAN LUIK: And we're coming to the

point where we're going to make a more realistic call of, can we still do this, or do we need to slip it? But that call has not been made yet, so right now the schedule is December of 2004.

MEMBER GARRICK: Good. Any other questions? Excellent. Thank you very much.

We're now going to hear from Dr. Andy Campbell. Andy was a recent member of the technical staff of the ACNW. We were very sorry to lose him, but he is now in a very important position having to do with the NRC's performance assessment.

Andy, why don't you tell us exactly what your new role is.

DR. CAMPBELL: Okay. Can you hear me okay? Okay. I'm the section leader for the Performance Assessment and Integration Group in the Division of Waste Management at NRC.

The section that I lead has fundamental responsibility in terms of reviewing DOE's TSPA analyses, integrating activities across various key technical issue groups within the NRC, and also in terms of when the license application comes in, reviewing those aspects of the license application dealing with performance assessment.

What I want to do is set the stage for

three other NRC presentations, one of which will occur this afternoon. Chris Grossman will provide an overview of our total system performance assessment code, what we call our TPA code.

Tomorrow Dave Esh will talk about the source term components of that code in some detail, and the bases and support for some of the assumptions and approaches that we use in that code. And then, Tim McCartin will talk about some of the results of various analyses that are ongoing in terms of understanding key aspects of system performance.

There are three main messages that we want to make. One is to convey to the audience and to the committee our role. What is NRC's role in reviewing DOE's performance assessment and our role as a regulator? How does our TPA code fit into that role? And then, some of the confidence building measures that we have developed for that code and are still ongoing.

Okay. On the next slide, I explain our role, the NRC's role. Really, this is focused on the role of performance assessment group, the prelicensing activities, and then ultimately the review of DOE's license application. In prelicensing, a lot of the focus in terms of the TPA code and ongoing analyses,

what we call our integrated performance assessment analyses, were focused on developing the staff review capabilities.

TSPA is a very complex code, and we felt that we needed to develop an independent capability to review that code, as well as looking at bits and pieces and the whole code that DOE -- and results that DOE comes in with.

Part of that is to understand important features, events, and processes, and the selection of those FEPs for the TSPA. And also, in terms of developing our own understanding of how barriers perform within the Yucca Mountain system and our ability to review information and modeling review, we will present in that area ultimately in the license application.

We have a series in the prelicensing mode of interactions we have had over the years with the Department of Energy on total system performance assessment, for example, TSPA 95, TSPA-VA, the viability assessment, and TSPA-SR, the TSPA developed for the site recommendation, and a wide variety of other interactions.

Outside of the PA group, there are, of course, a large number of interactions with respect to

our key technical issue groups. There are nine areas that we have developed in 1996 to focus on important issues at Yucca Mountain. And so I'm just focusing on the PA aspects of that.

And then, through this process, PA group has been helping to identify information necessary to review the license application, and those are the agreements that you hear about and the process we're going through right now with DOE to address issues that we feel -- information we felt was needed in order for us to be able to review a license application.

And that's the purpose of those agreements, but we are using TPA and our modeling capabilities to try and understand which of those agreements are really the key ones in terms of importance to performance.

Next slide.

A little bit of the historical background. NRC staff has been doing some integrated performance assessment modeling, starting actually in the late '80s. And, in fact, PA modeling dates back to even the '70s in terms of NRC's activities.

IPA 1 was completed in about 1990 and was published in 1992. Then we had an integrated

performance assessment Phase 2 analyses that was completed in about '93/'94 timeframe and published in 1995. In that context of IPA 2, the staff began developing its total system performance assessment code, the TPA code. And that was used -- an early version of that was used in the IPA 2 work.

In terms of development of the TPA code, we are now developing the final version for license review, which is TPA 5.0. The initial code after IPA 2 was the total system performance assessment 3 code, and there were a couple of different versions of that. And then, the total system performance assessment TPA code 4.0. So we're now essentially on the fifth iteration of the TPA code.

And associated with the development of those iterations of the code, the staff has conducted, along with the Center for Nuclear Waste Regulatory Analyses, a series of sensitivity studies that essentially became IPA-like activities leading up to where we are today.

And so I've already mentioned some of the interactions we've had with DOE on their TSPA, but these activities have really helped confirm in our own mind, what are the key issues and what do we need to probe with respect to DOE's approach in the

prelicensing approach?

And then, finally, I just mentioned the KTI framework. In 1996, the staff reconfigured its program to focus on nine key technical issue areas. It was 10 at the time, including development of the regulation.

As we transition to license application review, we will transition to the 14 integrated subissues which are embodied in the Yucca Mountain Review Plan framework.

Next slide.

What are some of the roles of NRC's TPA code? It provides us with an independent review capability. We are using it to evaluate the various TSPAs. We really want to understand and evaluate the models, assumptions, and data, and abstractions that go into TSPA. And it gives us -- we want a flexible code that gives us the ability to evaluate the completeness of their modeling approach.

We are also trying to enhance our own understanding to identify key elements of the repository system, to provide us, the NRC staff, with risk insights that help us establish our priorities in terms of review and an ability to integrate evaluations of subsystem performance from the

different groups that are doing what are called process-level modeling that are very detailed-level modeling that wouldn't necessarily appear in the code but provide information to the code.

Next slide.

Okay. Some of the applications of our TPA code include confirmatory analysis of DOE's modeling approach and their results. In some cases, simplified calculations that pull material out of the code and look at it in a more simplified manner to support some of our performance assessment analyses and understanding, detailed uncertainty and sensitivity analyses, which include identifying the uncertainties, and testing the relative importance of parameters, alternative conceptual models, and some of the key assumptions.

The integration of process models and our understanding of how this system works is really key to understanding the DOE model ultimately when it comes into the NRC for review in the license application. And so all of this is focused on enhancing that understanding, identifying the key uncertainties in their abstraction processes, and the importance of certain scenarios in the analyses.

This is basically for nominal performance.

This does not include events such as an igneous event or long-term seismic events in terms of impact on the repository. But in terms of nominal performance, these are the key areas -- infiltration, the near-field environment, including engineered barrier degradation and source term, radionuclide transport through both the unsaturated zone and the saturated zone, and biosphere and dose.

And what the presentations from the NRC staff will be focused on is the nominal system. We have presented material to the committee in the past on igneous activity, for example, and we don't intend to really go into any detail on that.

Okay. Finally, confidence building performance assessment. In 1999, through the Center for Nuclear Waste Regulatory Analyses, which conducted a peer review of the TPA 3.2 code, we looked at the overall code as well as areas -- hydrology, volcanology, geochemistry, FEPs, the development of features, events, and processes, and screening, health physics, and a number of other key areas of repository performance.

Some of the key recommendations included developing more transparency in terms of documentation of the code. There are a significant number of

specific -- very specific comments. The Review Committee felt that the code was appropriate for the review of DOE's license application, but then have a series of specific suggestions in terms of areas that we could improve.

And so staff followup, essentially, has consisted of implementing what we felt were the most important recommendations in terms of uncertainties and key portions of the repository in the development of the TPA 4.0 code and the current version of the TPA 5.0 code.

And then, we also are implementing a verification testing of TPA 5.0, which will look at not only the quality areas of the code, in terms of meeting the rigorous quality assurance standards that we have within the agency, and the Center also follows, but also in terms of the modules, the key modules that perform the calculations, and some of the stand-alone modules. And we can talk to that at some later time if that's desirable.

So, finally, in terms of our ongoing activities, there are a number of things we're doing right now leading up to December of '04, or whenever the license application comes in the door. One, we briefed the committee before on risk insights. We are

now in Phase 2 of our risk insights effort.

We are in the process of developing a risk insights baseline, which will describe in kind of an executive summary type of approach what the staff feels are the key areas of repository performance. And that report will be published by the end of the fiscal year, by October, the end of September or October of this year.

And then, we are using this type of approach to provide feedback to the other KTI staffs in terms of balancing which agreements are really the key agreements that we have to focus on in the short period of time we have before the license application would come in the door.

We are interacting with DOE on their risk prioritization report and making sure that our interactions with DOE are consistent with our own understanding from risk insights, finalizing the development of TPA 5.0 prior to the license application. And I put developing IPA 4; this probably should be IPA 5, given the various iterations of the code and analyses we've done over the years.

But through the risk insights process, what we want to do is identify key areas that require further analysis for our own understanding and ability

to review what DOE is doing. And then, prior to the license application coming in the door, we will update our risk insights baseline in preparation for that review.

So that's the end of the talk. Now I'd just, again, mention Chris Grossman will be talking about the TPA code and its overview. Dave Esh will be addressing tomorrow the source term modeling, and Tim McCartin understanding PA results.

And it's important to recognize that whatever results we talk about are preliminary. They don't indicate a final judgment on the particular matters that we're discussing. And they don't indicate a final judgment on the license ability or regulatory acceptability of approaches for the Yucca Mountain license application.

So with that, I am open to questions.

MEMBER GARRICK: Good. Thanks very much, Andy.

Questions from the panel?

I have one question, Andy. I notice that the Electric Power Research Institute was strongly urging you to do what evidently you're going to do, and that is use your risk model to prioritize the agreements. And you mention your -- can you tell us

a little bit about how you're going to do that, to what extent you're going to importance-rank, if you wish, the agreements?

DR. CAMPBELL: Well, right now we're developing and essentially redrafting a -- what we call a risk insights baseline, which will really lay out in kind of an issue-level approach, kind of like at the integrated subissue level, what the key areas of repository performance are.

And then, what we are planning on doing is aligning that with specific agreement and agreement areas that, based upon our long history of analyses and specific work that we've been doing in the last few years, aligned those agreements with our fundamental understanding of, what are the key features, what are the most important aspects of that.

And the idea is to not necessarily rule things out, but to really understand, what are the very key elements of all those agreements that we feel are necessary for our review of the license application.

MEMBER GARRICK: Now, of course, the agreements are not completely decoupled from the subissue, the key technical issues. But they're not necessarily the same either.

DR. CAMPBELL: That's right.

MEMBER GARRICK: Are you going to do any kind of mapping with this -- of the importance ranking of the agreements with the subissues of the KTIs? As you know, the committee has been urging for a long time that there be more of a PA template put on the KTIs. And it's probably not reasonable to think in terms of the KTIs themselves, but the subissues of the KTIs is more reasonable. Are you going to sort that out a little bit between the agreements and the subissues of the KTIs?

DR. CAMPBELL: Well, one of the things that we've done is we've mapped the agreements to what are called the integrated subissues, which are the 14 key areas of the Yucca Mountain Review Plan.

MEMBER GARRICK: Right.

DR. CAMPBELL: And what we're really focusing on is how those agreements map to the 14 integrated subissues, because that then leads into our ability to review the license application. So that kind of mapping is taking place.

And what we need to be able to do, because if you look at, for example, a KTI like CLST, container life and source term, there may be -- you know, there are something like 53 or 56 agreements

there. Not all of those agreements are maybe the most important. There are some that will rise to the top in terms of importance to long-term performance, certainly over the 10,000-year period, and others may fall down.

So with this mapping, we're, of course, mapping to the integrated subissues rather than to the KTIs. And what we hope to be able to do then is, within the context of those integrated subissues, which particular agreements are really the key ones.

MEMBER GARRICK: Very good.

Any questions from anybody? Rod?

DR. EWING: Just to follow up on that, and I'm just listening and trying to understand, as you establish priorities for the KTIs in terms of risk, how do you work into that considerations of multiple barriers? That is, I can imagine a barrier that in a certain analysis plays almost no role, but it is a multiple barrier. Is that part of the thinking as you organize?

DR. CAMPBELL: Yes, it is.

DR. EWING: And how is that done?

DR. CAMPBELL: Well, the performance of the barriers -- and I think Tim McCartin is going to address ways of thinking about different barriers and

how radionuclides transport through the system. And I think I'm going to let -- defer to Tim when he gives his presentation.

I don't know if, Tim, you want to say anything at this point on that issue. But Tim --

MEMBER GARRICK: Why don't we wait on that.

DR. CAMPBELL: -- McCartin will address that issue tomorrow, I think, in a level of detail that I can't provide at this point.

MEMBER GARRICK: Any other questions from the committee?

Andy, you've done a wonderful job of getting us back on schedule.

(Laughter.)

I think we're -- on the schedule it says we're going to adjourn for lunch now. Is that not correct? All right. We'll do that, and we'll see you at 1:00.

(Whereupon, at 11:59 a.m., the proceedings in the foregoing matter went off the record for a lunch break.)

A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

(1:04 p.m.)

CHAIRMAN HORNBERGER: The meeting will resume.

MEMBER GARRICK: Thank you. We're now going to get into some more details, an overview of both the TPA and TSPA, in reverse order. So I guess we're going to hear first from Peter Swift. Yes.

MR. SWIFT: Okay.

MEMBER GARRICK: Peter, why don't you tell us a little bit about your job.

MR. SWIFT: Sure.

MEMBER GARRICK: And yourself.

MR. SWIFT: Do you have a microphone?

MEMBER GARRICK: Yes.

MR. SWIFT: All right. I'm Peter Swift. I'm giving the presentation here on the agenda that's the overview of the DOE's TSPA. I should start off by just introducing myself. I'm from Sandia National Laboratories in Albuquerque. I'm a geologist originally by training. I've worked in performance assessment for quite a few years. And I am also the manager within the M&O for the project, the Bechtel SAIC Company, for the performance assessment strategy and scope subproject.

This is a group -- I work for Bob Andrews, who manages performance assessment in general. You'll meet Bob in a little bit here. The TSPA modeling group is within my subproject within Bechtel.

All right. I'm going to move on here. The next slide, please.

Probably while I had it up there, I should have credited the rest of the TSPA team. Just very briefly I want to mention Jerry McNish, who has modeled that group for many years, and a host of -- dozens of people who put a lot of work into what -- I'm here presenting other people's work, and it's what we all do. So give them the due credit.

I'll say a little bit here about the current status of the DOE's TSPA. Very brief summary of our methodology. First, what I'm going to try and do, following the agenda, is summarize the major model components. I'm going to try to map the workshop groupings or modules to what we model within the TSPA.

A little bit about the process models, the abstractions. I won't touch on the source term itself, because Bob Andrews will talk in detail on that and how things are linked together.

Next slide, please.

First bullet here -- everything that

either I or Bob Andrews is going to show in the next two days comes from existing analyses. There is no new work here. There are some graphics you may not have seen before, but we have not run new calculations. This is all essentially old work.

Here is where it comes from. The last slide in this packet, last handout in the packet, gives proper source material references for these documents.

The December 2000 TSPA for the site recommendation, the so-called SSPA, the supplemental analyses in July of '01, updated them again in September of '01, and last year there have been two more reports, one one-off style analyses where we neutralize or remove barriers one at a time, and one one-on where we added barriers one at a time. On both those there are brief reports that describe each of those sets.

The models and analyses for the license application are still under development. Dave mentioned this earlier. And we're not going to be able to talk about them here, because we don't -- we aren't confident exactly where they're coming out here, and they're literally -- back in Las Vegas people are working on putting them together this week,

next week, and in the coming month.

Our TSPA methodology -- and we believe this is consistent with what the NRC, and for that matter the EPA and Part 197, consistent with what the regulatory community is looking for in TSPA. It also follows international practice. We start out screening features of instant processes, determine those that should be in the models and those that need not be. We develop models. We identify uncertainty in them. We construct the -- an integrated model using all of those processes that we screened in.

We end up with a nominal performance model and a disruptive event performance model, which for the work done to date has been the volcanic scenario. They are different models.

We also have a stylized human intrusion model that is specified by the regulation, and it's a slightly different model. All we're talking about in this workshop I believe is the nominal model. This is the last time I'll mention the other two.

And then, of course, the last step in the system -- in the methodology is to evaluate total performance. And, in particular, there are the relevant standards.

We do this through a Monte Carlo

simulation, multiple realizations, run the model over and over again, sampling on the input parameters to give us a display of the distribution of possible model results consistent with the uncertainty and the input parameters.

Next slide, please.

This, believe it or not, shows the same thing graphically. Part of the point here is to show that we started out here with identifying the features, events, and processes, screened them in, screened some out. And if you follow through here -- I'm not going to walk through it -- but these are the component models we've had to develop going through, from the unsaturated zone flow down to the biosphere.

And we have to model different scenarios -- volcanic and human intrusion -- and different performance measures, groundwater protection, and total dose.

Next, please.

Okay. The point of this is to show how the workshop has grouped the major components of the system and how the DOE has grouped them. And so on the agenda we have something called infiltration and tunnel dripping. Within the DOE models, we have separate model components for climate infiltration,

unsaturated zone flow, thermal effects, seepage, and so on.

Already our model looks more complicated than this simple listing. But I believe that we actually do need to model each one of these various things in order to have a reasonable model for, let's say, the source term. And we need to be able to model the performance of each of those items there, and so on.

Next, please.

We also tend to group our model components by the barriers they represent. This will come up again in my second talk tomorrow morning, so I'm not going to spend too much time on it. But you can find those model components I described in the previous slide here arranged from -- in the -- sort of following the water movement, in the way in which we, the DOE, uses them as barriers in the performance assessment.

Next, please.

And now we'll look at the submodels within each of those major model components. This is a -- like a slide I showed two or three back, this is just for nominal scenario, and the major components going around here.

Each one of those major components has within it submodels. So unsaturated zone flow, there are submodels for it. Or the waste form here -- a raft of submodels. Each one of these things here we actually can point to a model within the TSPA code that handles those things.

Next slide, please.

And this is the kind of slide that only a numerical modeler would like. And they probably wouldn't like it either.

(Laughter.)

But the point is that each one of those little submodels has to be represented with numerical code -- equations written in a computer code that are then calculated. And no point in going through all of these.

They really -- there are all of these models embedded in our system. And some of them are run external to our TSPA model, where their results are essentially look-up tables. Others in this column here run directly within the TSPA model and are executed over and over again for each realization.

Next, please.

All right. Now, the actual components here. Components that are related to infiltration and

tunnel dripping.

Next slide, please.

Climate being the first one. I'm going to just stop briefly here and mention that I'm going to go through each one of those major model components, not the submodels, with the same level of information roughly. It's a one slide quick look at what's in our climate model.

What I'm trying to cover for you are the inputs, the key assumptions, the outputs, in some sort of graphic that hopefully, you know, says it all in a little bit. Clearly, this is a very superficial treatment of the model components. If you have questions on them and there's time, ask me. If not, maybe we can come back to them.

The purpose of this is to go through the -- I hate to say the complexity of the model because I'd like to think it was a simple model. In fact, this is a very simplified model of a system. But we believe it does take this level of detail to model it, even at a simple level.

So climate -- we have three different climate states, the present day; a monsoon, which is from 600 years in the future to 2,000 years in the future, where the site will be wetter but not colder,

it'll be mostly summer rains; and then the glacial transition climate, which will persist for the rest of the 10,000 years, which is a cooler and wetter climate, eventually building towards a full glacial climate, which does not occur in the first 10,000 years.

Our climate model -- its inputs aren't listed here. It doesn't have model inputs. It has paleoclimate inputs and, to some extent, actually observational weather data inputs. The outputs to the infiltration model is where it mostly feeds, gives that temperature and precipitation.

Water table rises are provided to the unsaturated zone, and to the saturated zone we provide the time of climate changes that are used to fix the time at which the water flux is changed. Basically, within a saturated zone, we account for climate change by increasing water flow.

Next slide, please.

The infiltration model -- this is actually a pretty important model in the system. This is one that takes that precipitation and determines how much of it enters the rock and starts percolating down towards the repository. It includes run-off and run-on, which is water flooding into low places and then

sinking in.

It takes precipitation and temperature data from the climate model, uses soil surface maps. So it's a detailed model.

It produces -- sorry it didn't come out on the screen there -- produces infiltration flux maps that are then provided to the mountain scale flow model. That would be its primary output. And it treats uncertainty infiltration by creating three detailed maps for each climate state -- a high, medium, and low infiltration level.

MEMBER GARRICK: When you say output is the infiltration flux, etcetera, etcetera, isn't the output the water composition?

MR. SWIFT: The water composition would be an output of -- actually, there's a thermal hydrochemistry model with several steps downstream. We're not worried particularly about the evolving water up here. It's the water down at the repository level that -- and so we get that water termed later in the system. I'll come to that.

MEMBER GARRICK: Okay.

MR. SWIFT: The head shaking there.

I mean, we have plenty of data on the water chemistry.

MEMBER GARRICK: Well, what I'm getting at is my original vision of this whole model was that the output of the infiltration would be the likelihood of different water compositions entering the near field and becoming the input into the near --

MR. SWIFT: Sure.

MEMBER GARRICK: -- the near field model.

MR. SWIFT: The way we use infiltration, the term, that stops at the bedrock.

MEMBER GARRICK: I see.

MR. SWIFT: What you're describing is part of our mountain scale model for flow and chemistry within the mountain.

MEMBER GARRICK: Okay. Next slide, please.

This just -- the mountain scale unsaturated zone flow. This is the movement of water through the unsaturated rock. And this is a -- it's a detailed three-dimensional model of the entire mountain underlying that outline of the mountain.

At the top here, this is actually one of the infiltration maps. This is the input to the mountain, to the mountain scale flow model. This is a horizontal slice taken at the repository elevation, and this is down at the water table.

These are -- there is real data on these. These date from the SR from two years ago. But what you can see here is the -- at the surface, most infiltrations up at the highest elevations where the greatest precipitation is on the ridge.

As you go down, you start to see focusing along faults. Not a whole lot of difference between these two, some though. Get down to the water table and the water flux -- blue is the highest water flux. Water is focused along the faults, and that we believe -- well, it's driven by the material properties in the model. We believe that is, in fact, realistic.

All right. The outputs from this -- for the hydrologic properties, the same framework developed for this map. This model is also used for the thermal hydrology model, and it provides the flow fields that are the primary basis for transport below the repository from this level to this level here.

Next, please.

DR. EWING: Peter?

MR. SWIFT: Yes.

DR. EWING: Just very quickly, the fracture systems at each level, the faults are in exactly the same position?

MR. SWIFT: No. It's a three-dimensional

map. So the faults -- they have drift loading --

DR. EWING: Could we go back just --

MR. SWIFT: Yes, go back one. I'm not sure you can see it at this scale, but the faults should not be vertical on this. No, they should move around.

DR. EWING: But they're nearly vertical, I take it, from --

MR. SWIFT: Well, they're pretty high angle faults, yes.

DR. EWING: Okay.

MR. SWIFT: Go ahead.

The thermal hydrologic environments, there are two separate models of interest here. One of them is the thermal hydrology model, which this is where we first put in the repository into the system. We've got the drift layout and heat loading from -- which are design inputs.

The water flux for SR for actually taken directly from the infiltration model. We didn't use that upper portion of the flow model. We used it for the transport below.

But the -- so we've got a thermal hydrology model of the whole mountain also that looks at what we did for SR. It looks at how the flow field

is perturbed by the heat pulse from the repository.

The outputs from this were the percolation flux. That's the water moving through any specified point in the subsurface, to the seepage model, and the environmental conditions in the drift in the adjacent rock. This is important. This is where we put in the temperature, relative humidity, in the drift. They come out of this model.

The thermal hydrologic chemistry model, the so-called THC model, it's a separate model, run separately. And it starts with initial water -- its purpose, well, first of all, is to calculate the water chemistry entering the drift as it thermally evolves. This is something that's of considerable interest.

Its inputs are the initial water chemistry based on well water data.

DR. MORGENSTEIN: Excuse me.

MR. SWIFT: Yes.

DR. MORGENSTEIN: Why would you use well water data to look at the initial water chemistry, which is in the soil zone? Why don't you use soil zone chemistry water?

MR. SWIFT: Well, then we would -- yes. We would then be modeling the evolution of the water from here down to there. In fact, we're picking it up

most of the way down in modeling this evolution in the thermal environment. We're --

DR. MORGENSTEIN: I don't get this at all.

MR. SWIFT: Okay. There's an assumption there that the real water collected from wells represents the real evolution of water in an undisturbed system from the land surface to the subsurface.

DR. MORGENSTEIN: And what gives you the right for that assumption? What data do you have that supports that?

MR. SWIFT: I guess I'm probably not the person to answer that question.

DR. MORGENSTEIN: Okay. I would suggest this is totally wrong. This is not the direction to go in. There is no reason not to collect initial water chemistry of the soil zone. I cannot believe that the program doesn't do this.

MR. ANDREWS: Peter, let me add -- this is Bob Andrews. You're exactly right. And, therefore, in the summer of 2001, we did a comparison of using so-called J-13 saturated zone water, which Peter is talking about here, and the available data at that time for water chemistry, and evolved both of those chemistries in the drift and compared their results in

the supplemental science and performance analyses, which was used to support the science and engineering, which was used to support the site recommendation.

Those analyses, which I did not bring but are in the supplemental science analysis report, showed very little difference by the time you evolved them in the drift. They are different starting water chemistries. You're exactly right. But by the time you evolve them and mix them, if you will, with the inert materials, you get very little difference in temporal evolution for the major constituents.

DR. MORGENSTEIN: Is it difficult to actually collect surface water for you guys, and to do a mass balance?

MR. ANDREWS: These aren't surface waters. These are all groundwaters. And taking water chemistry samples from the core is a very difficult process. There are data on those. The USGS has collected those data extracting water from cores for the last seven or eight years.

The preliminary sets of those data were used in the site recommendation that I just alluded to, and additional data, water chemistry data, will be used in the license application.

Extracting water from the fractures --

there is no water right now in the fractures. The fractures are at 10 percent or 5 percent liquid saturation. The temperatures are at 85 to 90 percent liquid saturation.

We do have water chemistry data, however, from perched water zones where we've encountered perched water zones. And those have been used to help constrain the in situ pre-thermal chemistry.

DR. MORGENSTEIN: Okay.

MR. SWIFT: Next slide, please.

The seepage model -- model designed to calculate the flow of water into an opening into the drift. And it includes only fracture flow, the assumption there being that's the water that enters the drift. The water in the matrix does not.

It includes flow-focusing effects, the idea that some fractures will carry more water than others. And it does include drift degradation in the sense that it looks at a range of drift shapes. Drift openings change shape as they degrade. And so for inputs to that, the thermal hydrology flux, the shape of the drift, and the rock properties.

For SR, TSPA-SR, the abstraction used thermal hydrology flux five meters above the drift as the input up there, recognizing that the model was not

adequate to account for the thermal effects in the stream near field. Therefore, we took what we felt was a conservative approach of using the flux from above that highly disturbed thermal zone during the thermal period.

In fact, that had relatively little effect on performance. We can come back to that. But the -- during the thermal period, the amount of water entering the drift is not that important a contributor, because there is very few failed packages and the drip shields are intact.

The outputs of a seepage model are the seepage fraction, which is the number of packages, the fraction of packages seeing seepage. It's more complicated than this, but that's a good number to start with. And the seep rate -- how much water is coming through in millimeters per year.

And there are seepage bins, depending on -- it used to be number of packages put into each grouping, so-called bin, based on different waste types and different infiltration scenarios. And there are, in my talk from tomorrow from the backups, there are some discussions of what seepage rates actually are or were for recent models for each of the different bins.

And seepage fraction -- this is worth noting there. Thirteen percent of the waste packages in the site recommendation saw seepage. A much larger percentage, 48 percent, in more recent analyses. That has to do with the frequent flow-focusing and episodicity, which is basically how often the fractures are flowing. And if they are flowing less often, you tend to get higher flow rates. And then, when they do flow -- and that's above the threshold.

Yes?

DR. PAYER: Joe Payer. A question -- when you say 48 percent, does that mean 48 percent of the packages are getting dripped on all the time, or 48 percent are dripped on --

MR. SWIFT: In the glacial transition climate, yes.

DR. PAYER: Okay.

MR. SWIFT: Next, please.

DR. LATANISION: Just to follow that up -- Ron Latanision -- there is evidence that suggests that the drip shield actually will stress corrosion crack in representative repository environments. Is that somehow integrated into the link?

MR. SWIFT: It was considered. There is not in this model, and Bob Andrews will talk more on

that later on.

DR. LATANISION: Okay.

DR. EWING: Just a very quick question. Earlier in the discussion of climates you indicated that the uncertainty in the magnitude of changes in precipitation and temperature are included through the infiltration model.

MR. SWIFT: Yes.

DR. EWING: So when we get to seepage, now that uncertainty --

MR. SWIFT: It's there. And you have to go to my backups from tomorrow morning to see how it's there. But it's through the different bins. We have high and low seepage, high, low, and medium seepage rates for each climate state, and --

DR. EWING: But is the actual uncertainty being propagated through the analysis?

MR. SWIFT: Yes. Well, yes, it is, in that we end up with different seepage rates for different waste package bins representing high, medium, and low infiltration states for each of the three climate states.

DR. EWING: So what does it mean to be included through the infiltration model?

MR. SWIFT: Because it's the infiltration

model that sets the -- sets two things. One is it sets the initial conditions for that percolation for the thermal hydrology model, eventually becomes percolation flux. And the other is that it sets the probability that you will be in a high, medium, or low infiltration state.

DR. EWING: So I could follow the uncertainty step by step through this. It's all connected, is I guess -- it's not truncated at --

MEMBER GARRICK: It's connected, but it's doubtful you could follow it.

DR. EWING: Okay.

(Laughter.)

MR. SWIFT: But it is -- it could be explained.

DR. EWING: Right. Okay.

MR. SWIFT: And I'm afraid that -- you know, I can take a shot at it, but it would take half an hour here, and that's --

DR. EWING: All right.

MR. SWIFT: -- I might not be the right person to explain it.

DR. BULLEN: Dan Bullen, NWTRB. Just a quick followup on the seepage question. And we learned in the last presentation from Abe Van Luik

that the design is actually integrated in some way into the TSPA. And the evolution of the design now is that there is actually a five-panel layout for the repository.

One of those panels actually crosses the Ghost Dance. And so could you explain how the seepage and the design are interwoven I guess? Because how do you deal with the Ghost Dance fault as a bottom line with respect to seepage?

MR. SWIFT: Thank you. I know I can't answer that one. That comes under the category --

(Laughter.)

-- of models we are currently developing.

DR. BULLEN: Okay. That's fine.

MR. SWIFT: Of course, we do have to change our hydrology models to fit the new footprint, and that work is in progress.

MEMBER GARRICK: Peter, maybe Bob will make these connections in his talk. But I hope somebody points out the changes in the models between the SR and the supplemental that accounted for the -- some very considerable changes in the doses.

I know that in treating uncertainty or accounting for uncertainty -- led to contribution to the dose in the zero to 10,000-year timeframe, and

that some other things led to almost a five orders of magnitude dose reduction in the 10,000 year to 100,000 year.

As you do this, can you help us connect with the differences in the models that accounted for these rather dramatic differences in the dose?

MR. SWIFT: Sure.

MEMBER GARRICK: Because it suggests a high level of instability in the analysis.

MR. SWIFT: We weren't -- neither Bob nor I was prepared to actually talk about that. I can talk about it. I'd rather do it in the context of tomorrow morning --

MEMBER GARRICK: Okay.

MR. SWIFT: -- when I've got some results to show --

MEMBER GARRICK: Fine.

MR. SWIFT: -- up there on the screen.

MEMBER GARRICK: Fine.

MR. SWIFT: I also -- somebody has to keep me honest on time.

MEMBER GARRICK: Yes. Well, your time is up.

MR. SWIFT: Okay.

(Laughter.)

Next slide, please.

But, please, do keep me honest on time.

MEMBER GARRICK: Yes.

MR. SWIFT: I have two slides in here which I'm not going to mention at all because Bob Andrews, if I don't use up all of his time, will talk about them later on -- the source terms as defined in -- for this working group.

Next slide, please.

And, again, I think Bob uses both these slides in his talk, and I think Joe Payer may have used versions of these also this morning.

Next slide, please.

Now, what we call the -- well, no, what the workshop grouping has called the near field as distinct from the source term, the engineered barrier system flow, chemistry, and transport models are what we're interested in here.

And, yes, we do have models for each of these, models for the -- for example, the one-dimensional flow model, it takes the thermal hydrology, the seepage, the flow out of the waste package, and produces a flow through the invert, which is the main point of interest there.

A chemistry model calculates the evolving

chemistry of the -- and Bob is going to talk about the chemistry package, but this model calculates the evolving chemistry in the invert for transport purposes.

And then, an engineered barrier system transport model that has both invective and diffusive transport mechanisms, and it provides the radionuclide flux.

Next, please.

The unsaturated zone transport model -- again, it's a 3-D model that uses those flow fields calculated by the mountain scale flow model. And it's implemented directly in the TSPA. We actually run the FEM particle tracker for -- continuously for each realization.

And what it -- its primary inputs are those flow fields, radionuclide fluxes out of the invert, and the time and magnitude of the water table changes. When a climate change occurs, the water table rises, by assumption essentially, and the radionuclides that are in transport in that zone are flushed into the saturated zone, added to the saturated zone source term. And it's the output to the saturated zone.

Next slide, please.

There's a process model that calculates three-dimensional steady-state flow at the site scale. That's the blue boundary shown on here. This, by the way, has been shown many times before, but it's a false color image, infrared range.

The red is vegetation, so that's high altitude up there, or alfalfa fields I believe they are, agricultural fields down here in the Amargosa Valley.

And the blue line here are the calculated flow pads away from the site. So the 18 kilometer boundary is somewhere about in there.

Transport is calculated here as breakthrough curves for release at the initial time -- time zero. And in my backups to my tomorrow presentation you can see some breakthrough curves.

The model includes sorption and both reversible and irreversible colloids. Reversible colloids are those that lose their radionuclides back into solution, where they then may be sorbed by other mechanisms or picked back up onto colloids again. Irreversible ones are colloids that stay as colloids and transport fairly quickly.

And we use a convolution integral to use those breakthrough curves to -- we apply them to the

releases at whatever time they enter the saturated zone. And we scale for climate effects just by increasing the -- we correctly scale the breakthrough curves.

The output to the biosphere model is the radionuclide flux at the withdrawal well. And I'll mention it here because it doesn't show up on the next slide. The withdrawal well -- we use the 3,000-acre feet per year specified in the regulation, and we assume that all radionuclides in the plume are captured in those 3,000-acre feet. So it is all radionuclide flux to -- excuse me. All of the radionuclide flux crossing the 18 kilometer boundary enters that withdrawal well.

Next slide, please.

The biosphere model -- a little graphic there just showing things that are included in the model. Important things here -- that the exposure pathways, food, water ingestion, dust inhalation, external exposure.

Lifestyle and groundwater pumping is specified by regulation, or our assumptions are consistent with regulation. The dose methodology is ICRP 30, and the inputs to the TSPA that matter there are those radionuclide concentrations in groundwater,

which is simply the flux to put into 3,000-acre feet.

The outputs from the biosphere model itself are the BDCFs, biosphere dose conversion factors, which are actually applied to those concentrations to get the dose in TSPA.

Next slide, please.

That's just a summary. I think I can stop there for time.

MEMBER GARRICK: Okay.

MR. SWIFT: And I apologize for that. But if there are questions, I'll try to field them.

MEMBER GARRICK: Thanks.

All right. Questions from the panel or the committee? Dan? Maury?

DR. MORGENSTEIN: Sort of a general statement, going back to water chemistry. Obviously, I'm not satisfied. One of the things that really bothers me is that we're utilizing a saturated zone water composition, say J-13, or any other you choose, and we're basing the entire reactive situation with respect to the EBS with that water chemistry.

We're saying that in the near field the only water chemistry of importance is J-13. We're saying that water coming down from different places, through different areas of the ground surface, have

all about the same water composition. And that going into the near field, as they go through Topopa Springs, they all equilibrate and have about the same general water chemistry. And that's about what J-13 looks like and we're reacting -- EBS-like C-22 material with that.

MR. SWIFT: As it evolves in the near field.

DR. MORGENSTEIN: Yes.

MR. SWIFT: Yes.

DR. MORGENSTEIN: And I'm saying that simplistic view is totally unfounded, that in reality different waste packages are going to see all sorts of different water chemistries in the near field.

MEMBER GARRICK: Yes, that's what I --

DR. MORGENSTEIN: And so I'd like you to speak to that. What can you say?

MR. SWIFT: I'm going to defer to Bob Andrews. Bob, you are going to cover this soon?

MR. ANDREWS: Yes, we'll talk about it more then.

DR. MORGENSTEIN: Okay.

MEMBER GARRICK: All right. We'll park it and get back to it.

Other questions? Yes, Rod?

DR. EWING: This is just a detail. But in the unsaturated zone transport models, you have this 3-D steady-state particle tracker, dual continuum transport sorption, reversible/irreversible colloids.

I looked at that maybe two years ago, and there weren't actually many data available. Has that changed at all? I mean, are there -- is there an experimental database to support modeling the sorption, reversible/irreversible?

MR. SWIFT: Well, yes, there is data. I'm not prepared to talk about data in detail.

DR. EWING: Okay.

MR. SWIFT: You are well aware what data there was two years ago. There's more since then. That doesn't help answer your question.

DR. EWING: Right. Okay. Thanks.

MEMBER GARRICK: Mike, didn't you have a question?

MEMBER RYAN: Yes. Peter, thanks for your presentation. But on the biosphere part, you made the comment that -- let me get it right -- all of the radionuclides in the water are exiting the well.

MR. SWIFT: Yes.

MEMBER RYAN: Could you talk about that? I mean, that seems to be unrealistic and, frankly,

overconservative because, as the water is depleted, lots of stuff will be left behind.

MR. SWIFT: It's driven by the regulatory specification of 3,000-acre feet per year. And our hydrologists say that a well pumping at that rate actually could draw down the entire width of the plume.

MEMBER RYAN: But all of the radionuclides won't come out with it.

MR. SWIFT: Well, they do in our model.

(Laughter.)

MEMBER RYAN: I understand that. But the point I'm trying to make to you is that there is an uncertainty there that needs to be assessed. You know, it's very helpful to understand whether that's conservative or not conservative and by how much.

MR. SWIFT: I would be personally very interested in seeing how the NRC has treated that question myself.

MEMBER RYAN: Okay. Well, I'll park that question, too.

DR. VAN LUIK: This is Abe Van Luik from DOE. We actually in our -- if you look at our EIS, we realize that the calculation that we're doing for the biosphere is a stylized calculation that assumes a

large withdrawal, and then, basically as a compensation, assumes that all flux enters that well.

At the same time, in our EIS we recognize that this is probably not the way it goes, and we do look at doses further downstream, making some I think reasonable assumptions about how much comes through.

But it's a stylized calculation. We were not trying to be realistic in this calculation. We were trying to follow the regulatory guidance, which I think is a reasonably conservative assumption here.

MEMBER RYAN: But you're saying reasonably conservative, but we have no measure of that. My point is we need to think about what measure we might have for that. I think it's quite large. That's why I'm encouraging it. Leaving it indeterminate doesn't seem to be consistent with how we're addressing other uncertainties.

MR. SWIFT: This is basically a -- something that the regulator has given us regulatory guidance on how to treat. There's a very large uncertainty as to what future humans really will pump out of the ground.

And simply saying they're all captured and pumped out, it produces the largest possible mass release at the surface of radionuclides. But it also

dissolves them, dilutes them, in 3,000-acre feet. Any other assumptions you have to adjust the amount of water you're going to put those into as concentrations in order to calculate the dose also.

So you could have fewer radionuclides and less water. You could have fewer radionuclides and all that water. This is pretty speculative.

MEMBER RYAN: All the more reason to do it more formally.

MR. SWIFT: All right. We are doing it as we believe the regulator has specified.

MEMBER GARRICK: Yes. I think this is the thing that sometimes concerns us, is that on the one hand when we're under the lamppost we do a very good job of addressing the issue of realism and uncertainty propagation and sampling, and what have you.

But when we get away from the lamppost and we're in the regions where we don't have much illumination, we make these gross assumptions that probably just completely wipe out any benefit of the more refined and realistic modeling that's done.

How do we judge that? That's a very difficult issue. This seems to be one of those kinds of assumptions. There's a lot of them.

MEMBER RYAN: You know, one specific

example, if I may, John, that is -- kind of exemplifies my point is we typically treat I-129 as an intake to diet. We never assess the iodine pool in the diet. And if you dilute I-129 in an iodine pool --

MEMBER GARRICK: Yes.

MEMBER RYAN: -- you can't get a real -- you can't get the dose that you can by applying the dose inversion factor. The dose is much lower. Iodine is an important transfer radionuclide.

So the fact we just kind of stick the biosphere on the end and not give it the same rigor that we give other components, I challenge that to be something we need to think about.

MEMBER GARRICK: Any other questions?

MR. SWIFT: Yes. Tim McCartin wants to comment on that.

MEMBER GARRICK: Oh, yes.

MR. McCARTIN: I guess I'd -- one question I had -- Tim McCartin, NRC staff. When you were talking about the -- what gets into the pumping well or into the concentration for the reasonably and maximally exposed individual, the dissolved radionuclides are in there.

Now, there is radionuclides that are

sorbed on the rock. That is accounted for. But what we're --

MEMBER RYAN: Okay. Well, that's a different story than all of the radionuclides get into the water.

MR. McCARTIN: Yes. All of the radionuclides have reached that point in the transport system.

MEMBER RYAN: All soluble radionuclides that are in solution. Okay.

MR. McCARTIN: All those that were transported.

CHAIRMAN HORNBERGER: Yes. But, Tim, in fairness, you still are making the assumption that the entire mass flux across the boundary is going into the 3,000-acre feet.

MR. McCARTIN: Yes.

CHAIRMAN HORNBERGER: And that is not a physical possibility.

MR. McCARTIN: Well, I think it's possible. Three-thousand-acre feet -- well, 3,000-acre feet is a fair amount of water relative to the size of the plumes that we and DOE have seen to date.

Now, the reason -- there is a couple of reasons why this was done in terms of when we

specified the regulation, EPA also -- that there was not a desire to find out concentrations in very small parts of the aquifer.

Clearly, an actual plume emanating from any source will be highly varied in concentration, and it was not deemed practical nor doable to try to estimate concentrations very precisely in small amounts. And so a volume of water was specified, and you're right, we will assume the concentration in this volume of water.

There is the flexibility that, indeed, this volume of water could not physically get the entire plume. The Department can make arguments and demonstrate that they aren't capturing the entire plume. But to date, their analyses indicate that 3,000-acre feet is sufficiently large that there would be very little reduction if one tried to estimate what might you not get in the 3,000-acre feet.

MEMBER RYAN: My comment isn't aimed at criticizing the convention. It's simply to say that there are some things that could be evaluated to evaluate that convention with regard to its nature of being conservative or not conservative in parts and pieces and see what those things are. And I think just to say it's the convention, that's what it says

in the regulation, let's just plug that in, misses the opportunity to make some other assessments that would be helpful.

MEMBER GARRICK: Any other questions? Yes, Milt.

MEMBER LEVENSON: I've got kind of a little bit of a generic question I guess. You've done things like one-on and one-off with barriers, etcetera, but almost all the discussion today has been about oxide fuel and power reactor fuel. And clearly, that's the bulk of what is put in the repository.

Maybe it's okay to automatically assume that's the major source term, but maybe it isn't. The chemistry is completely different. You have vitrified materials. You have Navy fuel. You have a hodgepodge of DOE fuel, some aluminum matrix.

Have you run any models adjusting the chemistry and corrosion, etcetera, for these other materials, assuming maybe that there isn't any power reactor fuel there, to see whether in fact it's appropriate to continue to ignore all these other things?

MR. SWIFT: We do not ignore all those others. We do model the other waste streams in a so-called co-disposed waste form, which is vitrified

waste with DOE spent fuel.

And, in fact, much of our technetium, which is the driver for dose for at least the early portion of performance, comes out of that vitrified waste rather than out of the commercial spent fuel.

No, we have not modeled the system without commercial spent fuel in it. I think that was your question.

DR. MORGENSTEIN: So you have one source term rather than a variety of different source terms?

MR. SWIFT: I'm not quite sure how to answer that question. We looked at one suite of waste, which design -- our design specifications say will be the type of waste shipped to Yucca Mountain, that includes in it many different waste forms, which we do include in our modeling. But we do not attempt to model a system with different types of waste, other than those that are already planned for it.

DR. MORGENSTEIN: How do you treat the variation in waste release from the different types of canisters?

MR. SWIFT: We model primarily two large -- Bob, you're going to talk about this, aren't you? Yes. This is Bob Andrews' talk. I'll put it off here. Sorry.

MEMBER GARRICK: Okay. Any -- yes, go ahead, Abe Van Luik.

DR. VAN LUIK: Yes. Of course, we -- this is Abe Van Luik, DOE. We are looking at the contributions of different waste types, basically as an off-line report, to see if our assumptions about categorizing those in these larger bins is appropriate. And, in fact, Jim Duggett has just completed another set of analyses in that regard as part of our cooperative effort with EM about what they're going to ship us.

Another point I was going to make, which we can revisit tomorrow also, is the idea that we have actually looked at the water geochemistry quite closely. We have seen that the water in the pores is a slightly different composition than the water that we do find in the fractures, and that it looks like the predictions that Bob was referring to are basically a good integration of those sources. And that, in turn, matches pretty well the J-13 water.

If we were drawing down into the carbonate aquifer and drawing up carbonate waters, I would agree with you, we're out to lunch. But we are looking at waters that are very close in composition all through that system. And the interesting thing is that, of

course, what the water is telling us is that most of the fuel through the system is through the fractures, and that the matrix basically has a lot of pleistocene water in it still.

MEMBER GARRICK: Okay. I think we'll excuse Peter. Thank you very much.

MR. SWIFT: You'll see me again.

MEMBER GARRICK: We'll look forward to that.

All right. I guess our next speaker is Chris Grossman.

Chris, you'll tell us your job and who you are, etcetera.

MR. GROSSMAN: Can you hear me? Okay. My name is Chris Grossman, and I am a new member here of the Environmental Performance Assessment Branch of the Division of Waste Management. I started with the NRC a little over a year and a half ago, and they've gotten me involved pretty heavily so far, and I'm enjoying what I'm doing.

So with that, I'd like to thank the committee for inviting the staff here to provide -- to give us the opportunity to discuss our TPA code, the total system performance assessment code.

My goal this afternoon is to provide you

with an understanding of the key approaches and assumptions upon which our TPA code has been constructed by the staff both here at the NRC and our support contractor, the Center for Nuclear Waste Regulatory Analyses.

Back to the title slide, please.

I plan to focus this talk on the current version of the code, which is Version 4.1. However, performance assessment is an iterative process, and the staff, with technical assistance from the Center, is currently upgrading the code to Version 5.0.

During this talk I will highlight some of the modifications being made for that version of the code, but I do not plan to talk to the modifications in much detail. But if the committee is interested, the staff will be glad to come back at a later time and discuss those modifications.

I'd also like to thank both staff from the NRC and the Center for contributing their expertise in the development of the conceptual models from the TPA code. In particular, I'd like to single out several staff members listed here on the slide for making significant contributions to this presentation.

Next slide, please.

As Andy Campbell mentioned this morning

before lunch in his presentation, that the NRC is responsible for reviewing a license application for a potential repository at Yucca Mountain. Currently, the NRC is engaging the Department of Energy in prelicensing activities to ensure that any license application contains sufficient information to support our review.

The TPA code is a tool to assist that review of both the prelicensing activities and the potential license application.

We conduct detailed technical performance assessments to independently understand the potentially important isolation characteristics and capabilities of the proposed repository system, thereby enhancing our review capabilities.

Staff relies on evidence gleaned from prelicensing interactions with DOE, as well as scientific research conducted by the NRC and the Center, to develop or support our models that are used in the TPA code.

This, and the subsequent presentation by Dave Esh, regarding the source term modeling will detail the use of that -- some of that available evidence that's been used to support the conceptual models in the TPA code.

I'll give you a few examples here. Some of the independent research conducted by the Center has included detailed process-level modeling of coupled water, and energy transport through pores and fractured rock. This is used to estimate long-term shallow infiltration rates at the site, or in our simulation.

Another example would be field investigations at the Nopaugh 1 site. This is a natural analog site in Pena Blanca, New Mexico. And we've used this information to estimate oxidation and release rates of spent fuel.

A third example would be laboratory corrosion experiments that have been conducted at the Center for Alloy 22. We have used these to help develop our waste package corrosion modeling.

The TPA code employs fundamental first principles and experimental -- or, excuse me, empirical evidence to simulate repository behavior. This approach also can allow flexibility in conceptual models to assist our review capabilities.

The code facilitates our understanding of the results of our models and our associated strengths and weaknesses. It allows us to probe uncertainties in data or models and challenge DOE's assumptions,

data, and models, as well as our own.

Next slide, please.

DR. EWING: Excuse me.

MR. GROSSMAN: Yes, sir.

DR. EWING: Just the phrase "first principles," what do you mean by that?

MR. GROSSMAN: These would be things such as conservation of mass would be an example of a first principle.

DR. EWING: Okay. Thank you.

MEMBER GARRICK: That's a good first principle.

(Laughter.)

MR. GROSSMAN: The approach we take in the TPA code is to conduct probabilistic dose calculations for specified time periods. We attempt to account for essential features of the engineered natural barriers as well as chemical and physical processes affecting degradation and release to the biosphere.

The approach attempts -- also attempts to account for uncertainties, including spatial variability of system attributes, model parameters, future states, and the lifestyle characteristics of the reasonably maximally exposed individual.

This is included with the TPA code

scenario -- classes include a nominal case, which includes climate change and seismic activity. There's a disruptive case involving faulting, as well as a disruptive case involving igneous activity.

Next slide, please.

This is a simple schematic of a repository conceptualization. And for ease in use -- for ease of use and some computational efficiency, we replace the intricate layout and the complex geologic setting with relatively simple conceptual representations. For example, the repository layout is represented by an idealized planer feature, broken down into 10 subareas.

The number of waste packages in each subarea are assumed proportional to the fraction of total repository area represented by that subarea. Radionuclide releases in each subarea are calculated by modeling a single waste package for each subarea and for each failure type.

Also, TPA replaces the geology by a sequence of homogenous layers represented here in the unsaturated zone. The properties for each subarea for soon to be uniform. For example, the stratigraphy is assumed to be laterally continuous and uniform within a subarea to represent the unsaturated zone as a

sequence of hydrostratigraphic layers.

Except for thermal loads, flow and transport processes in and below a given subarea are soon to be independent of those processes in other subareas. Thus, flow is entirely vertical with no lateral diversion in the unsaturated zone.

TPA models flow and transport in the saturated zone, represented by the three diagonal hatch box below, with three distinct stream tubes over the width of the repository footprint and normal to unsaturated zone flow. Each subarea in the unsaturated zone connects to one of the three stream tubes in the saturated zone.

And then, finally, the mass flow rate of radionuclides exiting the saturated zone stream tubes is used to compute the average concentration at the weld head. This is then used to calculate the annual dose to the reasonably maximally exposed individual.

For the remainder of the discussion, I want to walk through the repository system following the expected progress of water and radionuclides. First, I plan to discuss the processes associated with water movement to and through the repository level, represented here above the repository. Then, I plan to briefly highlight some of the key processes

associated with degradation of the engineered system followed by processes affecting radionuclide release from the engineered system.

I only plan to highlight these processes, because in the subsequent presentation by Dave Esh these processes will be discussed in much more detail.

And finally, I plan to provide some detailed discussion of radionuclide transport through the natural system.

This will give you an idea of the format I'm trying to attack here with this presentation. It's going to follow the same general progression. On the first slide, I plan to introduce the processes and some of the approaches used to represent these major areas.

The next several slides then will discuss particular conceptual models in more detail. During the discussion of the details, I will generally introduce the conceptual model, provide any evidence that's been used to develop or support the model, and provide some process-level output to give us an understanding of how the model is working.

So let's move on to our first topic, which is the water flow -- water movement through the repository.

It's important to have an understanding of the water available to the engineered system for radionuclide release. The key processes affecting the movement of water to and into the engineered components of the repository system include climate change, shallow infiltration, deep percolation, thermal hydrologic processes, as well as focusing for diversion -- flow focusing or diversion processes.

Climate change is represented in TPA as the variation in temperature and precipitation within anticipated glacial cycles. Process-level modeling incorporates climate, soil depth, and bedrock permeability to estimate the shallow infiltration flux for bare soil conditions.

Once the time evolution of shallow infiltration flux is determined, TPA then constrains the deep percolation flux equal to the shallow infiltration. During early periods, water percolating downward will be affected by thermal processes due to heat generated from the emplaced waste. Water movement will be impacted by coupled heat transfer and flow processes such as vaporization, condensation, and refluxing.

Finally, TPA partitions the water flux at the repository horizon into water flux diverted around

the waste packages and water flux entering the failed waste packages due to diversion or focusing processes.

Next slide, please.

So let's get into one of the -- some of the details of one of our models, and this is the shallow infiltration model. And we use a one-dimensional modeling approach to describe how water at the land surface moves vertically downward through the unsaturated zone to the repository horizon and ultimately to the water table.

Infiltration rates are strongly affected by precipitation and evapotranspiration, which in turn is strongly affected by air temperature.

Over the period of repository performance, the average precipitation and air temperature are anticipated to change with the glacial cycle. Evidence suggests that precipitation may have been at one and a half to two and a half times larger than the current climate, while temperature may have been 5 to 10 degrees cooler at the last full glacial maximum.

TPA calculates the change in temperature and precipitation due to bulk climate changes based on the Malenkovic cycle, as well as shorter term climatic changes superimposed on the long-term changes. And you can see some of the bulk change in terms of the

overall shape of the curve in the lower figure, and then some of the shorter term perturbations.

Process-level modeling then determines the net infiltration for the modern climate from one-dimensional simulation results that are based on meteorological data from Desert Rock, Nevada. The process-level modeling incorporates climates, soil depth, and better rock permeability, as mentioned previously, and these are used to estimate infiltration flux based on a range of temperature and precipitation.

The TPA determines the net infiltration flux from the process-level modeling based on the calculated temperature and precipitation. This figure, as I said, shows the bulk variation as well as the shorter term variations in some of that information that the code is using.

Next slide, please.

One of the other processes I mentioned two slides ago was the groundwater refluxing from -- during the thermal period. And heat emanating from the waste packages at early times -- and we can kind of get a sense of the temperature profile at the drift wall there from the top figure.

It will cause the temperature in the drift

wall to exceed the boiling point of water, and will drive water away from the repository due to coupled thermal hydrologic processes.

The lower figure here displays the conceptualization of the drift scale thermal hydrologic model incorporated in the TPA. The process -- we use process-level modeling to calculate the thickness of the dryout zone. What we have here are a series of drifts represented at the lower portion, and the dryout zone that is calculated offline in process-level models would represent this distance here up to the boiling isotherm.

We then used the code to calculate that the distance -- calculate the distance that water will flow down a fracture to penetrate into the dryout zone before it completely vaporizes. And this would be represented here by this length here where we have this circulation of water.

If the penetration distance exceeds the thickness of the dryout zone, then water will reach the drift and be available to potentially contact the waste packages. For flexibility and to evaluate uncertainties associated with the thermal hydrologic modeling, we also incorporate two additional alternative conceptualizations of this refluxing into

the model.

Next slide, please.

After the thermal reflux, there is a net downward percolation to the drift. TPA assumes that the water will flow in fractures within the repository horizon. Our dripping abstraction determines the quantity of water eventually entering the failed waste package.

We use a simple and efficient approach to modify the percolation flux involving sample distributions. These sample distributions are factors that account for large-scale diversion as well as drift scale processes. Specific factors account for the fact that not all the waste packages will experience dripping water.

They also account for focusing or diverging of water away or toward the drifts due to flow and fractures. They account for the diversion of water around the drift due to capillary forces in the unsaturated products. They account for flow of water that does reach the drift boundary along the wall of the drift in the film flow.

They account for drips that actually do drip from the drift boundary, but miss the hole or potentially the hole is plugged with corrosion

products. I'm not going to go in too much more detail on these, but I just wanted to give you an overview sense here of how we approached water entering the waste package.

Dave Esh plans to address the abstraction in more detail later today in his presentation regarding the source term modeling approaches.

Next slide, please.

And speaking of Dave, this will be the lion's share of the presentation. The degradation of the engineered system also represents the next step in our progression towards the biosphere here. We've completed water movement through the repository.

I want to give you, though, a brief preview of some of the processes which Dave will detail later to provide an understanding in terms of the integration of these processes with the entire repository system in our model.

TPA samples the time of drip shield failure. This distribution was developed from process-level modeling based on some evidence. The code considers -- for the waste package, the code considers several failure types. The first is a juvenile failure. These are failures that may occur due to fabrication defects or emplacement damage.

The code samples a small number of waste packages which are assumed to be failed at the beginning of the simulation. The code also considers corrosive degradation failure types for the waste package; specifically, uniform and localized corrosion. The mechanism and rate of corrosion is dependent upon the conditions of the near field environment, and the code assumes that the waste package fails with a single penetration of the containers.

And because the near field environment affects the corrosive failure mechanism, as well as waste form degradation, the code determines some key thermal hydrologic parameters -- the waste package surface temperature and relative humidity of the air between the waste package and the drift wall.

The code also uses the results of process-level modeling to estimate some key contributors to the near field environment. And I'd like to discuss the thermal modeling as well as the near field environment abstractions in a little more detail to give you some more understanding of the approaches and assumptions in these areas.

Next slide, please.

Relative humidity initiates the corrosion

mechanism in the TPA code for the waste package. The code performs a series of analytic calculations to determine the temperature of the drift wall, the waste package surface temperature, and the maximum spent fuel temperature, which is for waste form degradation.

The drift wall temperature is calculated using a mountain scale conduction-only model. The heat sources are represented as a series of parallel lines across -- spread across the repository region. The waste is assumed to be emplaced in drifts so closely that there's no spatial variation in the waste heat output along the drift, but there is variation between the drifts.

Ventilation during the pre-closure period can also be accounted for in the TPA code. A conceptual model of the drift scale is illustrated in our top figure here. The drift is idealized as a series of concentric circles. The waste package surface temperature and maximum temperature of the spent fuel are calculated using analytical approximations of multimodal heat transfer.

The abstraction relies on an analytical conduction model with thermal conductances that approximate conductive, convective, and radiative heat transfer. The model accounts for the temperature of

the drift wall in calculating the waste package surface temperature.

After computing these, the code then calculates the relative humidity as a function of the drift wall and waste package surface temperatures, as well as the moisture content of the air at the time of closure. And, finally, the code has -- incorporates alternative conceptual models for determining temperature and relative humidity.

Next slide, please. Yes?

DR. MORGENSTEIN: Do you look at transient heat on the canister at all?

MR. GROSSMAN: In the code itself -- there may have been some offline modeling. But in the code itself, it's modeled as explained. In terms of transient heat, I don't believe we do. Dick Codell can speak to this.

MR. CODELL: This is Dick Codell. Yes, the heat rate is a function of the radioactive decay of the waste, and that's built into the analytic model that's in the TPA code. That's what you were talking about.

DR. MORGENSTEIN: Yes. I was more concerned with variations on the metal surface based on geometry of the surface.

MR. ESH: This is Dave Esh, NRC. That's not included in the current version of the model. I believe our abstraction for TPA 5.0, which is going to have a pretty substantially revised near field chemical environment model, may consider it. I'm not sure.

MR. GROSSMAN: Besides the thermal regime, the composition of the near field environment can affect the corrosion modeling. Chloride here is considered an influential species for localized corrosion, and the corrosion abstraction, which will become apparent during Dave's presentation when he talks about engineered degradation.

Currently, the process-level modeling simulates the change in chloride concentration at the drift wall due to evaporative processes. The TPA then adjusts the chloride concentration to account for uncertainties and limitations of the modeling to represent the chemistry on the waste package surface.

This figure here depicts the chloride concentration resulting from the process-level modeling that is currently in the TPA code. The code fixes pH at nine, which has some basis in process-level modeling.

And we realize that this is somewhat

limited, but that the next version of the code will substantially redesign the near field environment chemical abstraction to include a suite -- include the time evolution of a suite of environmental parameters.

Next slide, please.

So we've talked about the degradation of the engineered components, and next I'd like to move on to radionuclide release from the engineered components.

Here again, Dave will present much more detail in his presentation later today. I only wish to highlight the major areas here for your benefit.

Our code considers two models for advective transport of radionuclides out of the waste package. We have a bathtub model in which water dripping into the waste package must reach a particular depth before radionuclides dissolved in the water can flow out of the package. And we also have a flowthrough model in which water drips into the waste package, contacts the waste, and immediately exits the waste package.

Currently, TPA does not incorporate a diffusion model. However, to assist our review capabilities, TPA 5.0 will add such a model in the future.

The code relies on experimental evidence as well as natural analogs to support the spent fuel dissolution rate model. The code also incorporates three additional alternative abstractions to model the dissolution rate. And currently, the code does not include a high-level waste class source term in its inventory, because the spent fuel contributes to the bulk of the emplaced waste. However, to assist our review capabilities, we do plan to add such a source term in TPA 5.0.

And, finally, the TPA code allows for cladding protection, though the current version of the code takes no credit for that protective feature of the cladding.

MEMBER GARRICK: Chris, just help me understand something. You said that you rely on data and information for the way it was modeled with respect to the dissolution. What do you rely on for your specific bathtub modeling assumption or your advective flow-through assumption?

MR. SWIFT: Well, in terms of what we rely on, these are two conceptual models that allow us to evaluate some of the uncertainty associated with the act of radionuclide release from the waste package.

MEMBER GARRICK: Yes. Well, I can

understand if you saturate the waste package that you have a strong basis for knowing how the waste is actually mobilized. What I don't understand is why the bathtub assumption in the first place makes sense.

MR. SWIFT: Well, in some cases, we can envision where you might have water entering through the top of the waste package. And for some reason, you would have corrosion, possibly on the side or somewhere near that same hole where the waste package would have to fill up to a certain level before spilling over and then releasing radionuclides to the invert.

MEMBER GARRICK: Yes. I plan to come back to this issue when we hear from the DOE.

DR. EWING: Can I just follow up? Probably the bathtub model is not so appropriate, but it's useful from an experimental point of view. There are many experiments in the literature of spent fuel dissolved under static conditions, in a beaker, let's say, essentially in a bathtub. Does your model predict the experimental results?

MR. SWIFT: Not to my knowledge. But Tae Ahn would like to speak to this, I think, a member of our staff.

MR. ESH: This is Dave Esh first. I'll go

over that some in my presentation.

DR. EWING: Okay.

MR. ESH: And you'll hopefully get a flavor for what we're doing.

DR. PAYER: I had a question. Procedurally, it sounds as if, as you went down through this -- Joe Payer, by the way -- that you've got several alternative models and you're thinking about or are actively developing some others and plugging them in.

Contrast that with what I think I heard Peter Swift say that, you know, the TSPA has to lock in their models as of now and can't, you know, make dose changes for the LA documents. How can you all plug these things in? Is what you're doing analogous to the -- what the TSPA folks called their one-off analysis?

MR. SWIFT: No.

DR. PAYER: Or help me with --

MR. SWIFT: These would be instances where we want to apply a different conceptual model. Maybe the thinking with, say, the bathtub model is completely wrong. So we look at another model, a flow-through model, to get a sense of the uncertainty associated with the various models.

This helps us in our review capabilities when we would need to evaluate DOE's models and --

DR. PAYER: I guess it just -- and maybe there's not a simple answer for it, but I don't see how you have that flexibility to make those conceptual model tradeoffs at this point, and --

MR. SWIFT: Well, actually, when running the code through a simulation, you choose one or the other. They don't both run simultaneously. And then we would compare from there. So there isn't this shift in and out between the two.

CHAIRMAN HORNBERGER: Joe, I think maybe their advantage is that they don't have to produce a license application.

(Laughter.)

DR. PAYER: I guess the point is that, is it the number of simulations that you have to run? I mean, I --

CHAIRMAN HORNBERGER: Joe, our TTPA is a much simpler model. And in that sense, they can run more simulations. But I don't think that that's the end all and be all. I really think that DOE is locking in because they have to have something stable from which they can produce a document, whereas the NRC has to review the document, and they can do it

much more flexibly.

Andy, I think you had a comment.

DR. CAMPBELL: Yes. I was going to actually follow-on to that statement. The whole point of TPA is not to provide a compliance demonstration. It's really to probe what DOE comes in with in terms of their compliance demonstration. So we need the ability to probe different concepts, alternative conceptual models which DOE actually has to come in and consider in their analyses.

And so a lot of these different modules and different approaches that we implement in TPA are focused on trying to get a handle on, what are the most important in terms of contribution? So in a number of instances, we bound processes through looking at a range of possible performance. We bound the possible impact of a waste package filling up, or water flowing through the waste package by having two different conceptual models.

Even within the bathtub model, it doesn't all just fill up. There's actually a sample parameter that allows water to drain out at different levels, so that we can look at the impact of a partially-filled waste package or a waste package that only has a little bit of water. And that gives us an idea of,

how important is this particular issue or process to our review of their license application and their processes and models.

MEMBER LEVENSON: And I presume, Andy, that's the same reason that you're looking at backfill in the one earlier slide on thermal modeling, and also looking at the high temperature repository.

DR. CAMPBELL: There was an earlier version of TSPA, the design for the repository where they were considering backfill, and so that was incorporated into the modeling approach.

MEMBER LEVENSON: That was the example, actually, that he showed.

DR. BULLEN: Dan Bullen, NWTRB. Just one last quick question about your last bulleted item here on cladding, which you've said you don't use in your nominal case scenario. What type of data would you expect to need to justify the use of cladding? And how would that data be essentially incorporated into your code?

MR. SWIFT: Well, for a discussion of that, I would like to refer to our KTI expert in terms of the container life source term, and that would be Tae Ahn, in terms of the type of data we would use then to -- in the model for the cladding.

MR. AHN: Tae Ahn, NRC staff. If we would like to include the cladding proponents in the base case, we need to have a model such as localized corrosion condition, pH, which stabilized -- to induce the localized corrosion, and that criteria will apply to the stress corrosion cracking as well. Those two are currently ongoing issues within DOE.

DR. BULLEN: Bullen. Quick question before you leave. The cladding is also temperature-dependent, though, Tae Ahn. And so, do you unzip the cladding at higher temperature and then not unzip it at lower temperatures, or --

MR. AHN: Zipping is -- we consider that. However, in keeping with the curve for the cladding with the initial defect, and the zipping kinetics is so fast, we can't give credit to the zipping kinetics itself.

DR. BULLEN: Thank you.

MR. ESH: And this is Dave Esh. In TPA 4 versions, we only had a cladding correction factor, which you could specify, which would be constant in time. We realize we needed more flexibility than that going forward. And in TPA 5.0, I believe the cladding corrosion factor can be time-dependent. So the user will specify what the time dependency is, and they can

take into account, say, an unzipping process or something similar.

DR. BULLEN: Thanks.

MR. GROSSMAN: Okay. Next slide, please. So now we've moved on to the unsaturated zone radionuclide transport, and after the radionuclides have released from the engineered system, they must travel through the natural system to reach the REMI.

And the first component of this system it'll encounter is the unsaturated zone below the repository. The TPA models, the UZ is a simple 1-D vertical flow field through hydrostratigraphic layers whose thicknesses were derived from the geologic framework model 3.1.

The figure here depicts the relative thicknesses of each layer that are used for each subarea in the code.

MEMBER GARRICK: This is a real test, to read this one.

MR. GROSSMAN: You might have better luck on the screen here. They use the abstraction, models, flows, and fracture when the percolation flux exceeds the matrix hydrologic conductivity for a given tuff layer. The TPA code does not include matrix diffusion for the unsaturated zone, because there is limited

evidence that the diffusion does occur to a significant degree in the unsaturated zone.

Matrix diffusion is considered most effective when the flow velocities are slow, flowing fractures are not far apart, and available fracture surface area is fully wetted to allow fracture matrix interactions. All these factors appear to be limited in the UZ. Additionally, the inclusion of the matrix diffusion into the code results in long run times, which limits our review capabilities.

Next slide, please.

This is a plot of some unretarded unsaturated zone travel times, to give you an idea of what the model is doing here. And you see here that for subareas 2, 8, 9, and 10, which are the four lines on the left, exhibit the fastest unretarded travel times, while the remaining subareas experience longer unretarded travel times.

And if we go back one slide, if you look at the gold layers, that's the Calico Hills, non-welded vitric layer, and pay attention to that. That's something that Tim McCartin will talk about to gain an understanding of some of the significance of that layer in terms of our code.

You'll see in subareas 2, 8, 9, and 10, it

does not appear, whereas it does appear to some extent in the other layers.

Next slide, please.

You'll see here that we account for some uncertainty in the unsaturated zone through the different subareas.

MEMBER RYAN: Chris, just a quick question. What's probability of exceedance of what?

MR. GROSSMAN: That's the probability that if you go to a particular point on the line, say here, if we follow this out, this is 10 percent, you have a 10 percent chance of exceeding this. Excuse me here. Oh, we have this time in terms of travel time. Does that clarify that or is it still --

MEMBER RYAN: The probability of exceeding the travel times.

MR. GROSSMAN: Right. Okay. Next slide, please.

The saturated zone radionuclide transport, then, is depicted here -- our conceptual model. And the way we model this is there's three stream tubes that are based on a 2-D horizontal flow net interpretation of the hydrologic gradients in the upper-most aquifer below the region.

The actual weld locations which were used

to develop this flow net, and then 3-D stream tube interpretation, can be seen on the figure provided, some of these small points. There are several points around on the map.

TPA predicts the mean trajectories and travel times of radionuclides in the saturated zone and accounts for variation in geochemical properties along the transport paths. The saturated zone model models flow through localized conductive zones through the tuff, but uniformly distributed through the alluvial aquifer.

Because there is some uncertainty associated with the distance to the tuff-alluvium interface beneath the repository, we sample this distance in the code. And, finally, TPA models radionuclide sorption in the alluvial aquifer and tuff matrix for the radionuclides.

And unlike the unsaturated zone, the conditions promoting matrix diffusion in the saturated tuffs appear to be more common. Therefore, matrix diffusion is included for the saturated zone modeling.

Next slide, please.

This figure was analogous to the unsaturated zone transport, and this is unretarded saturated zone travel times. We have them for

subareas here, but if you recall each subarea dumps into one of the three stream tubes. So you essentially have three curves there representing some of the uncertainty.

The unretarded saturated zone travel time averages approximately 640 years, but ranges from as quick as 57 to as long as 1,800 years.

Next slide, please.

And this is a conceptualization of our biosphere modeling. After the radionuclides are released from the saturated zone, they are captured in 3,000-acre feet and modeled in the biosphere then. TPA predicts radiological exposures for pathways applicable to the reasonably maximally exposed individual, including ingestion, inhalation, and external exposure.

Some parameters are specified in the regulation, while others are drawn from site-specific data, and those I believe are marked here on the figure. And using federal guidance reports, the code calculates dose conversion factors for each radionuclide and exposure pathway, and then converts the radiological releases from the saturated zone to total effective dose equivalent.

Next slide, please.

In the interest of time, I'll just run through this quickly. This is disruptive events. I wanted to provide this for completeness, though it wasn't the focus of the workshop. We do model seismic disruptive event, in which we predict the number of waste package failures caused by falling rocks that mechanically load and deform the waste package.

We also calculate the number of waste package failures that result from movements along undetected or new faults when they exceed a displacement threshold. And then, finally, we also account for waste package failures caused by both extrusive and intrusive igneous events. And we model airborne releases of radionuclides for volcanic eruptions.

And the final slide.

And this just reiterates what I mentioned earlier, that with the code we try to provide a flexible framework that allows us to independently evaluate a potential license application from the Department of Energy, as well as review prelicensing activities.

It also helps us to enhance our understanding of what's going on at the -- or what could potentially go on at the repository.

We try to use, where possible, fundamental principles to develop our approaches and to simulate the repository behavior. And we also like to allow for computational efficiency where it's warranted. And when the data is available, we base our approaches as much as possible on data or evidence.

And with that, I'll open the floor up to questions.

MEMBER GARRICK: Thanks, Chris.

Joe?

DR. PAYER: Joe Payer. Just to followup on your last comment there. What's the overlap, or how consistent are the databases being used by DOE and you folks? Are they the same database?

MR. GROSSMAN: No. In some cases, we rely on information we glean from the prelicensing interactions with the Department of Energy. In other cases, as I mentioned in the beginning, we rely on work that's being conducted at the Center for Nuclear Waste Regulatory Analyses and some of the independent research they're conducting, such as in the area of corrosion modeling and spent fuel dissolution.

DR. PAYER: Is somebody looking at the issue of where -- if the predictions, if the outcomes are different, is somebody analyzing how much of that

might be the result of differences in the data that you're using, and differences in the approaches you're taking to modeling, and separate that?

MR. GROSSMAN: Yes. We're very interested in where the differences would be. Those highlight potential points where we, you know, may challenge the Department of Energy in their models and assumptions.

Currently, the structure we have here is we group staff into key technical issues which we believe are areas important for the performance of the repository. And the staff involved in those technical issues then would help to evaluate the data, the sufficiency of the data on the Department's part, as well as our own data that goes into the models.

And Tim would like to add, I think, to this.

MR. McCARTIN: I guess just one real-world example. If I go back, oh, I'll say three to five years ago, ourselves and DOE were -- are estimating the same release rates from the waste package. However, we had a much lower dissolution rate for the fuel and took no credit for cladding. DOE had a much higher dissolution rate for the fuel but took significant credit for the cladding.

Even though the end product of what was

the release from the waste package was very similar, they were for drastically different assumptions. And those are the kinds of things that we -- we're using this to help assist our thinking, as Chris indicated, and probe DOE. But, yes, absolutely we need to -- just the fact that you compare doesn't mean anything. You need to understand why the comparison is there.

MEMBER GARRICK: Would this be because the source term analysis or the source term modeling is probably less constrained than any other of the models? That is to say, the biosphere and uptake models, they're pretty well prescribed. The infiltration model you would expect that that would -- there could be consistency there.

Radiological -- radionuclide transport you would assume similar things. But the one thing that seems to be the opportunity for great variation is in the source term model, much more than any other model. Am I off target, or is that --

DR. EWING: Yes. I'd want to disagree with you, actually. I think if you look at --

MEMBER GARRICK: Rod, you would disagree with me?

(Laughter.)

DR. EWING: Well, at every opportunity.

(Laughter.)

If you look at the variation, say, in transport of radionuclides versus, you know, release from a waste form, the most important issue are the boundary conditions.

MEMBER GARRICK: Yes. But when I talk about source term, I'm talking about the model that takes it to the point of release.

DR. EWING: From the waste package.

MEMBER GARRICK: Yes.

DR. EWING: Right.

MEMBER GARRICK: So I'm talking about the release states.

DR. EWING: Yes.

MEMBER GARRICK: That the --

DR. EWING: This is just an opinion, but I would say one of my great disappointments is that actually we know a fair amount about the chemistry associated with the dissolution of spent fuel and the chemistry of these individual radionuclides, given the boundary conditions, which can I think be pretty well estimated inside one of these waste packages if we take the time and do the work.

And so I would say not only is this very important, because this is where the radioactivity is,

and if you really understood that you would, you know, have the right release to carry through the rest of the modeling. But I think this is an area where we could make tremendous progress in --

MEMBER GARRICK: I think we're in violent agreement. That's what I'm saying.

DR. EWING: Well, then, I disagree with what I just said.

(Laughter.)

DR. BULLEN: Dan Bullen, NWTRB. Just along the lines of incorporating new data, you mentioned that you try and use sort of the similar databases that the DOE uses. But do you also use data -- like I'm looking at your saturated radionuclide transport model, and your stream tubes have sort of a dearth of data in the kind of northeast quadrant there, yet Nye County has a number of wells that are going on.

So as the well data becomes available in the saturated and unsaturated zones, will those data be incorporated into your models?

MR. GROSSMAN: I can't speak to that directly. I do know that in the future code -- where they are using a three-dimensional model now to improve that abstraction. So I can't speak to the

source of the data for that at this point, but the model is being updated.

DR. CAMPBELL: This is Andy Campbell. We will incorporate, to the extent that we can, information from the Nye County wells.

MEMBER GARRICK: Milt.

MEMBER LEVENSON: Yes, I have a couple of questions for clarification. One, you've made the statement that you make the assumption that when there is first penetration of the package that means the waste package has failed. How do you define waste package failure? And the context of my question is, a while ago the other group --

(Laughter.)

-- made the assumption that in case of waste package failure 50 percent of the surface of the canister disappeared. So what's your assumption for failure?

MR. SWIFT: For our waste package failure assumption, with the corrosion mechanism, we assumed that a through penetration is a breach of the waste package.

MEMBER LEVENSON: Well, what does that mean?

MR. SWIFT: That's failure. The waste

package then offers limited protection. There is some accounted for in those flow factors that we discussed, but it's minor.

MEMBER LEVENSON: And if stress corrosion crack minuscule width goes all the way through, you assume you have a wide-open hole and water is free to drip in with no resistance? Is that --

MR. SWIFT: In some respects, yes.

MEMBER LEVENSON: Okay. The second question is, there's a lot of talk about the water as it concentrates, evaporates on surface, and a lot of water chemistry. Then, consistent with the model that you've just mentioned, does that mean the minute the waste package has failed any water going inside is now plain dripping water that's never been concentrated? Or do you assume it's the same water as is on the surface, highly concentrated, etcetera?

MR. GROSSMAN: I'm going to let Dave deal with that, because he talks about --

MR. ESH: Yes. This is Dave Esh, NRC. Hopefully, in my presentation you'll get an idea for what we're doing for that question.

MEMBER GARRICK: Yes, Maury.

DR. MORGENSTEIN: With respect to disruptive events, although, you know, we're not

concentrating on that, do you look at other events that DOE might not be looking at? Or do you follow the DOE lead?

MR. GROSSMAN: No. We do in terms of the auspices of this key technical issue framework. But in terms of the code itself, you know, what you see here is what you've got. So in terms of investigating issues that the Department of Energy maybe has not considered, I mean, that's part of what we consider our job is to review these areas. And so I would say under the auspices of this key technical issue, we have staff that do investigate those sorts of things.

DR. MORGENSTEIN: In that light, have you looked at the possibility -- when we look at volcanic events, we've have looked at volcanic events that -- where lava has hit the near field, or there's a surface flow. Have you looked at maybe something like just lukewarm water coming off of the heat of a volcanic event someplace else, reaching the repository, but having typical high-deleterious species that might affect C-22 or other EBFs?

MR. SWIFT: That's something I'm not prepared to answer today.

DR. MORGENSTEIN: Okay.

MEMBER GARRICK: All right. Any other

questions? Yes.

MR. McCARTIN: Tim McCartin, NRC. Not that specific scenario, however, with volcanism we do look at intrusive effects, where the magma affects both the waste package and the release of the fuel. And so you're looking at a wide -- a potential for a significant alteration of the integrity of the waste package within the repository, not quite the same as water contacting it.

However, one thing to keep in mind, that the probability of a volcanic event is quite low. And so when you're multiplying, say, even if you had a -- say you have 7,000 waste packages, if you had a 10^{-3} probability, 7,000 times 10^{-3} is 7. So it would quickly get reduced to the effect on seven effective packages. So there is -- in that sense, it tends -- from a groundwater release standpoint, it isn't as significant as the direct release.

MEMBER GARRICK: All right. Any other questions? Any questions from staff? Al right. I think we've arrived at a break point, which I'm sure will make several of you happy. So let's return in 15 minutes.

JL: Remember, if you leave the floor you need an escort, if you have a visitor's badge.

(Whereupon, the proceedings in the foregoing matter went off the record at 2:42 p.m. and went back on the record at 3:02 p.m.)

CHAIRMAN HORNBERGER: When I said we were ready to reconvene, I didn't mean just the ACNW.

DR. GARRICK: Okay. Our next speaker is going to be Bob Andrews, whose spoken to us many times in the past and probably has a new title as well. So, Bob, I'll let you explain that to us.

MR. ANDREWS: Well, we're very stable. Have the same title for the last 2½ years. Performance Assessment Project Manager within the Bechtel SAIC company, which is the prime M&O contract to the Department of Energy for Yucca Mountain.

I'm going to walk through elements of the source term, try to address some of the individual comments that have been coming up on previous presentations, but if I miss them, I know you won't be shy and you'll raise them again.

That clock says 3:00, and I think I have until 3:30. But I will add any time that's a question time during the presentation, so that will be how I will treat this.

I do not have a list of other

contributors, but let me go to the next slide because I think it's useful to walk through the outline with how the work was performed and who performed the work. And before doing that, say that everything in here has been presented in a number of project documents. They're either in the TSPA SR itself, the Supplemental Science Performance Assessment done in the summer of '01, some aspects are in the science engineering report or in the SR suite of documentations themselves.

I'm not going to talk, however, about work that's gong on as we speak, work that's been going on in the last 6 to 12 months that will improve and provide the basis for the license application. You're free to ask questions about that, and I will inform you the best of my ability about those ongoing tests and analysis, and models. But everything I'm presenting is historic information.

To talk about the contributors, I'll use the outline here, because we're going to walk through the key aspects that affect the source term, and then ultimately the source term itself.

Actual radionuclide release rates based on the discussions we had with ACNW staff, we deferred to tomorrow morning where the staff, and I believe the

Board, wanted to see time slices of interim results including radionuclide releases from various elements and various barriers as you marched through time. So Peter will be back up again tomorrow morning to talk that aspect. I'm going to talk about the basis and the component parts that lead to that from the source term perspective.

And for definition purposes the source term means different things to different people, we're going to talk about all of the processes, events and features that can effect and in the model do effect ultimately the radionuclide release rate from the engineered barrier system, which for our purposes are going to be defined as the edge of the invert, so into the rock. I will not talk about transport within the rock itself, within the UZ or SZ. So that's how we'll take source term here.

Walking through the major components of it, we have the in-drift environment at work. I'm going to use this as an introduction to the contributors to that.

The chemical aspects of the in-drift environment are driven by work and testing done by Lawrence Berkeley Labs and Lawrence Livermore Labs.

The mechanical aspects is work done by

ITASCA and some other BSC subcontractors, primarily with support from Livermore.

The thermal aspects and the hydrologic aspects in the rock and in the drift are a little bit separated. Lawrence Berkeley Labs is doing the analysis in the rock and doing the testing in the rock from underground primarily and the thermal testing that's underground; most you're aware of the drift scale test that was used as a basis for a large number of the conceptual models, both chemical conceptual models, thermohydrologic conceptual models and thermal hydrochemical conceptual models. And Berkeley and Livermore were actively involved in those investigations.

And the hydrologic aspects of the in-drift environment is principally a Berkeley aspect with respect to seepage. And the Livermore aspect with respect to humidity, condensation and remobilization of heat and moisture inside the drift.

Going to the degradation of the engineered barriers, the drift shield and the package, most of that work was done by Livermore scientists, their subcontractors either through Livermore or through the Department of Energy supporting the model development, the testing, the analysis of the test results, the

development of the models, the review of the models and actual implementation of those models in the total system performance assessment.

Coming inside the package, the in-package environment was generally done by Sandia scientists with support from other BSC subcontractors. We'll talk about that.

The waste form degradation models and analyses are based on testing and data principally done by Argonne and PNL, but there's other contributors including LANL with respect to colloid, colloid ability, colloid source terms, etcetera. Those data tests and models are within those institutions' purview.

The release from the waste form and engineer barriers through the package, through the invert has generally been a Livermore and Sandia activity, based on some laboratory tests and the model developments and validations with respect to those laboratory tests.

And that's it. So that gets us to the edge of the drift.

We do all these things under QA controls under analysis and models. The tests are controlled under scientific investigation test plans and

scientific notebook processes. The data are all controlled, the software are all controlled by various process steps that we follow. So there's probably represented in these simple 30 slides 40 or 50 analyses or models documentations that relate to what I'm talking about here. So as Peter said, each page almost represents one or two analyses or models and many more tests that support those analyses or models.

So starting in the rock and talking about the chemistry -- we can go on to the next slide. I have some place holder slides there for you. The next one. Thanks. Okay.

Joe had this conceptual picture. The model of what happens in terms of the chemical evolution in the rock is driven by not only the in situ to ambient conditions, but also by the evolution in time as a result of the thermal history that that water is going to be exposed to. So it is a function of the thermal environment, and we have models to evaluate the evolution of the chemistry in the rock both in the matrix and in the fractures as a function of time. And it is that chemistry which then comes into the drift if there is seepage.

DR. MORGENSTEIN: Do you have lab experiments to support the models?

MR. ANDREWS: This is mostly field testing in situ field testing. There are in addition mostly from the drift scale thermal test and a single heater test, which also evolved the chemistry as a function of time and temperature. There are additional laboratory experiments that have been conducted principally at Livermore and Berkeley, but they've looked at more of the change in the hydrology as a function of time induced by a couple of chemical processes as opposed to the change in the chemistry. So we've used more of the in situ chemistry and its evolution with time from the drift-scale test, which was a -- I'm going to get the numbers wrong -- 4 year heat up and now we have one year cool down of that to, if you will, compare the model projections against.

Now, of course, at the time of the SR we had 2, 2½ years of heatup. So since that time we've had remainder of the heatup phase and one year of cool down phase. So that's that second bullet there.

I've shown here in the bottom right hand corner just one element, it happens to be PC02, evolution as a function here of different infiltration rates. So we've tried to analyze. I mean, these couple geochemical models tend to be quite complex, somewhat laborious that's run. It's a week or 2 weeks of

computer time and have a fully coupled thermal hydro chemical model. So there's only limited amount of sensitive analysis that have been performed. But one of the sensitive analyses that was performed as a part of the Supplemental Science and Performance Analysis in the summer of '01 was what effect of different flux rates, i.e, infiltration rates, percolation rates have on the chemical evolution in the rock. Because as one might theorize that different fluxes that you have uncertainty in fluxes may yield differences in chemistry. So we evaluated those different chemistries and processes of those different chemistry in the drift.

DR. MORGENSTEIN: Is there a simple explanation for why the C02 concentration at 100 years drops, what, 5 orders of magnitude and then at a 1,000 years jumps back up to where it was originally? It looks like a strange shape.

MR. ANDREWS: There probably is in that analysis, but I don't have that in front of me right now. We can find the answer to that or get the answer to that particular question.

Going on to the mechanical aspects, the in-drift environment not only is effected by the chemistry of the water coming in, but is also effected

by the mechanical degradation of the drift itself, or can be. To assess that we had a rock degradation model. That rock degradation model is based primarily on analog type information but using in situ properties, fracture characteristics and fracture properties measured from the exploratory study facilities at Yucca Mountain.

Shown here is a distribution of rock sizes for different levels of seismic loading and for the nominal case without a low probability seismic event. These rock stresses were allowed to occur. The rock fall was allowed to occur, impinge on the drip shield. There were stress counts done on the drip shield. The drip shield does crack if its stressed under a high enough rock load, but those cracks from a chemical perspective and from a morphology perspective were assumed to plug the calcium carbonate precipitation during the thermal period.

Going on to the next --

DR. MORGENSTEIN: Is there a reason to make that assumption for some experiments?

MR. ANDREWS: Yes. There were some experiments that were started at Purdue that supported it. There was also observations, if you will, of cracked morphology through titanium that were used as

a basis to identify sizes of cracks, characteristics of cracks and the hydrologic characteristics of those cracks. Typical cracks with uncertainty in a titanium metal.

So in part it was observation, but in part it was -- I don't want to say first principles, but in part it was analysis and models developed of cracked morphology and hydrology through cracked morphology.

DR. LATANISION: Let me just follow on. I understand the DOE has adopted a criterion that suggested if the stress exceeds 50 percent of the yield point, that for the drip shield they would consider that to represent a --

MR. ANDREWS: A crack.

DR. LATANISION: -- a crack? Is that what you're using here or what sort of stresses are you envisioning when you make the comment that rock falls do not induce sufficient mechanical stress?

MR. ANDREWS: The stress criteria -- I have to get back with you. Right now it is 50 percent. I'd have to get back with you of what percent was used.

DR. LATANISION: Okay. I mean asked the same question of DOE. I don't quite see the basis for 50 percent. I'm not sure what it should be, but I'm

curious about how it comes about.

MR. ANDREWS: Yes, we can talk.

DR. LATANISION: Okay.

MR. ANDREWS: I will talk about stress cracks for the Alloy 22 here in a second. You'll probably have the same question about why 80 percent for that one, but we can talk about that as well.

Going on to the next aspect of the environment, so we've talked about chemistry and mechanics, now let's start talking about hydrology, at least one aspect of hydrology which is driven by temperature. So what you have here is the temperature distribution, a range of temperature distributions are actually used. There's package-to-package variability in temperature, location-to-location variability in temperature and of course a temporal evolution of temperature. And that variability is principally driven not just by the local variations from one package to the next, or where that package might be located in 2-D space at the repository plane, but also is a function of the infiltration rate or percolation rate, if you will. Higher percolation rates generally cooler temperature. This is a full 2-D thermal conduction model.

The other aspect of aqueous environment is

seepage. I think Peter talked a little about this, so I maybe won't belabor seepage as much. The seepage representation for the site recommendation and the seepage representation as we go forward is based on the underground testing and model validation associated with that testing and the uncertainty in those models of that testing of the various rock units at repository horizon. So these distributions will change because there's additional data, but it's nominally the same approach that's being used. And that is to say that the seepage and seepage distribution and seepage uncertainty is driven principally by the uncertainty in the hydrologic characteristics right around the drift, which changes with time because of drift degradation which also changes with time. So the degree of degradation and how that's incorporated in the model is assessed in these models and was assessed in the Supplemental Science analysis.

You can see the principle drivers are the rock permeability and the rock capillarity and the relationship between those two drives seepage.

The other controlling factor, of course, is how much water is moving through the mountain at that particular location to begin with, i.e., the

percolation flux as Peter talked about, which is driven by infiltration which changes with time. And it's also driven by some uncertainty that we have associated with flow focusing or episodic potential flow that can increase locally the percolation flux, and therefore can increase the probability of seepage.

DR. PAYER: Bob, could you help me with the figures here? What would the sort of middle of the road seepage fraction and seepage flow be? I'm not sure I'm reading the diagram correctly.

MR. ANDREWS: Present day percolation flux at respiratory at horizon is between 1 and 10 millimeters per year. With climate change it can up a little higher than that at certain locations in the model. Peter had a map, I believe, of the actual spacial distribution of percolation flux for the mean climate state. So you have uncertainty in climate and you have uncertainty in percolation flux. So the range even under present -- or I should probably be careful and go back to Peter's figures rather than try to guesstimate it. But present day's 1 to ten. It can up to a 100 with some uncertainty. And it can go up to several hundred with climate state changes.

DR. PAYER: But the vertical yellow line on your diagrams is considered to be the --

MR. ANDREWS: That's the mean of the K over alpha.

DR. PAYER: Okay.

MR. ANDREWS: So I'm looking at uncertainty in variability of K over alpha, permeability over capillarity. So that's the ability of the rock to bypass the water. And then this is the actual percolation flux.

DR. PAYER: So what would be a good average value or nominal value of a seepage flow rate?

MR. ANDREWS: Let's go to the next slide. I think I have that.

DR. PAYER: Okay.

MR. ANDREWS: If you take percolation flux of present day, so you got to be -- Peter was giving these percentages of 13 percent and then changing an SSPA to 46 percent, that's for the glacial transition climate, which is the maximum infiltration rate over the regulatory time period. It's not present day climate, it's going to be wetter and cooler, at least the climatologists in their model think it's going to be wetter and cooler over the next 10,000 years. So you have to be in this percolation flux range between 10 and 100 millimeters per year for that climate state change and the flow rate becomes mean of a tenth of a

cubic meter per year if there is a seep. So this is flow rate given you have a drip.

Okay. So we've covered sort of what's happening in the rock and what's coming through to the drift, and how that is a little bit evolving in the drift. But I think it's useful in a summary way to go to slide 9. Thank you. Where we look at how that seepage and moisture is redistributed in the drift.

We make the assumption that if there is a drip into the drift, that drip hits a drip shield and if the drip shield's not there or not functioning or has some degradation, there's a possibility of that drip going through the drip shield. If the package has some kind of a hole or a breach, there's some possibility that that same drip gets into the package and gets out of the package. We'll talk about in and out of the package here in a little bit; the bathtub representation or nonrepresentation. And then that same drip can pick up nuclides and go through the package through the invert and into the rock carrying with it some radionuclides at some concentration that we'll get to here in a second as well.

If the drip shield's intact, then that's not a advective pathway. I can still get moisture on the package. And we'll talk about that here in

deliquesced salts and have a humidity that's high enough such that I could have moisture on the package, but I can't get liquid on the package if the drip shield's intact.

The same thing, of course, through inside the package. Can't get liquid water even if the package has failed, but I can still have moisture in the package if the package has a breach. So we have to be kind of a little careful through this as how much of this is liquid water and how much of it is moisture. And moisture can dissolve waste. Moisture can corrode waste packages. Things can diffuse at some rate through a thin film, and that's what we're talking about here is a thin film.

So this picture is trying to get schematically at the difference between liquid water and therefore the potential for advective transport versus nonliquid water but still moisture is present, and therefore the possibility anyway of diffusive transport.

The second bullet there is fairly clear.

DR. MORGENSTEIN: Question. Go ahead, Dan.

DR. GARRICK: I'll wait until he hits that third one.

DR. MORGENSTEIN: Oh, okay.

MR. ANDREWS: Somebody mentioned something about a 50 percent assumption. I'm not sure where exactly that had come from.

What exactly we do, when the drip shield degrades, it degrades as a function of time. It corrodes as a function of time. It cracks as a function of time. The same thing with the package. So there is a temporal evolution of the fraction of the drip shield that's degraded and a fraction of the waste package that's degraded. And that fraction is used to evaluate the fraction of water, given that it hits the drip shield that can penetrate the drip shield. Or given that it hits the package, that it can penetrate the package.

I believe the 50 percent was an allusion to the fact that we made the assumption that when 50 percent of the, I believe, drip shield -- maybe it was package. No, I think drip shield. When 50 percent of the drip shield was gone, that the rock stresses, rock fall stresses could impinge upon the cladding and therefore give no more credit cladding.

DR. LATANISION: Just to put a little perspective on that. As I understand it, DOE has adopted a criterion for failure which for the drip

shield is 50 percent of the yield point. And 80 percent of the yield point of the package.

MR. ANDREWS: Okay. That's correct.

DR. LATANISION: It's the Alloy 22.

MR. ANDREWS: Okay. We'll come to that 80 percent here in a second, as I promised.

Okay. Dan, you had a question?

DR. BULLEN: Well, before you go to the next slide, I just looked at that credit for thermal gradient not taken.

MR. ANDREWS: Yes.

DR. BULLEN: Do you think that's conservative or --

MR. ANDREWS: Yes.

DR. BULLEN: And why would that be conservative? If you have a thermal grading and you're focusing water transport by convection, is that--

MR. ANDREWS: We're inside the drift.

DR. BULLEN: Right.

MR. ANDREWS: And we did evaluate the effect of this conservatism in the Supplemental Science Performance Assessment. The argument is that for commercial spent nuclear fuel, it stays hot for a relatively long period of time. And it stays hotter

than its surroundings, i.e., the package or the drip shield or the rock for a very long period of time. There are some analyses in the Supplemental Science that showed how much time, but it's generally in the thousands to up to 20,000 years where that delta T between the waste form, the waste package, the drip shield and the rock is positive in that direction.

So, the argument would be if I didn't have seepage during this thermal period, and we have the possibility of seepage during thermal period, but if I didn't, then I'd have no way of condensing liquid water on the waste form.

DR. BULLEN: I misunderstood. I'm looking at waste package-to-waste package variabilities and the transport from a hot waste package to a cold waste package. That's not what you're addressing here?

MR. ANDREWS: Not in this particular one. We did address that on in the Supplemental Science, but that's not what I'm talking about with that bullets. That's a good point. Thank you.

DR. BULLEN: Okay.

DR. GARRICK: Now you didn't take credit for a thermal gradient between the spent fuel and the waste package, of course later on we're going to learn that you did take credit for a concentration gradient

so that you could defuse outward.

MR. ANDREWS: I'm not sure that's taking credit for a concentration gradient. To say the concentration gradient is greater between the waste form and its --

DR. GARRICK: It's only greater because of the way you modeled it with aggressive water chemistry.

MR. ANDREWS: I think the solubility at the waste form will always be -- well, yes, solubility can change with time. Peter will be back to show us some interesting results tomorrow where you see the effect of solubility changing with time. And it's the solubility or concentration that can change the direction of your diffusive radionuclide transport. Here I'm talking just thermal and hydrology.

DR. GARRICK: Right.

MR. ANDREWS: Okay. Going on to the degradation of the engineered barriers.

The drip shield and the package, we've just distributized the repository into its 1200 plus/minus packages and its same number of drip shields, and the distribution of what we've called patches from location-to-location on a drip shield and location-to-location on a package primarily to

incorporate spacial variability and uncertainty that exists in corrosion rates and stress states and other factors that can lead to degradation of the engineered barriers.

These are kind of a summary slide, but I'm going to talk about each one of these in a little more detail in the subsequent slides, except for that third bullet. So let me talk about that third bullet right now.

In the TSPA for the SR and the Supplemental Science Performance Analysis we did have data for corrosion potential and for critical potential, the difference of which drives the possibility to initiate localized corrosion. For the data that existed at that time there was no possibility over the range of environments that we stressed the drip shield or package to that corrosion potential ever exceeded. And there was uncertainty, by the way, in both of those because there's uncertainty in the data and uncertainty in the representation of those data. But for the TSPA and the Supplemental Science there was no possibility of ever exceeding the critical potential with the corrosion potential.

A number of you are aware that there is

more recent data, some of it that we've collected at Livermore, some of it by the state and the center have collected. So we're reevaluating that particular representation as we go forward. I think we realized in TSPA methods and approach document, which we sent to NRC last fall. But for the results I'm going to show you, there's no possibility of local corrosion for the environments that we tested and for the model and information that was available.

General corrosion was treated as both -- treated a lot of different ways for different sets of analyses. If there's uncertainty in the corrosion late, it's difficult to tell whether that uncertainty is real fundamental uncertainty associated with corrosion mechanisms and some details of corrosion processes or it's in part that and in part some aspect that shows metal-to-metal variability. So we did a range of different ways of representing that variability or uncertainty; from location-to-location on a package, from package-to-package and representing it as total uncertainty.

Those rates that I've shown here, I have not actually shown the raw data upon which these rates are based, but this is the 2½ year data or 2 year data. There's probably 60 samples in that

representation, in that CDF.

We enhanced those corrosion rates to represent the microbe influence corrosion and aging effects, of which there are additional laboratory data at Livermore that supported the range of enhancement factors, if you will, on general corrosion rate.

Yes?

DR. LEVENSON: Does that laboratory data, it's a little ambiguous that last bullet. Is there laboratory data both for the microbiologically influenced corrosion and for the aging effects?

MR. ANDREWS: Yes. They accelerated the aging tests, obviously, and then they did corrosion potential measurements to try to ascertain what would be a potential enhancement factor. They did not look at weight loss.

DR. LEVENSON: Okay. That's the aging, and I understand that. But do they also have laboratory data that justifies the microbiologically influenced multiplication factor?

MR. ANDREWS: Yes. It's limited, but there are data.

DR. LEVENSON: Okay. Because we had a presentation to the ACNW from Livermore and I don't remember that being the case. But okay.

DR. PAYER: I think the last time comment, my understanding is it is limited and it comes to pretty much technical judgment as to what we do.

MR. ANDREWS: Yes. It's not general corrosion data. We didn't put microbes in the tank and look at weight loss type measurements for that effect. But they had with and without various microbes looking at corrosion potential differences and then extrapolated those corrosion potential differences that they observed from laboratory tests to that enhancement factor.

Okay. The next degradation mode is stress corrosion cracking. Slide 12 is kind of an intro slide, but going at Dr. Latanision's question is slide 13.

There are stresses. Those stresses are principally at the welds, that's the key area of stresses. There are two stress mitigation techniques that are applied to the welds in the SR. Department of Energy is reevaluating those stress mitigation techniques going forward to LA as we speak. But to the SR, it was laser peening on the middle weld and solution annealing on the outer weld.

These stress profiles shown here are the results after laser peening on the right hand side and

solution annealing on the left hand side. And what was used as a stress threshold was the 80 percent of yield strength prior to initiating a stress crack.

We have data that show that threshold should be or could be -- and could be is probably the best way of saying it -- between 170 percent and 220 percent of yield strength for Alloy 22. And these are over 100 day tests under a range of different chemical environments. I don't think they were done at Livermore, but I'd have to verify that.

We used 80 percent of yield strength because there are also U-bend tests at Livermore, when you extrapolate those that the range of 80 to 90 percent at least seemed possible. So there are some data that say you might be 170 to 220 percent, and other data that say range 90 percent is clearly on the conservative end of this spectrum.

DR. MORGENSTEIN: Maury, GMI.

What was the range of the chemical environments used?

MR. ANDREWS: They were using those simulated acid waters, the evolved chemistry. There's four basic chemistries they've been using their test environments. I'd have to actually get the report with the data, to be honest with you. But there's four

different chemical environments they were looking at for these stress measurements.

So this is one place. John, I think you asked differences between TSPA-SR and SSPA, and actually between SSPA and what we did for the final environmental impact statement. This is one area where it was different. In the TSPA-SR the best available information, which was pretty much an assumption, although there was some literature information that was used to support it, was a yield of 20 to 30 percent. So at 20 to 30 percent of yield strength, things would start cracking from a stress crack. And if it starts cracking, although we have two different models for crack propagation, generally if it starts cracking it continues cracking. That's the more conservative representation. There's no stifling or arresting of the crack.

So, if I had 20 to 30 percent of yield strength, you can see the amount of material I'd have to corrode away before I initiated a crack was going to be less. So the failure degradation mode of principally in the TSPA-SR was failure through a stress crack. The failure started to occur -- and I don't have those plots -- roughly 15,000 years, I think maybe even a little before that, and continued

up from that point on; principally from stress cracking.

DR. MORGENSTEIN: I'm sorry. Do you have any sense of what the temperature regime was for those?

MR. ANDREWS: When they crack or for the tests?

DR. MORGENSTEIN: For the tests, yes. What temperatures?

MR. ANDREWS: I'd have to look at those data. I'm not sure how high the temperature -- my recollection --

DR. MORGENSTEIN: Pretty low?

MR. ANDREWS: -- it was up to 90 degree C, 95. I don't think they went above a 100 degree C for those particular tests.

That's one difference. The other difference, and that's associated with when you do a solution annealing technique, i.e, a heat treatment technique, there is a possibility to improperly apply the heat; keep the heat on one location too long or too short. There is some literature information not so much about the uncertainty associated with annealing techniques, about the uncertainty about a well controlled human process that would lead to a

possibility of improper heat treatment. That improper heat treatment was the degradation mode during the Supplemental Science Performance Analysis that was carried forward into the TSPA or FDIS that lead to the possibility of an early waste package degradation, i.e., something that's degraded at emplacement. Because this occurs up at the surface when the annealing is being applied.

That annealing is applied on the outer lid. The inner lid was in the design, was laser peened, but we made the assumption that if I had a bad anneal, that it might have in fact degraded the inner lid so that the lid -- of the other Alloy 22 lid.

DR. GARRICK: Where on earth would you get data that would support that second bullet?

MR. ANDREWS: That's not data. The first one. It's hard to even call the first one data. It's industry observations, is probably the best way of characterizing it.

The second bullet's not data.

DR. GARRICK: Yes. It's dropping of a cliff.

MR. ANDREWS: That's an analysis.

DR. GARRICK: How did you get the number, 2.26 out of 12,000?

MR. ANDREWS: Well, essentially it's rounded here a little bit, but --

DR. GARRICK: Two times ten to minus 5 times that? Yes.

MR. ANDREWS: I said approximately two times ten to minus 5 because the actual number was like 2.2 times ten to the minus 5.

DR. GARRICK: Yes, I understand.

DR. RYAN: Did the probability just came from an industry something or other, or exactly what?

MR. ANDREWS: Yes. It was industry observations -- I'd have to get that analysis for you to be honest with you.

DR. RYAN: The reason I'm asking is that the steel industry has a wide range of --

MR. ANDREWS: Yes.

DR. RYAN: -- steel levels and steel sets and it would be interesting to know where it came from.

MR. ANDREWS: Yes. We can get that. We can get that for you. It was nuclear industry, I believe, yes.

Okay. Let me keep moving along. Based on all those inputs, the degradation the characteristics of the drip shield are shown here on slide 15.

DR. LEVENSON: Excuse me. Just before that slide you jumped from, earlier you said you did include time factors in corrosion.

MR. ANDREWS: Yes.

DR. LEVENSON: But on this early waste package failure, the next to the last bullet, says you assume immediate failure.

MR. ANDREWS: After this one.

DR. LEVENSON: Is this --

MR. ANDREWS: That's correct. Other degradation modes; corrosion, stress cracking, the potential for localized corrosion were in there as potentially time dependent, which are driven by temperature dependency or environment dependency or humidity dependency. But for this particular one it was essentially at the surface, not effected by the subsurface environment and it was brought --

DR. LEVENSON: Are we talking about a stress corrosion failure due to improper heat treatment, right?

MR. ANDREWS: Yes.

DR. LEVENSON: So how does it fail immediately?

MR. ANDREWS: It failed by the improper--

DR. LEVENSON: Did you have the same time

constance to get water in there and concentrated, and all the rest of the things?

MR. ANDREWS: Oh, well wait a minute. Let's talk, by failure I mean I have now degraded that barrier --

DR. GARRICK: You have a pathway?

MR. ANDREWS: -- from performing -- I have a crack -- actually a hole, but in that package.

DR. GARRICK: He has a pathway now.

MR. ANDREWS: I have a pathway. It is no longer keeping the potential for water out of that particular package.

DR. LEVENSON: Well, I don't think that goes with the probability number in the first bullet. The improper heat treatment doesn't result in a crack.

DR. PAYER: Milt, I think the rational is that it fails by stress corrosion cracking as soon as it gets wet. Now, it's not going to fail immediately, but in the time steps that you take, it's going to fail in tens of years or 100 years, or whenever.

DR. LEVENSON: Okay. But --

DR. PAYER: So they turn that on. They're saying they got -- I believe they say they got to suspectable weld because it's got high tensile stresses at the surface.

DR. LEVENSON: Right.

DR. PAYER: So as soon as that weld gets wet, the stress corrosion cracking will start and it goes at a rate that will penetrate that package immediately in a time frame of repository time.

MR. ANDREWS: That's what we're looking at.

DR. PAYER: I think that's the rational.

MR. ANDREWS: Yes. Thanks, Joe.

Okay. And then you get to the actual waste package degradations shown in slide 16, which is combining all of the above potential effects. And there you see those early degradation modes and the later degradation modes which generally are by corrosion now because stress cracking, in this particular case, with exception of that initial improperly heat treated weld, effectively doesn't occur or such a low probability that you don't really see it in the results.

Okay. That's the package.

Now I'm going to go inside, transition slide and then slide 18.

Chemistry inside the package is predominately dominated, at least for the analyses that we've done and the models that we've constructed

so far, predominately affected by what's inside the package. There is different chemistry if there's glass in there than if there's cladding and CSNF. We've factored those differences in chemistry in the results, so we're essentially tracking two types of packages.

You know, the chemistry effects the cladding degradation. The chemistry effects the alteration rate of the fuel. The chemistry effects the solubility of at least some of the key radionuclides. It doesn't effect all of them, but it does effect the solubility of some key ones.

DR. WYMER: You talk about irreversible colloids. But you don't talk about real colloids.

MR. ANDREWS: Well, you know some colloids are reversible in nature. Things go on them and come off them. There's many --

DR. WYMER: No, I'm thinking of plutonium colloids, for example.

MR. ANDREWS: Oh. plutonium. Some of it is irreversible and some of it reversible.

DR. WYMER: Some of it is real. It by itself is a colloid.

MR. ANDREWS: Oh, waste form colloids. Yes. We have waste form colloids -- yes, good point.

Good point.

These are nomenclatures, if you will, for the transport aspect of colloid migration where the transport aspect outside of the waste form area or outside of the waste package is dependent on how is the radionuclide attached to colloids.

DR. WYMER: And what I call a real colloid would be grouped in with irreversible colloids.

MR. ANDREWS: Yes. Yes. Yes. I mean, the types of colloids we have inside the package and at the waste form are glass colloids, waste form colloids, iron colloids, amorphous silica colloids. But from a transport perspective, how they are transported we lump them into these two categories; those that stay totally absorbed on the colloid and move with the colloid and those that move with the colloid but can come off of the colloid through transport.

DR. WYMER: What's a last colloid?

MR. ANDREWS: The actual chemical constitutes of the glass colloid?

DR. MORGENSTEIN: What's a glass colloid?

MR. ANDREWS: Was the degradation of the glass, which is a waste form here, the waste glass. As it degrades there are silica byproducts that can

attach to radionuclides. And those radionuclides that are attached to those silica bearing waste form colloids--

DR. MORGENSTEIN: These are sylenol groups?

MR. ANDREWS: I'd have to go check how they distinguished which colloid was which.

DR. EWING: Bob, maybe to answer that question and I have a question on the previous slide, if you don't mind.

Usually it's the gel layer that forms in a glass and it sloughs off and it contains particulate actinides or radionuclides that are included in the glass colloid part.

If I looked in the box you've labeled solubility, what I understand or what I guess that would be is you dissolved some of the cladding, the fuel, the waste glass so you put things in a solution that are in the box. And then by geochemical code you calculate where you've reached solubility limits for different phases and you remove those phases, and then continue on. It would be some pattern like that, is that correct?

MR. ANDREWS: In a very general way.

DR. EWING: Right. Right.

MR. ANDREWS: Yes.

DR. EWING: And, of course, the problem is always having the right --

MR. ANDREWS: Chemistry.

DR. EWING: -- chemistry in the solutions and also the right data for thermodynamic perimeters so that you can get the right phases and their kinetic effects and so on.

MR. ANDREWS: Yes. Yes.

DR. EWING: It's a little bit of digression, but as an example of the difficulty, the European Union had a project at Oklo where they have a small natural reactor under oxidizing conditions, so relevent to Yucca Mountain. They went through a series of blind predictive modeling exercises with two or three different teams of very competent geochemists using in various combinations six different databases for the thermodynamic perimeters, EQ-36, Mintech and so on. And then they took the ground water composition, dissolved some of the uranium and modeled it.

And the result was that most of the models converged on the same basis as reaching the solubility limit and being precipitated. One would be uranium silicate sopite. But then in our research group we

went back and we looked at the actual material and we found many different uranium phases, we didn't find sopite or any of the predicted phases, okay? And that had to do with not accounting for the trace element geochemistry of the solution. It's not a sin, it's very competent people. But, you know, going through several iterations we could see how difficult it was to actually model the solubility limiting phases and get them right. Okay.

So I guess my question is, and these were talented people, in this part of your modeling effort why do you expect to be successful? I mean what --

MR. ANDREWS: When I come to one particular radionuclide, we'll talk about the uncertainty.

DR. EWING: Well, but it's not doing it one radionuclide at a time. It's probably already wrong, right? I mean, that we know doesn't work because the experience is that the very low concentrations of trace elements,phosphorous, sulfur have effect on the system. So I guess, you know, it's a broad question, but when I look at some of these flow diagrams I compare that to actual experience of geochemical modeling. And it seems to me the expectations here are relatively high compared to

actual experience.

MR. ANDREWS: Let me skip to --

DR. EWING: Or to reduce that to a question, are there experiments that support the more complex chemistries that you're trying to model?

MR. ANDREWS: Yes, let's go to slide 25.

DR. EWING: Okay.

MR. ANDREWS: This is --

DR. EWING: And I won't ask anymore questions.

MR. ANDREWS: No, please. Please. Your eating into your cumulative question time.

DR. EWING: Right. Right.

MR. ANDREWS: So here shown in this distribution is the neptunium solubility data shown with the actual Xs from a lot of different sources.

DR. EWING: Right.

MR. ANDREWS: Under a lot of different conditions, both from above and from below. Some different chemical environments. These have been collected not only for this project, but for other projects as well. And then shown with the two curves is the model which includes the geochemical specisation for the key controlling phases that were assumed for this model. And the key controlling, which

is kind of in part getting at your question, is a basis of the experience of the modelers as a collective team trying to capture as reasonably as they can the range of uncertainty associated with the characteristics of, in this case, neptunium solubility. For some other radionuclides such as technetium or iodine, although you can have solubility limits for those species under certain geochemical constraints, we don't believe from the modeling that we've done inside the package that we have those geochemical constraints, i.e., we don't have a reducing environment inside the package; that it is mixing and degrading and consuming oxygen, that's true. But it's not going to a reducing environment inside the package, even after we've degraded the package.

DR. EWING: Why all?

MR. ANDREWS: It's after we degraded.

DR. EWING: After you degraded?

MR. ANDREWS: Before we degraded the package it has whatever environment was in there.

DR. EWING: This is great. I mean, this type of work has to be done and it certainly supports the approach. But if you look at elements for which we have a lot more data, uranium, and look at the

literature, you'll see that the geochemical models often match the solubility limits for U-307. The only difficulty is U-307 doesn't occur in nature. And Np205 probably doesn't either.

MR. ANDREWS: That's correct. Yes.

DR. EWING: Particularly in a typical ground water composition.

MR. ANDREWS: There are plots I did not bring them, an analyses where we looked at uranium and uranium solubilities under a range of different conditions inside the package as a means of, hopefully, constraining our solubility projections for the actinides and radionuclides of interest. There is uncertainly, however, in that constraining and we need to, I think, address that uncertainty as we go forward. And a point well taken.

DR. EWING: You know, to me what it calls for experiments specifically designed to the system that you're trying to model.

MR. ANDREWS: Yes.

DR. EWING: And I realize neptunium with everything.

MR. ANDREWS: That could be.

CHAIRMAN HORNBERGER: Bob, I realize we're hanging up, but I just have what I think is a quick

question.

So when I look at this cartoon, you have solubility and it's aqueous solubility, am I correct in inferring that you're viewing this as being on thin films of moisture?

MR. ANDREWS: Yes.

CHAIRMAN HORNBERGER: And so you do a mass balance on the water to keep track of you have the right amount of water and to get the right concentrations and whatnot?

MR. ANDREWS: Well, we've done various -- we don't know how much water exactly will be dripping in there or present contacting with the waste. So we've done a range of calculations with different water amounts to evaluate do different water amounts make much different into the bulk chemistry which then could drive the bulk solubility.

But right now the -- if the package is degraded, and by that I mean the environment outside can come into equilibrium with the environment inside, whatever that environment is, whether it's dripping or no dripping and the temperature and humidity conditions that are outside come into equilibrium with what's inside and if it's not dripping, then it's a thin water film that essentially covers all components

inside. There's not a spacial distribution of that thin film inside. So it can contact all cladding. It can contact all structural steel inside. We make no distinction, if you will, to detail out how the water is distributed inside. But we do distinguish whether it's a film, i.e., can only condense, if you will, on the form or if it's dripping. So liquid water.

DR. MORGENSTEIN: And you do this for each different type of package separately?

MR. ANDREWS: We really only have the two. We kind of lumped all the CSNF, the commercial fuel together whether it's PWR or BWR and made no distinction there. And we have codisposed that Peter talked about, codisposed package which have glass and DOE spent nuclear fuel in them. So we created those two.

I think somebody asked a question about what about naval fuel, because the naval packages are a totally separate set of packages. They're much bigger and the Navy through Bettis Labs is actually doing the in-package environment and degradation of their fuel and actual source term for us. There's some reasons for that, as you can imagine.

DR. MORGENSTEIN: How do you treat the competing chemistries between the different packages?

MR. ANDREWS: We say if I'm in the commercial spent nuclear fuel package, then that is the chemistry with its uncertainty for that type of package. And if I'm in a waste package, then that's the chemistry with its uncertainty for that package. We don't mix those two. Because we say if it's coming out of this package, it's coming out and releasing through the invert and into the unsaturated zone. So there's no, if you will, lateral chemistry gradient along the drift. There's lateral temperature and hydrology and moisture gradients, but no lateral chemistry gradients. In other words, water doesn't defuse from one -- or chemistry doesn't defuse from one package location to the next. That's the assumption that we've made.

DR. MORGENSTEIN: So you have independent different source terms?

MR. ANDREWS: Yes.

DR. GARRICK: The question I've always been puzzled by is how you rationalize saturated water in-package conditions and diffusive transport external conditions?

MR. ANDREWS: The saturated in-package is a chemistry model assumption, I think is probably the best way of saying it, John. It's essentially a

mixing chemistry model --

DR. GARRICK: It's a way to mobilize the waste such that --

MR. ANDREWS: It's the way to develop a reasonable range of chemistries.

DR. GARRICK: Yes.

MR. ANDREWS: Which then mobilize the waste.

DR. GARRICK: The waste. And then when you do get a stress corrosion crack, you have a concentration gradient that allows --

MR. ANDREWS: That will allow it to defuse.

DR. GARRICK: -- diffusive transport outward. But I've never been able to quite satisfy myself in the spirit of realism --

MR. ANDREWS: Yes. Yes.

DR. GARRICK: -- the rational of these what appear to be completely incompatible assumptions.

MR. ANDREWS: Well, the gradient we're interested in for diffusion out of the package is not really gradient in bulk chemistry. It's not florid or florid gradient. It is technetium gradients or neptunium gradients. So bulk chemistry and evolution of that bulk chemistry differences between the package

and the edge of the package or between the package and the invert, that is not considered.

I don't defuse chlorides, you know, between the package and the invert.

DR. GARRICK: Yes.

MR. ANDREWS: I just say I'm doing a package chemistry model and I'm doing an invert chemistry model, and letting water if it advects, advect through that, but I'm saying from a bulk chemistry point of view which then drives solubility and colloids and things like that, I'm not doing a totally coupled geochemistry model between the package and the invert.

DR. GARRICK: Well, we'll have to talk about that.

MR. ANDREWS: Okay.

CHAIRMAN HORNBERGER: But conceptionally then diffusion is through these thin films of water?

MR. ANDREWS: That's correct.

CHAIRMAN HORNBERGER: And it has to be continuous through the --

MR. ANDREWS: It has to be continuous through.

CHAIRMAN HORNBERGER: -- waste form out into the invert?

MR. ANDREWS: Yep. Yep.

Okay. Let me in the interest of time skip over some of these other ones. I show cladding in here.

I show in slide 22 the waste form alteration rate. In this case it's the commercial spent nuclear fuel, which is based on the laboratory data, both dripping and humid air data from Argonne, principally.

Cladding degradation model or representation is shown as slide 23.

We do have a distribution of clad failures, if you will, driven principally by the as received initial perforation of clad. We don't make it a distinction -- this total distribution in fact is driven by some early cladding information and some more recent cladding information. The more recent cladding information virtually has zero penetrations, not quite, but very low. Whereas the 20 year old, 30 year old clad does show some penetration. So this is the as received distribution.

DR. BULLEN: Just a quick question. As you go to higher and higher burn up and hotter fuels, you're going to get essentially more oxide thickness on the cladding and you're going to have a different

morphology on the surface of the clad. This model doesn't address those kinds of issues? Because, obviously, they last a long time now, but as you go to 60 gigawatt days per metric ton, you're going to have a different morphology and the clad lifetime may be significantly less in repository. Not even in storage, but in repository. You realize that?

MR. ANDREWS: Well, we need to look at that.

DR. BULLEN: Okay.

MR. ANDREWS: Thank you. Appreciate that comment.

Slide 24 just walks through the major radionuclides.

DR. RYAN: Just out of curiosity, radium is there because it must be for "huge" times?

MR. ANDREWS: Yes.

DR. RYAN: "Huge" being millions of years?

MR. ANDREWS: Yes. We generally had the same inventory we were using for the 10,000 year period and for peak dose, because these results are used for what we did in the FEIS or the TSPA for the FEIS and that as required says go to peak dose, in the FEIS.

DR. RYAN: I guess all this is just a

little bit, you got to think about it because some of those won't be there in a million or 5 million years, or whatever.

MR. ANDREWS: That's correct. But they're in there in the inventory and wanted to be complete. If the package fails early, they are certainly mobilizable and transportable for whatever the solubilities and however they are transported.

We talked about neptunium already.

EBS transport, slide 26, is useful. I think we've kind of talked around this, and that is if it drips, there's a possibility for advection through the package, i.e., radionuclides in the soluble phase transporting with the liquid water as it's advecting through the package through the hole in the package and through the invert. But it's also possible, at least in our representation, to allow diffusion through this thin film, through the package wall and through the invert. That diffusion rates of liquid saturation, there are a lot on diffusion rates through very low liquid saturation soils and other granules. Extrapolating that to very thin films was an extrapolation and a bit of an assumption, conservative assumption.

We were asked on slides 27 and 28, and I

don't want to steal Dave Esh's thunder, but where we thought differences between our representation of the source term as defined in the previous slides and where NRC's interpretation in IPA, I'm not sure where we compared this to. 3.2 -- I think 3.2, because we may not have had -- yes, I think we looked at 4, too. I'm not sure.

We looked at 4. Okay.

And these are where we think some of those differences are. Now when NRC gets up after me, you'll prove me wrong or right, but I think these are where some of the differences occur. So I'll just save that and stop now.

DR. RYAN: One more quick question on the inventory. Where does the thorium 232 come in with regard to ground water protection, slide 24 again?

MR. ANDREWS: Thorium for ground water protection?

DR. RYAN: It says thorium 232 and radium 228, which are in the thorium series, obviously.

MR. ANDREWS: Yes, these are the explicit requirements, you know, EPA had for the --

DR. RYAN: Thorium 232 is primordial. I don't think it's in fuel.

MR. ANDREWS: No, it's generated.

DR. RYAN: Where?

MR. ANDREWS: Either of you know?

DR. RYAN: It's a primordial radionuclide at the head of the chain. Is thorium based fuel on the inventory? I don't think so. There is so. DOE fuel.

DR. WYMER: Indian Point had a thorium core early on.

DR. RYAN: Okay. Because it's odd that it shows up there and nowhere else.

MR. ANDREWS: Yes.

CHAIRMAN HORNBERGER: Bob, just to make sure I understand your response to Rod's question. Whether you have the geochemical modeling right to get the right phases, even if you don't have the right phases, do you have any phases?

MR. ANDREWS: Yes. Yes.

CHAIRMAN HORNBERGER: Seriously, are you taking into account secondary mineral precipitation?

MR. ANDREWS: Yes.

CHAIRMAN HORNBERGER: And so you have some data on it --

MR. ANDREWS: Secondary phases are in there.

CHAIRMAN HORNBERGER: And you have some

data on I think it was Joe Payer this morning had a big question mark as to how radionuclides get incorporated into these crystal structures?

MR. ANDREWS: There are some data, you know, at Arogonne from the degradation tests of the different phases and phase evolutions of the spent fuels that they've done. So we've compared those phases with the phases that we've incorporated in the EQ-36 type, you know, thermodynamic model.

I think Rod's point, you know, is well taken. The actual thermodynamic data, you know, for some of those phases is scarce, you know. There's some, but you know you're --

DR. EWING: Well, experimentally there are data for two of the phases, good data. Now there are ways you can calculate that are turning out to be very accurate. So, you know, there's a way out.

CHAIRMAN HORNBERGER: Okay, go ahead.

DR. BULLEN: Bullen, NWTRB.

Just one more quick question, I know we didn't give you time to cover all your items, but on slide 15 where you talk the calculated cumulative drip shield failures, the drip shield failure mechanism is only by gentle corrosion.

MR. ANDREWS: Yes.

DR. BULLEN: But the invert and the support structure for the drip shield are carbon steel and basically tuff, crushed tuff, right?

MR. ANDREWS: Yes.

DR. BULLEN: So the assumption is that they remain stable, that the invert doesn't rust and that there's no subsidence and no changes?

MR. ANDREWS: Sufficiently stable for the drip shield to maintain its function.

DR. BULLEN: Okay. So do you know how much movement you have to have before the drip shield doesn't work? Just curious.

MR. ANDREWS: Movement like due to what?

DR. BULLEN: Well if it rusts and the carbon steel expands and you get, you know, movement of the rails. And if the crushed tuff goes back in and, you know, settles in or whatever. I just wonder.

MR. ANDREWS: Okay. There have been calculations by the design group, you know, on that. And I don't have them.

DR. BULLEN: I understand that.

MR. ANDREWS: But we can get those.

DR. BULLEN: I was just curious as to how you might incorporate that into another failure mechanism besides general corrosion? I mean, it would

probably be a little bit more reassuring if you actually had built one and watched it, you know, as to how much force do I have to put on it to move it and those kinds of things. I guess I was just curious --

MR. ANDREWS: Yes.

DR. BULLEN: -- as to other failure mechanisms you might have for the drip shield. Because if you use a drip shield here in the performance model and it works for, you know, better for years then it kind of solves a lot of your problems, right?

MR. ANDREWS: Well, it solves --

DR. BULLEN: I there's still diffusive transport below this shield under --

MR. ANDREWS: We have the possibility of some other futures and events that can effect the performance of all of this, right?

DR. BULLEN: Exactly.

MR. ANDREWS: Which you haven't talked about.

DR. BULLEN: But I just wonder about another mechanism.

DR. GARRICK: Rod, and I think we've successfully disrupted your presentation, and used up all the time. And introduce some more questions. Yes, Dave?

DR. VAN LUIK: We just wanted to make one happy point. That we do have a work in Mexico right now and we're hoping to get more information. This is not in-package chemistry, but we're looking to get more numerologic and secondary phase information from that analog by looking at the vertical profile.

DR. EWING: Have you made any predictions as to what will be there? That would be the, you know, really interesting.

DR. VAN LUIK: It's my considered opinion that we should never do any work without doing a prediction. I'll check into that.

DR. EWING: Yes. Okay.

DR. GARRICK: Anymore questions? Thanks a lot, Bob.

Okay. We're now going to hear from David Esh. And he's going to a similar presentation with respect to the NRC's model.

MR. ESH: Well, I'm David Esh. I'm in the Environmental and Performance Assessment Branch of the Division of Waste Management. And I'm going to talk about NRC's source term model and support today.

I'd first like to acknowledge all the main contributors, and also there's a lot of people involved in the TPA code development, source term

development. They aren't all listed. It would be a very long list of names. And a lot of work goes on behind the scene that never even ends up in a TPA code. So I just want to make you're aware of that, too.

And I'll try to give you some indications during the presentation, some little snippets of that type of information.

In general, you heard Dr. Payer talk about corrosion science and how it's evolving. Well, the performance assessment is evolving, too, and in particular our TPA model from the NRC is evolving, our source term modeling is evolving. And I'm going to try to give you some indications of that during this presentation.

Next slide.

And, hopefully, I will provide enough information to allow the Committee to evaluate whether we have what was referred to as gross assumptions. And so, and a number of you asked questions that were deferred. I'll try to answer the ones I could remember. If I miss them, feel free to ask them again and we'll go at them.

In general, our model is what we would call databased. We try to use as much objective

information as possible, as much realism as practical. We also try to be open about the information and its uncertainty. And we base our models on simple concepts. That doesn't mean that our models are simple. Sometimes they are quite complicated.

The key point is that we must have flexibility in our model to enable our review. So that flexibility can take different forms. Sometimes we'll do a really simple abstraction. That will allow us flexibility to look at a variety of alternatives.

And our model isn't always completely flexible, though. We can't do everything with the TPA code. Sometimes we have to go to an auxiliary analysis or something else to evaluate the problem.

Our development is independent of DOE. Somebody asked, I think it was Dr. Payer asked what were the sources of information that were common. We do have some common sources of information, but we always do an independent interpretation of that information. And we'll do an independent abstraction, too.

A key for us is that we have something that's computationally efficient. It might not seen like a big deal, but if we don't have a model that we can run in a reasonable amount of time and get some

results from, it really doesn't serve our purpose well. So that's a consideration that we have. And sometimes we come up with a similar model then maybe what we would like, but we have to always balance that level of detail and the computational efficiency that we put into the code.

And I'll try to speak directly to some cases where we have alternatives represented in our model, alternative conceptual models, that is.

Next slide, please.

And this is not a pretty picture, but maybe that's confidence building that we don't spend our time making pictures. It's just designed to give you an indication, here's the boundary for our analysis. We start with this dash line, and I'm going to talk about what I can going on inside of here.

The main process is I'm going to include a bullet here on the side.

Next slide, please.

The first thing that we have is we do this process of water getting into the drift, potentially interacting with the engineer barriers. Then the waste forms, mobilization of the waste and eventual release. Is how much water is actually getting in and contacting the waste.

We have two main processes that we consider in the TPA code. There's the potential for dripping to the barriers and then there's also the fraction of that dripping that can actually get into the waste package. And actually there's an appendix in the TPA and user's manual that describes this in detail.

You could really spend an hour on any one of these things that I'm going to try to cover in two slides. So you're really only getting a real surface skim to the information available.

Our model, our concept is pretty simple. We have variability in the amount of water, we have variability in the hydraulic properties of the units. And when you take both of that and you consider well when there is the ability of the matrix to have flow through the matrix, then the water is going to flow through the matrix. When the water in the rock exceeds the hydraulic conductivity of the matrix, then it petitions into the fracture system. It's basically a stochastic analysis of that simple concept. And what we do is we correlate a number of perimeters so we don't get anything unphysical, but the result is that you get this variable amount of water that may drift to the packages. And it's correlated to the number of

packages that see drift in water. So it's very unlikely that you have a lot of water to a lot of packages. If you have a lot of water, then you typically have fewer packages. If you have less water, than you have it to a lot of packages.

Once the water gets in the drift it gets to potentially to the engineered barriers, then we have a number of processes that can all divert this water. It's shown in the figure here in the corner.

We take into account that water can flow on the surface of the drift. Just because it enters the drift, doesn't mean it's going to drip onto the engineered system. So that's the water running down the walls into here.

If it does drip on the engineered barriers, it doesn't necessarily impact holes in those barriers or breaches in those barriers. So I think it's roughly to about a 30 percent degraded stage before the barriers don't really act like a hydraulic barrier anymore. Up until that point they'll provide some diversion capability.

And then even if you do have holes, and I think this was a question Milt was somewhat getting at, you can have diversion from the holes because of corrosion products, or maybe the holes may be small.

They might not be hydraulically active. So, in our model we account for these two main processes, and they result in modifications to the amount of water that could potentially get to the waste form.

The next slide, please.

We have two conceptual models for water contact. We have a bathtub and we have a flow through model. And these are pretty good figures to show the concept.

The one here on my right is the bathtub model. Basically the water comes in and the height at which the water connects to the sample, the height at the location where the water comes in the sample, they're both stochastic so you get a variable amount of water that can fill up in the package.

The water that fills up the package, the fuel that's in the wet region can then release and degrade. This area that's wet inside the package, it's modeled as a stirred tank and the solubility limits are applied to that region.

For the flow through model, the water simply comes in through a hole, it runs over the fuel and then exits through a hole in the bottom. And it's similar to the bathtub model, but there is only a very tiny volume of water accounted for inside the package

during that process.

Next slide, please.

CHAIRMAN HORNBERGER: So it's all flow of liquid water, there's no consideration of vapor and condensation, and all the stuff DOE considers?

MR. ESH: That's right. And I'll talk to that later in the presentation. We've added a diffusive transport model to give us the flexibility to evaluate DOE's model, but there are various reasons why we didn't have that up to this point. And I'll try to talk to those.

The reason why I showed the conceptual models for flow is I wanted to talk to this result here. Basically I've presented the flow into the waste package as a fraction of deep percolation. This is what our model would produce. What you can see is that you get a very small fraction of the water into the package up to the amount of water -- and this is a fraction of depercolation. So depercolation in our model is between 4 and 13 millimeters a year, I believe. So the mean is 8.5 millimeters per year.

The flow into the package is on average about 5 percent of that value. But it's highly variable because of those processes going on that I talked to earlier.

Now, if you combined that with the bathtub model for the water contact, you get a range of results from the fill up time can be as small as less than 20 years to a very long time. And what we see in our TPA 401 sensitivity analysis is our model is very sensitive to the water contact perimeters. And it's easy to see from this simple presentation of our model does, why you get that result. It creates a large variability in the timing of the releases.

Okay. Next slide.

In addition to the water flow processes that can influence the amount of water that gets to the waste form, when the drip shield is intact in our model, we have no evective component for release. So we have no releases from our model when the drip shield is intact, in TPA 401 or previous version.

Our drip shield corrosion model is very straight forward. And there's been a number of questions, and Dr. Payer showed in his presentation the whole concept of the window, the environmental window and the material properties. Well, we're directly taking our independent measures done at the Center for Nuclear Waste Regulatory Analysis, to converting the passive current densities to corrosion rate. And that becomes the abstracted distribution

that goes into the TPA code.

So this is our evidence or objective information, and it directly goes into our abstraction in the TPA code. So you could say that our environmental lingo for drip shield corrosion is defined by our test conditions. That's what we're doing.

Next slide, please.

For the waste package, we also have uniform corrosion, and as I'll show on the next slide, our extraction approach to the uniform corrosion for the waste package is identical to what we've done for the drip shield.

This slide is to indicate that a lot more goes into our models and our conclusions than, say, one set of experimental results. This slide is basically showing a model calculation for this extension of a point defect model to evaluate what happens to the current density over time. And it's used to evaluate this conclusion at the bottom how likely is breakdown of passivity or enhanced dissolution for the material.

Sure, go ahead.

DR. PAYER: Dave, just a clarification, perhaps, or a comment.

The overlapping diagrams I showed were for the potential of localized corrosion, crevice corrosion to occur. This general corrosion is assumed to go on when it's wet anytime there's moisture on the surface. So I don't think there's disconnect there.

MR. ESH: Yes, I don't think so either.

DR. PAYER: It's the issue of is a localized corrosion process going to kick in that will go faster than this.

MR. ESH: Yes. And I think in the next slide or two I'll be talking about this.

But this slide is an indication that, okay -- go to the next slide, please.

On the next slide it's similar to the drip shield slide. We take passive current density measurements and calculate the corrosion rate based on Faraday's law, extractly convert it into a corrosion rate, and then that's converted in a failure time distribution that you see at the bottom. And the mean is about 80,000 years. The shortest is around 40,000 and then it's up to about 180,000. So it's a direct conversion of the experimental measures, what objective information we have to a model in the TAP code.

The previous slide was to say that, okay,

we're using this experimental data on this limited set -- or this set of environmental conditions. But a lot of other work goes on to evaluate some of the assumptions inherent in the simplified models.

Next slide, please.

DR. LATANISION: Let me just interject.

MR. ESH: Sure, go ahead.

DR. LATANISION: A very major assumption here is that -- not assumption, but condition is that you're looking at 95 degrees centigrade.

MR. ESH: Yes.

DR. LATANISION: What happens if it's 180 degrees centigrade?

MR. ESH: Hopefully we'll see that in a side or two.

DR. LATANISION: Okay. Good.

MR. ESH: Localized corrosion, that's the window of susceptibility that Dr. Payer was talking about. Our model for that, this is the first instance in the TPA code where we're directly comparing an environmental condition calculated in the code to properties of the material. In this case we developed from experimental observations a relationship for the crevice corrosion repassivation potential, and that's compared to the corrosion potential and the localized

corrosion occurs when the corrosion potential is higher than the repassivation potential. So the expression is a regression of experimental data, and it happens to be a function of temperature and chloride. And I want you to remember that. There's a backup slide, I think 29, that shows this a little more clearly. But it basically defines the window of susceptibility based on our experimental results and this abstracted model when the packages would experience localized corrosion.

Now, there's a number of considerations in the data here. The processing, mill annealed, whether it's age, whether it's welded; they may all effect the localized corrosion susceptibility. And those things, including the effects of inhibiting species such as nitrate, can be introduced through changes to this relationship. So that's how we handle it.

We feel a model is pretty flexible if we're not tied to any particular result, but we can evaluate localized corrosion in somewhat of a fundamental or mechanistic way based on the empirical observation.

Next slide, please.

Now, this slide is kind of to get the engineer's attention, to get all the science and then

you say, okay, well what do I make of it. Well, what you make of it is this analysis is to evaluate ranges of critical relative humidity for the onset of aqueous corrosion. And what's particularly happening here is that when you're going to a lower range for the relative humidity, in effect you're saying that the temperature at which I can have an aqueous environment is increasing. That's the way it works in our model. So as this critical relative humidity goes down, I don't know what the exact temperatures corresponding to these values are. Well, I can tell you from slide 29 it would be that this is probably corresponding to about 110 C and this is probably corresponding to about 130 C, maybe. I don't know exactly. But as their critical relative humidity goes down, then you can have the potential based on the model that's abstracted in the base case for localized corrosion to occur.

Next slide, please.

We also have considered stress corrosion cracking, and here's a very small subset of the experimental results. The conclusions are that for the conditions evaluated and the types of tests performed they haven't stress corrosion cracking. It appears that the corrosion potential is less than the

potential for SCC or the stress intensity factor is less than the stress intensity factor.

Now, one thing you may take from this graph, well we're automatically applying aggressive conditions in these experiments. We're also automatically applying a stress to it. So it's assuming an aggressive environment, it's assuming a stress and then it's trying to see whether it cracks or not. And no crack growth was observed in these three, or in most of the subset. You do see in this case it's mentioned grain boundary attack and in this case minor secondary cracking. Those are attributed to somewhat of a localized, in the terminology I'm using, localized phenomena as talked about in the previous slide and not necessarily SCC. Although the language I'm speaking and the corrosion community speaks are probably different.

Sure, go ahead.

DR. MORGENSTEIN: Could you tell us something about the fluoride?

MR. ESH: The fluoride in the SCC experiments? I don't know what the fluoride concentration were in those experiments. Tae or Gustavo?

MR. CRAGNOLINO: No fluoride was used in

these tests. Our team, we are going to explore the possibility of interaction in between chloride and fluoride on the first corrosion cracking of Alloy 22. But in a variety of environments that contain chloride and other species, we didn't observe a test corrosion cracking even using much more extreme loading conditions than the ones that are described here for this test.

MR. ESH: Thank you. Gustavo Cragnolino was the speaker.

Next slide, please.

In summary, our TPA 4.1 code does have an SCC extraction and we don't plan on adding it in TPA 5.0. That's because of our experimental observations to date, and also additional analysis for the risk impacts.

This is an offline analysis not done with a TPA code. It's done with the GoldSim software platform where basically we developed cracks in the waste package, we assumed them, gave the geometrical properties and then calculated the diffusive releases from the waste form to outside of the package. And you just don't get an extremely risk to these very small cracks. So we're not carrying this forward in our TPA code.

We see our TPA code, we have an initial defect model that you can assign any amount of failure and any temporal evolution in the failures. We can evaluate any type of SCC phenomena if we need to, we're just not going to build an explicit for it in the code.

Next slide, please.

Moving on to the waste form now. We'll first cover spent nuclear fuel. This is a select representative of spent fuel dissolution rate sample. And what you see is that we took -- we got dissolution rates reported in milligrams per meter squared day. They're done on a variety of different types of samples. They're done under different solutions. They're done with different test methods. And you see if you look at the data here, quite a bit of variability in the rates that are reported.

Now, our model -- go to the next slide, please.

Our model -- actually we have 4 different models in TPA for spent nuclear fuel dissolution. Our first two models are based on the experimental data. We've also added a model to represent a natural analog and one with secondary mineral formations, schoepite in this case.

The base case in TPA is model 2, but we have the flexibility to turn on and off any of these models very easily.

We have a temperature dependence that's defined from emersion and flow through tests from a temperature range of 25 to 85 degrees C. And we have two different models for the surface area, because remember it's the contact of the fuel with the water that you have to take into account.

So our simple expression is given here at the bottom. There's an arhenius term in here. And we have a pre-exponential coefficient, and the arhenius term that gets temperature dependency, and that's our model that we use for this base case model two.

The other models are described in a lot of detail in the TPA code manual, and they're somewhat more complicated.

DR. GARRICK: How do you take into account the secondary mineral formation in the model?

MR. ESH: I can't answer that. Dick, can you answer that?

MR. CODELL: This is Dick Codell.

The schoepite model, as it's called, model 4 we assume that all the radionuclides are released at the rate that schoepite would dissolve. And we have

mass action expressions for the various ions in the uranium water schoepite equation. And this gives us the concentration of uranium as it was coming out of schoepite. And we assume that the degradation rate of the schoepite is controlled by that solubility so that ever thing inside in the schoepite would come off at that rate.

MR. ESH: Sorry, go ahead.

DR. GARRICK: What kind of effects does it have on the actual corrosion rate?

MR. CODELL: Well, this is the corrosion rate of the fuel. It gives a very low release because the schoepite is pretty insoluble. So it's at the lower end of the spectrum of release rates. Model one gives the highest. Model 2 is in the middle.

DR. GARRICK: Okay. Thank you.

DR. EWING: Do you expect schoepite to be the phase that forms at Yucca Mountain in the presence of typical silicate rich ground water?

MR. CODELL: Well, that would depend on if you have schoepite in the water coming in.

DR. EWING: Right, you do.

MR. CODELL: Yes, I think so.

DR. EWING: Schoepite would form?

MR. CODELL: Yes.

DR. EWING: Certainly not, I think.

MR. AHN: There are a couple of reasons we study the schoepite. Under the very logic conditions silicate water was -- silica was depleted in quite often in testings. Predominately they observed the schoepite later. That's one reason we study the schoepite release model.

The other model was at this moment radionuclides are considered to be entrapped in the schoepite, but it's not confirmed in the celloids, that's another basis we study the schoepite.

DR. EWING: So all the technetium you think is in the schoepite?

MR. AHN: Maybe the --

DR. EWING: No, this is strictly an assumption, and probably the technetium would not be in the schoepite.

MR. AHN: Yes, right. Let me add one more thing.

In our model 2, which is base model, already factored in the secondary phases, because the solution rate determined included the secondary phases. Even you formed the secondary phases have technetium will not be trapped i the secondary phase.

DR. EWING: What about cesium or

strontium?

MR. AHN: Right. Pardon me?

DR. EWING: Cesium or strontium?

MR. AHN: Cesium and strontium will not be released -- will be released and will not be trapped in the secondary minerals. However, cesium -- also cesium and strontium we do not consider, except the cesium 135. Because those are not long-lived for radionuclides.

DR. GARRICK: Most of it will be gone.

DR. EWING: Well, not the 135.

DR. GARRICK: Well, not, no.

MR. AHN: 135 is no.

DR. EWING: My major point is if you look at uranium deposits around the world under oxidizing conditions, schoepite forms for a while and then it's a very different phase assembly that you would expect at Yucca Mountain or under these conditions.

MR. ESH: Go to the next slide, please

This is kind of where the rubber hits the road. I've basically taken our model and the inputs that we have for our model number two, and converted it into a spent nuclear fuel degradation time. What you see is at higher temperatures it degrades faster, of course, as you would expect. And I've plotted a few

experimental points where they would convert back to this result on the plot here. And this was for the particle model, not the grain model. The grain model is more conservative.

This is another perimeter, the pre-exponential factor that we typically see as being very sensitive in our performance assessment results. And you can easily see that from this figure. Some of the time it degrades very rapidly, some of the time it degrades very slowly, and so it creates quite a bit of temporal variability in the timing of the release.

I think there's slide 29, can you skip to that. No, let's see. Keep going. 30. 31. 32. Here's your question about the alternative fuel dissolution models.

Basically model 1 is the most pessimistic and this schoepite model is the most optimistic of the four that we considered. But alternative model uncertainty can add -- can be pretty significant in this case, and I think that was the point that you were seeing discussed earlier, maybe by Mr. Garrick. I would agree with him that I believe that source term modeling can be pretty -- the uncertainty in the source term modeling can be pretty significant. We feel we have the capability in our code to look at a

lot of different alternatives, and that's all we really need to do. And we'll look at whatever alternatives the DOE wants to come forward with and try to support.

Let's go back. Okay. We can go to the next slide then.

We've added a model for glass in TPA 5.0. We didn't originally have it. Primarily because the inventory in the glass is a lot smaller for many of the key radionuclides than it is in the fuel. But to have the flexibility to evaluate DOE, we felt we needed to add a glass model, and it's very analogous to the fuel. There's a lost of estimated glass dissolution rates. They can be dependent on glass formulation testing methods, test conditions, a lot of things that can influence them, a lot of variability in these rates. And we use a rate expression that's similar to what the Department of Energy uses. Our ultimate rate has a forward dissolution rate term that it basically slows down as the silica builds up in solution.

The intrinsic dissolution rate is given by this expression. It's a function of the ph and the temperature inside the package.

DR. MORGENSTEIN: That would only work

with -- not a flow through situation.

MR. ESH: I don't know in particular whether --

DR. MORGENSTEIN: Because, I mean, you wouldn't build --

MR. ESH: Well, I would expect that in the flow through situation this term is essentially zero. So it essentially goes at the forward rate, yes. And even, as I've stated earlier in our conceptual models for release, we still do apply a small volume of water associated with the flow through model. It's just not the large volume of water like you have in the bathtub type of release.

You can go to the next slide, please.

The reason why we added glass is because the temperature dependence of the glass, the arhenius term is typically stronger than what you see for the fuel or at least is abstracted in our model. So under some circumstances the dose from the glass can exceed the fuel. But as you go to later time overall the fuel has much more inventory, it dominates our risk. And these are preliminary results from our current version of the code.

Next slide, please.

Waste form cladding, I think you heard

earlier that we don't take credit for cladding in our TAP 5.0 base case, but we feel we have a flexible model. And there's a failure mechanisms that can influence the cladding. I've listed eight of them here. I'm sure people in the audience could add some more.

Our TPA 41J has a factor, it's called the cladding correction factor. And it can be set by the code user for complete to no protection. But we realized that, okay, it isn't quite going to give us what we need with respect to the cladding failure, so we're adding time dependency in TPA 5.0. That should allow us to evaluate any sort of cladding failure without spending the effort to develop a mechanistic model for any one of these corrosion mechanism.

DR. GARRICK: What there corresponds to what DOE calls unzipping?

MR. ESH: The unzipping would come in here in the time dependency, actually. It's not -- you have a failure mechanism, which is listed here in the 8 different points. Then after it perforates, then the cladding can unzip. And so the perforation might be temporal and the unzipping might be temporal. That would be some sort of convolution to get one expression, I imagine, for the overall behavior.

DR. GARRICK: Yes.

MR. ESH: It might not be completely straight forward, but this sort of change to our code is not simple, but it's not nearly as difficult as adding in these detailed mechanism.

Let's go to the next slide, please.

We basically have a variety of explanation, a number of explanations for why we don't take credit for cladding our base case. Basically the assessment is as complicated as assessing the metallic spent fuel waste packages. The chemistry inside the package is quite complicated and to assess the incidence of localized corrosion and stress corrosion cracking in the cladding, we would need to have pretty good estimates for what's going on inside the in-package chemistry. So we don't take credit for cladding in our base case.

Now you might say, well that's very great but it's not as conservative as you can imagine because there is going to be glass source term. There's roughly, I think, 3 percent of the fuel going into the repository of the stainless steel clad and not much -- and I think the technical experts generally agree they wont' take credit for the stainless clad fuel like they will the Zircaloy. And

there are initially failed cladding that goes into the repository. Then there's the additional uncertainty of rail transport and what that might do to the cladding as it reaches the repository. And interim storage and the temperatures imposed on it there. There's a lot of uncertainties that we did a sensitivity analysis considering those factors. And roughly we could reduce our base case doses by about 80 percent if we took cladding credit. But it's not 100 percent effective, and that's somewhat of a misconception whenever would people would look at, okay, you don't take credit for cladding.

This is pessimistic, but our technical staff don't believe it's overly pessimistic, nor with our current results do we need to worry about it too much. If we had results that we were getting -- that were much larger, we'd pay a lot more attention to something like this.

Next slide, please.

Once we get our waste forms corroded, our EBS corroded, our waste forms corroded, then we have two mechanism that we can release. We have advective transport and we have diffusive transport. The advective transport requires flow and it carries the dissolved radionuclides out at their solubility limit.

Our diffusive model that we added for TPA 5.0 it's going to be transport of the films of the water both inside and outside the waste package, and the user defines the lengths and thicknesses of these films.

We found that the thickness of the film, the lengths and thickness of the films in particular inside the package can have a big risk limiting effect for a lot of scenarios. You can imagine if you pulled the end off one of these packages, the diffusive area isn't the open area. It's the water film area on the inside contact area. That's a lot different. So you have to be careful how you abstract and how you model this diffusive transport, and that you're being reasonable for the phenomena you're trying to look at.

Next slide, please.

Our release and transport auto package, as I said easier, we have two contact models, bathtub and flow through. The bathtub can have variable height. Flow through is the same, but we don't allow the build up of the fluid. And basically the mass-out of any radionuclides is a product of the water flow rate and the concentration. The concentration is determined by solubility limits.

Solubility limits abstraction is based on

the likely solid phases precipitated or co-precipitated in the chemistry of the fluid that reacts with the solid base.

Let's go to the next slide where I cover solubility limits.

There are a number of radio elements; cesium, technetium, carbon iodine. We basically say solubility limits are one molar. We don't believe they'll be any significant solubility limit in the solids.

The range and probability distributions for many of the other elements in TPA are based on the elicitation of experts conducted by DOE. So this is a source of information that we are using. They've actually progressed from this point. We're using some information that was from the project, as we didn't have any better information.

The assumptions behind their distributions is that UZ water is bounded by that of J-13. The solubility limits are going to be determined by the far-field groundwater. And the environment is oxidizing.

Now, we needed a backup side, so I have number 33. It gives you some indication of how -- yes, that's great. How sensitive the model can be to

solubility limits. You have a set of the radionuclides, but basically their solubility limited all the time, even considering the variability and the flow coming into the package.

Then you have another subset of radionuclides that are rarely if ever solubility limited. And then you have some that fall in between. And it can be sensitive to the type of water contact you're using. And this paper goes into a lot of detail about all the influences you can have on solubility limits and release.

The set of radionuclides here on the right hand corner, those are the ones that we typically see get now. They're relatively lightly retarded and they have a high solubility limit. These other guys, in addition to being solubility limited, typically also absorb rather strongly, too. So they're doubly maintained in the system and these guys you could say are not very well retained in the system.

So the output of our performance assessment for the regulatory time period is typically strongly influenced nuclides down in this corner, whereas the longer term risks are more influenced by the nuclides that fall in the middle and the far hand side of the graph here.

DR. LEVENSON: I have a question.

MR. ESH: Sure.

DR. LEVENSON: I understand those down on the right hand side, their solubility for all practical purposes for this is almost infinite, etcetera. And you calculated at one molar for calculating for -- is there enough that in the fuel at any one cask to really get you to one molar or anywhere near it?

MR. ESH: I don't know. I know that it only takes about .007 millimeters per year for any reasonable release rate of, say, technetium and iodine to mobilize that. It only takes a little bit of water.

DR. LEVENSON: Oh, I'm not talking about-- I'm not questioning at all that it might be all mobile. All I'm saying is that if you're calculating what's coming out of there based on concentration gradients and you're using one molar, you may not have anywhere near enough material to get one molar.

DR. CAMPBELL: Dave --

MR. ESH: Well, it might be better to present this information normalized to the inventory. That might provide you an additional piece of information.

DR. CAMPBELL: Dave, let me take a stab at

that. That's an upper limit. It's not the concentration of iodine or technetium, or whatever, coming out in the solution. That's driven by the release rate for the degradation of the fuel. The whole point of the one molar is it just simply moves the solubility limits so high that you'll never have a solubility limit. It's not coming out at one molar--

DR. LEVENSON: You're saying the one molar is not used in the calculation?

DR. CAMPBELL: It's just you've set the solubility so high that what drives the release is the rate of degradation.

MR. ESH: So sometimes you'll have release rate dominated nuclides and then sometimes you have solubility nuclides basically.

Can we go back to --

DR. PAYER: Dave, while you're on that, there's quite a bit of steel on the inside of the waste package that's going to generate quite a bit of iron oxides. Do you account for any beneficial or detrimental or any effects of that iron oxides?

MR. ESH: The answer is no. If we can go back to the solubility limit slide, which was 22 maybe. 23.

For the solubility limits that are

uncertain, we're getting most of them from this expert elicitation. And these are the assumptions assigned to the expert elicitation. They, I believe, did not take credit for the corrosion products inside of the package.

It's actually interesting that you mentioned that. DOE has gone to more process oriented solubility limit calculations, which were the discussion point that Rob was getting at. And those are typically functions of the in-package chemistry that they calculate. The in-package chemistry was generated with an EQ-36 simulation.

I believe that you could potentially have beneficial effects from the corrosion products. You could also have a chemical environment that is more aggressive and you have higher effective solubility limits than based on what these assumptions are.

DR. PAYER: Yes. I was thinking more -- I mean that's all true; it could have certainly a function of the water chemistry of the water that's there. But I was thinking more from the standpoint of how it might effect the diffusion path link or the transport processes. And also if it would provide any retardation of any of the radionuclides absorbing to the iron oxides. These are fields I don't know much

about it, I've just heard the terms brought up.

MR. ESH: Yes. The interesting thing for the elements that you consider solubility limits inside the package, they tend to be the ones that also absorb rather strongly in the geosphere. So what you'll find is that only under conditions of lower than expected absorption and higher than expected solubility do they start significantly contributing to the risk.

The invert below the waste package typically has a chemical environment that is less aggressive than inside the package in DOE's model. And what happens is you may have a higher solubility inside the package, but then when that nuclide releases from the package, it hits this environment that's in the invert more dilute, more benign, has a higher ph and a lot of the nuclides precipitate once they hit the invert and they're released at a lower rate from the invert. So it's a system problem and you have to consider the solubility limits both outside and inside the package whenever we discuss it. It's not an easy problem, by any means.

Next slide, please.

In conclusion, what I wanted to get across was we've based our models on the data we have, the

objective information that we have. We use simple concepts where possible, but the models can be pretty complex.

Probably the first source of information you'd want to go is the TPA user's guide that describes all these models in much more detail than I could do in this presentation. But then contact any of us if you want further discussion on any topic.

And a key point, though, is that our code has to be flexible enough for us to do a review. Yes, we may make selections for models of perimeters in our base case, but we aren't going to base our decision on our model. We're going to base our decision on DOE's model, their results and their support of it. We'll use our model to question things that maybe we can't directly run DOE's model or directly evaluate something. Or maybe we have a quick question about something, we use our code to do that sort of work and to evaluate those sorts of questions.

So, in summary, I believe our tool is flexible enough and it'll provide us what we need to do our licensing review.

Be happy to answer any questions.

DR. GARRICK: Yes. Go ahead.

DR. LATANISION: Well, I guess this may

applied to the first of your bullets up there, the databased modeling. And I'm thinking of the figures that I asked the question about earlier, and this would be 6, 7 and 8, I guess on uniform corrosion rates.

MR. ESH: Yes.

DR. LATANISION: The date in these studies is at 95 degree centigrade. And if the project goes forward and the high temperature operating mode, then a considerable period of the lifetime of these packages and drip shields will be at higher temperatures.

MR. ESH: Sure.

DR. LATANISION: I guess I'd feel a lot -- I think intuitively the conclusion is right, that uniform corrosion probably is not an issue. But I guess I'd feel a lot more comfortable if I saw a temperature dependent corrosion rates that would, you know, allow that sort of careful analysis. And I don't recall. Maybe Bob Andrews knows the answer. I don't know where he is. But is there project data that shows the temperature dependence?

MR. ANDREWS: Yes, there is some limited general data and temperature dependence of those. Those were also documented in the Supplemental Science

Performance Analysis.

DR. LATANISION: Up to what range of temperature.

MR. ANDREWS: Oh. That's a good question. Probably only up to about 95. I'm not sure we exceeded.

DR. PAYER: I think there's polarization data both at the center, perhaps Gustavo could mention.

DR. LATANISION: Oh, I know that.

DR. PAYER: But also Livermore has one polarization --

MR. ANDREWS: Livermore has the polarization data, but I think they were general.

DR. PAYER: -- so passive current density interpretation are up to 120 and 130, I believe.

MR. ESH: Your point is right on. I mean, yes, if you believe you have a window of susceptibility possibly at higher temperature, and that's what the fundamental science says, then you want to have some information to hang your hat on there. And it's completely reasonable.

DR. LATANISION: Well, my point's very simple. I mean, I think intuitively your conclusion is correct. But I think I'd also be much more certain or

comfortable with that if I could see some temperature dependent data.

MR. ESH: What we find -- sorry. What we find for the general corrosion information, I believe, both at the center and this would hold for the DOE weight loss data, it's very noisy or uncertain, whatever you want to call it. Experimental uncertainty. And if you try to do a regression on what's the change in the general corrosion rate based on the environmental influences, you can't come up with anything really. You don't see it's sensitive to ph, you don't see it's sensitive chloride. You don't see it sensitive to temperature. You just see it's an uncertain set of data. So you have to go to other types of measurements than those particular measurements that are confounded by silica precipitation in the DOE's case, and I just think inherent measurement uncertainty in some of the measurements we get.

DR. LATANISION: You know, I'm sorry, I don't buy that. I mean, that's just not good enough. I mean, if you look at a couple of different temperatures with the same solutions, that's what I'm looking for. You've got a reasonable environment here. And if you look at 90, 120 and get corrosion rates,

then I think -- I'm not sure that would be all that noisy.

MR. ESH: The data I had, and I did this regression, that we're at 25, 60 and 90 --

DR. LATANISION: We have to go into your lab and look at this.

MR. ESH: You basically get R squares that are statistically not significant. You can't -- there's a lot of additional sources of uncertainty in that data.

DR. LATANISION: So classical rate theory doesn't apply to corrosion rates in this case?

MR. ESH: I would expect it would. My opinion is I would expect it would, but the data you can't elucidate that from.

DR. LATANISION: Yes.

MR. CRAGNOLINO: This is Gustavo Cragnolino from the center.

Let me clarify a little bit this point. I think I would have to combine the range of temperature of all the boiling point of water solution, diluted solution. Because we did experiments in the range of room temperature to 95 degree. And it's true that, as it was mentioned, there is a lot of uncertainty in the data, and we

can't come out with a very worthy value for the activation of energy and for the preintervention value. But we are confident that at least temperature's right. Now we are using to the temperature about 100 degree, but in order to do this, we have to work the concentrated solution of cells that are -- I asked to do experiments on the liquid cells without using a natural system that create particular complications. And this is what we have done and try to do now, and to see if the values that we are getting in the temperature range that we know when, that is from 25 degree to 95 degree can be extended out to 120, 130.

DR. LATANISION: Right.

MR. CRAGNOLINO: And this is the current situation. There is good reason to believe that the continuity of this physical process that's going to have to work with final concentrated solution, and we have a few weeks. And I think the project, the DOE is sensitive to doing the same thing, but they are confronting the same problem that we are.

DR. LATANISION: Good enough.

DR. GARRICK: Okay. Any other questions? Yes, go ahead, Marty.

DR. MORGENSTEIN: Can we go to 23?

Looking at the water chemistry again, was there a particular reason to go and look at UE-25p#1 as a bounding with J-13? In other words, if you guys were going to do this over again today, would you go down this direction?

I hate to put it this way, but looking at UE-25p#P1 is like going back to Szymanski. I'm sorry, but the states not going -- we can justify an upwelling of water into the -- you know, in their field. And I don't see how else you're going to get that composition. Are you suggesting that Szymanski was correct?

MR. PABALAN: This is Roberto Pabalan at the Center.

I think the analysis that was done by the DOE, their expert elicitation used the UE-25p composition only because it has more present in the solution phase. And -- is a very strong complex -- that's I think the reason for using a UE-25p as one of the bounding compositions in addition to J-13.

So we're not implying that any uploading would occur, of course.

DR. MORGENSTEIN: I'll just let it ride.

MR. AHN: I have one information for you.

This is Dr. Ahn.

You mentioned about the solubility limits in the presence of various secondary minerals. In fact, in the expert elicitation as you see on page 23, you can see the database mention it at all. That really include the secondary mineral. I don't mean to include the whole -- minerals, but it included minerals during the spent fuel dissolution.

DR. GARRICK: Any comments more from either the panel or the committee?

DR. PAYER: One other question, I guess. IS the treatment of the water into the waste package, is it ever found or has it been looked at if the water becomes the controlling rate, that it just comes in and it's being used up or is it -- is it looked at that there's just this very large amount of water and that's never an issue. It's either dripping in there or the film?

DR. EWING: So is your question that the evaporation potential exceeds the amount of water --

DR. PAYER: Yes, the possibility of evaporation potential as things are corroding they use up some of the water, and this can effect the kinds of waters that remain.

DR. EWING: Sure.

DR. PAYER: IT could also effect if it's

wet or if it's dry and just the issue. I mean, you've got the package that in some cases the vision is it's got some stretch corrosion cracks in it. In other cases there are holes drilled in it. You know, that exchange, has it been looked at? Oxygen is consumed by these products as well during some of these periods. Has that ever been found to be a controlling rate?

MR. ESH: That's a very good suggestion. Because some of the rates as I've presented can get very low under certain circumstances. So you could possibly have a limited from those processes.

We primarily only consider the hydraulic limitations to those water pathways, but not as you suggest.

DR. PAYER: Well, my understanding the Swedish program goes through an exercise where if they penetrate their outer package, they deal with the amount of oxygen that can come in and what kind of condition remains.

MR. ESH: Sure.

DR. PAYER: You know, obviously, it's a different situation. But the treatment of it is available.

MR. ESH: Sure. It's a good suggestion.

DR. CAMPBELL: Just one comment here.

Andy Campbell, NRC staff.

A number of years ago I was part of a NEA panel that reviewed the safety report 97 for the Swedish KBS-3 concept. They essentially put a large amount iron inside the waste package and they have an environment that is extremely reducing. So what happens is they've engineered the package to generate hydrogen if any water gets into it through the copper canister through pinholes or something like that. And the canister is in a bentonite shell, if you will. And it's very strongly reducing environment both because of the geology and because of the bentonite.

And so what they do is that generates an over pressure inside the waste package which tends to limit how much water can defuse in. So that's basically what's happening in the Swedish system, and they modeled the diffusion of moisture into that and the generation of the over pressure, and then the possible stopping point where water can no longer diffuse in because there's too much hydrogen over pressure.

DR. GARRICK: Any other questions? Any questions from staff? Okay.

Thanks a lot, David. Very good.

As you can see from the agenda, we have allowed time for public comments, and I think we would like to ask if there's anybody in the room that would like to make comments at this time, this is the time to do it.

MS. TREICHEL: Judy Treichel, Nevada Nuclear Waste Task Force.

Well, you can be grateful I don't have a comment. I have a question.

On the schematic the invert is crushed tuff. Is that like gravel that you just -- is it just thrown in there and smoothed out, or do you actually make a surface out of it like a cement that's made out of real small crushed tuff? Because it always looks like this flat form, and I know in Joe Payer's slide, he was still back to the carbon steel invert, and that's gone.

DR. GARRICK: Abe, you want to orchestrate that one?

DR. VAN LUIK: It's my impression, and I'll go back and check it, that it's a metal frame that is filled with crushed tuff and is perhaps smoothed out to the way that you smooth gravel with a rake. But it's not a hard surface. All of the support is on the metal supports, not on the crushed tuff

itself. It's not a load bearing gravel.

MS. TREICHEL: Okay. Is it a carbon steel frame then that this stuff goes in?

DR. VAN LUIK: Do we have some people here from the engineering side?

It's my impression that it's a -- not a carbon steel frame, but it's a stainless steel frame.

MS. TREICHEL: Okay. And then the pallet is made of Alloy 22, is that right?

DR. VAN LUIK: The pallet is made out of Alloy 22.

And I should identify myself I guess every time I speak. Ed Van Luik -- oh, I don't need to. Okay.

And I believe that where the pallet meets the invert, the components that it meets are also Alloy 22. So there's not going to be a reliance of an Alloy 22 to stainless steel interface.

MS. TREICHEL: Okay. Thanks.

DR. GARRICK: This is an opportunity. Any other comments? Well, hearing none and unless there's questions from either any of the speakers or participants, or the panel or the Committee, I think we'll --

DR. LEVENSON: I have one kind of generic

question. I don't know who to ask it of.

In the calculations for humidity and moisture and things like that, originally the concepts assumed that this was a gas type mountain, whereas the USGS measurements are that this is a giant chimney passing some thousands of CFM of air up through it, whether there's any fans running or not. Is a combination of the chimney effect and barometric pumping being taken into account these days in calculating things like humidity in the mountain?

The USGS has made extensive measurements on it.

DR. BULLEN: Bob Andrews?

MR. ANDREWS: Yes, let me try.

The observations of barometric have been factored into the hydrologic models upon which the seepage models are based. But the actual transient effects, you know daily or yearly transient effects of gas pumping have not been directly incorporated in the thermohydrologic calculations themselves.

DR. LEVENSON: I think the USGS measurements indicate that the steady-state chimney effect pumping is greater than the barometric pumping.

MR. ANDREWS: Yes.

DR. LEVENSON: It's not yet been taken

into account?

MR. ANDREWS: No. The thermal chemical models that I alluded to, the thermal hydrologic chemical models do allow that air phase gas exchange for the chemistry, but not for the hydrology.

CHAIRMAN HORNBERGER: How about for the thermal?

MR. ANDREWS: Not for the thermal hydrology. The thermal chemistry, but not for the thermal hydrology.

CHAIRMAN HORNBERGER: You know, I guess the real question that arises that Milt has brought up before is to what extent this air movement carry moisture and heat along with it and is that transport significant with respect to the other mechanisms that you consider?

MR. ANDREWS: Let me go back and try to find the answer to that. Thanks.

DR. GARRICK: Bob, before you leave, I'd like to ask a general question of you and Dave Esh. And that is, and focus on the source term. In your opinion, not in the opinion of the model, in your opinion as an expert what do you consider the 3 or 4 greatest sources of uncertainty in the source term model?

MR. ANDREWS: Gosh. What an opportunity.

Well, defining the source term the way we did here, I think the degradation modes of some of the engineered barriers, in particular the waste package, are significant and alternate degradation modes. So that's a key uncertainty that effects performance for this nominal scenario class that we've been focused on in here, as opposed to other disruptive events that we have not focused on in here.

I think that some of the solubilities and the in-package chemistry effects on those solubilities are also significant. And the transport out of the package, you know this diffusive effect on the diffusion lengths or advection and effects of plugging and its potential effects of advection and diffusion would also be major significance.

I think the first two are covered in a lot of KTI agreement items. The third one I don't think we have a KTI agreement item on, actually.

DR. GARRICK: Where would you put water composition on there?

MR. ANDREWS: Well, it's the water composition and its effects on bullet number one, which is the degradation of the engineered barriers. And on bullet 2, which is the solubilities and release

rates.

DR. GARRICK: Dave, you want to share with us your wisdom on this?

MR. ESH: Sure. I think I would say the source term release, the source term uncertainty that I feel is the biggest, is the actual conceptual model or model uncertainty with respect to the waste form, in particular the fuel. It's related to water composition question because it effects both the phases and potential secondary phases that can form inside the package and the solubility limits for some of these species. They typically don't show up in the output of the performance assessment because of how much they're retarded in the geosphere. But they would be the ones that would most influence the longer term peak risks.

So, I don't know how to say whether it's water composition or whether it's the source term model solubility release rates. But I don't know how you separate them. That concept, I'd say, is one. And then the second one is what is the high temperature performance of the engineered barriers.

So I kind of have given you maybe five that are described as two.

DR. GARRICK: Okay. Do any of the other

presenters or speakers that are here want to add or amplify or illuminate. Go ahead.

DR. MORGENSTEIN: Probably if we take a step back and look at the most important aspect of what we really don't understand, it's the environment. And it's the geochemical near field environment, and that breaks down into the water chemistry. But it's not limited to just the water chemistry. It's limited to an understanding of what the temperature regime looks like with respect to what water chemistry comes in contact with which canister at what point in time.

And a gross assumption by most activity has been to look at one or two water chemistries or one or two temperatures and say this is what the behavior will look like. And that over-simplification is probably driving our frustrations today. Until we understand those basic perimeters, we really can't speak to what authegencis are going to form because we don't have the conditions.

We can't speak to transport out of the system into the saturated zone, because we really don't know what's being transported. We don't know what those colloids look like, if there are colloids. So that we really don't have a sound framework of understanding of the environment of the near field,

and I think that's what perturbs us the most.

MR. ELZEFTAWY: Mr. Chairman, I have a comment.

DR. CAMPBELL: Yes. Your name.

MR. ELZEFTAWY: It's my personal comment as a member of the public. I don't want to think about traveling 2,000 miles to make the comment.

By name is Atef Elzaftawy, and I'm a hydrogeologist.

The last thing I did with this program i 1988 or '89, but I have been -- my hands have been dirty reading some reports here and there. But as a modeler I think listening to the presentations and looking at the DOE program, and looking at the NRC program, one of the worst fear I have in terms of computer models is simply what I call it MPL incident. MPL stands for Mars Polar lander incident.

If you'll remember, NASA sent those two probes and the two big contractors in Pasadena and the other one in Denver, programmed it. One of them put the metric system and the other one put the English system, and we finally lost both of them anyway.

So you can -- my first program was, I don't know, 15, 16 subroutine back in 1970. But what goes into those subroutines between one subroutine and

the other of all this big humongous computer program is very important. You need to look at the data and how the data is being transformed from one organ -- let's look at our body -- from one organ to the other. What does the heart do? What does the brain do? What does the pancreas do? What's all these organs are doing to give you a nice temperature healthy body. If you don't have all this coordination together, at the end you will have some data but you ask yourself am I sick or am I well.

I'll just leave you with that. So, thank you very much.

Good luck.

DR. GARRICK: Yes, go ahead, Rod.

DR. EWING: Just a comment to follow Maury's discussing the environment.

Separate from all of the modeling, I think one thing that always impresses me and depresses me a little bit is that this is a repository for spent nuclear fuel and yet the amount of data that we have on the behavior of spent fuel in an oxidizing environment is remarkably limited. And I think if we had a stronger scientific program investigating this, then our discussions of models would bear a closer relation to scientific discussions on other issues.

I mean, it's really -- you know, this is spent fuel that we're disposing of. It's oxidizing conditions, we know that much about the environment. There'll be water present. And yet the experimental data we have with real fuel, the characterization of real fuel, it's function at burn up, the knowledge of the secondary phases, this is very limited.

And I'd also suggest it's the secondary phases that are actually the source term. The UO2 will go so quickly that we should be looking at the uranium 6 phases as the source term. That of course is self-serving, because this is something I work on.

DR. GARRICK: That's all right. That's why you're here. Okay. Yes, go ahead.

DR. VAN LUIK: I was wondering in the comments about the wind blowing through Yucca Mountain what the daily pumping is directly related to how much -- what the composition is of the atmosphere in our tunnels, for example, as far as radon is concerned. If you look at the west side of the mountain, if the wind really blew through the mountain as some people have suggested, there should be a dryout zone there, but there is not. The flow is basically vertical on the west side as well as over the top and on the east side.

If you look at the holes that the USGS drilled through the PTN, through the non-welded unit, those are the ones that showed up, you know, basically the mountain sucks and then blows, depending on the weather conditions. But inside the mountain itself where the cross drift is where we put up some barriers, basically we see a very stable gaseous environment inside those sealed tunnels.

So I don't know where the question was going.

We do have a proposal from Nye County saying that because you can engineer the mountain to take advantage of this by basically putting drifts upward through the PTN, rises through the PTN, you could actually create an environment where you get a lot more air exchange and actually cooling. I'm not sure we want to engineer the mountain like that, but you would have to modify the mountain to take advantage of the atmosphere conductivity of the mountain.

I'm just wondering the question was coming from or going?

CHAIRMAN HORNBERGER: From my standpoint, I don't anticipate or I didn't expect that the question was whether the mountain was going to have

dry-out zones. It's more a question of, and perhaps you have the data, I don't know the answer to the question. It's an honest question.

We look at the USGS and the suggestion is that there is air movement, whether it's barometric pumping or whether there is a standard upflow throughout the whole mountain. And then the question is that air will transport heat and moisture. And I'm just curious as to whether it transports a significant amount of heat or moisture, particularly moisture with respect to, say, relative to the depercolation flux. It's basically an upward flux, and it may be negligible. I just don't know. I just never have seen the answer to that.

I don't think it will change the ambient conditions. As you know from your own drift, it's not going to lower the relative humidity in the drift. That's not the point.

DR. VAN LUIK: Okay.

DR. GARRICK: Yes. Go ahead, Joe.

DR. PAYER: Just sort of a general discussion and comment here.

Having looked at the international peer review of the TSPA, I guess at site recommendation time and having participated over the last several

years in a couple of different peer review activities and monitoring what this group said and TRB said, it seems one of the common suggestions that comes out of that or requests that comes out of that is the desire to have a series of similar models that capture reality in one of the boxes, in one of the modules that you started us off for this morning, and they keep recurring.

And I think from that standpoint the need and the very clear recognition on the part of DOE that they're following the orders they need to get a license, to go in that direction, that you have to have a TSPA and all, and then with that and the combination of some budget times and people times and all that, there seems to be a lot of pressure that if this doesn't reduce uncertainty in TSPA or if we do a one off sensitivity analysis or in the flexible NRC model, if it shows up it doesn't have a big effect on the tail somewhere, then that gets a lower priority than something that does. And I understand that logic.

DR. GARRICK: Yes.

DR. PAYER: However, it's driven us to a point where there hasn't been much effort really put in developing some of these simpler understand it kind

of models, for example in something near and dear to me. If we really had a wider data set and a better understanding of the initiation of localized corrosion, the likelihood of it, and importantly I've seen little or no work done on the stifling of that process.

We know that both stress corrosion cracking and localized corrosion can stop, they can start, they can start up at a rate, slow down. And we just haven't -- the general "we," as all the community studying this problem from their stakeholder positions, haven't really addressed some of those very fundamental kinds of issues.

And I just make this as a comment. I don't know what the fix is. But, you know, I think part of the hope of the science and technology program that DOE's putting together is to be able to address some of the issues. But having sat around that table, that the same kinds of pressures comes forward. It's hard to do and to pay for some of these things that could have a major impact on just people's -- gee, we understand that, you know.

And I don't know exactly how it's captured in TSPA, but here's reality and that's what they tell me they're ding.

DR. GARRICK: Well, several years ago this Committee coined the phrase SPAM, which stood for simplified performance assessment model. And we were pushing the concept quite aggressively for a spell. And one of the reasons I showed that diagram is that if we really did have a scenario based model of the performance assessment where we could rank the importance of the model to the performance measures, then the concept of a dominant sequence become reality. And that's something that would be very fascinating. Because one of the major breakthroughs in reactor risk assessment work was when we did become much more rigorous with respect to adopting a scenario based approach to risk and we took the notion that what a risk assessment is is basically a structured set of scenarios, we were able to look at those scenarios and some very small fraction of the scenarios generally was responsible for some very large fraction of the risk. And if you could take that small fraction that was responsible for a large part of the risk and create a dominate sequence model as we did in the reactor safety arena, these models became enormously beneficial. In fact, they became the basis for creating onsite models that were almost real time in the sense that we're able to monitor the

dynamics of the risk of their plant on the basis of these models.

Now, these models were not the big model and the big model's not the plant. And you have to be very conscious of that. But the search for some counterpart of that in the performance assessment field goes on.

And I agree with you, that would be enormously beneficial if we had some sort of physics based model that was physically understandable that we could get our arms around that we could manipulate rather routinely and straightforward, and that we could communicate with to the public, it would be a very desirable thing. And I think it's something to continue to pursue.

Yes.

DR. BULLEN: Actually, we should give the DOE a compliment because about 4 years ago they did a simplified TSPA and made a presentation to our Board. Unfortunately, that work didn't continue. And one of the biggest benefits goes back to what you said earlier this morning, is that it's a much more transparent operation if you've got some simplified model that you could, you know, base at the level of, maybe a high school senior or a general member of

public who can tweak the knobs or turn the dials and say, "Well, what's the worse case you can get," and try and get them to understand the fundamental physics of what's going on in the mountain.

Now, that may be a very difficult task to undertake, but that simplified model may be a real benefit, perhaps in the licensing stage or perhaps in the performance confirmation stage where people are trying to understand just exactly what goes on.

DR. GARRICK: Well, it's not just a theoretical concept in the reactor field. It has become the basis for implementation of something called the maintenance rule. And it's been a very powerful device for bringing the whole concept of maintenance into the arena of having something that gives you reasonable assurance that you're working on the most important things as it relates to safety.

So, I don't know what can be done about that. But I do know that if we could do something in that direction, I think the dividends would be great.

DR. BULLEN: Okay. I agree.

DR. EWING: Related to that, John, and correct me if I'm wrong, the advantage you have with the safety analysis of reactors is that it's an operating machine and you're constantly updating your

knowledge and your models with what you've learned on a day-to-day basis. And the challenge here is that we're going to build something and leave it, and not be able to update the design or the procedure to the waste forms in the future. I mean, we're limited in that respect.

And what I'd suggest is the equivalent of increased knowledge by operating the reactor for repositories increased research to develop the fundamental understanding that you need to have these simple models have some meaning.

A simple model doesn't mean to me that, you know, it's dumbed down. It becomes simple when you have a good physical and chemical basis for your understanding.

The chemistry and physics isn't complicated, but the models can be so elaborate as to be a pain.

So I think it's really two different challenges.

DR. GARRICK: Well, they are two different challenges. And there's been lots of debate of active system models versus passive system models, which is basically what we're talking about here. Passive systems that have very long time constants. But on the

other hand, I'm still not convinced that somehow we constitute the information we already and the extensive analysis we have into somewhat end-to-end scenarios through some sort of a structure like we've been talking about that you couldn't approach what we're looking for here.

Any other discussion, comment? We're right on schedule.

Yes?

DR. VAN LUIK: Peter also.

Rod took the balloon that I was going to raise and popped it right away. But we do have a simplified model that we use in, for example, I just used -- gave away 25 copies to a high school science teacher's group. And I had a copy with me I could have given you, except my neighbor on the plane got interested on what I was working on and took it away from me.

But this not the kind of a tool that you would use to gain basic insight. It's a kind of a tool that we would use to communicate to the public that science is indeed in our models, and that's about as far as it goes.

This is a joint venture between the M&O and MTS. MTS created the simplified model and put it

on an M&O basically interactive CD, which is a very nice piece of work.

And we are moving forward with that, except when I said I need money to do this this year because I promised the TRV, in fact, that it was my goal in life to do this, I was told okay, here's the work scope for the LA, what would you delete. And hence, it has to wait a while.

DR. GARRICK: Yes.

DR. EWING: Well, I would say that has value and I would like a copy.

DR. GARRICK: You've got my email.

DR. BULLEN: It can't be emailed.

MR. SWIFT: If we have time, I have a comment.

DR. GARRICK: Okay. Go ahead.

MR. SWIFT: I'm Petter Swift. And I'm speaking here as someone who will in some way react to and perhaps implement suggestions from this group.

And I hear requests here that I find I'm getting a mixed message. Simplicity and realism, from a modeler's point of view they don't always converge. They rarely do.

I hear Rod asking for trace elements to be considered in the formation of secondary phases, a

realistic and sensible thing to do. It's not an easy modeling task.

I hear Joe asking for cyclic processes in corrosion be treated explicitly. This is not a simpler path. It's actually a more complicated path.

And Abe's comment is a good one. What a simple model can do, typically is limit it to results that are within the scope of what your more complex and deeper understanding tells you is reasonable. So the simple model Abe talks about, it's basically -- it'll reproduce the range of results and let the user tinker within the range for which the larger more complicated model appears to be valid. But once you take a simple outside the range of validity of the understanding you just develop more complicated. Underlying models, you've gone beyond the range of validity for this simple models.

So I want this group to think about that as they recommend a simpler model. What are we really asking for? I think we're asking for a tool to help us understand what we already know from the more complicated models or what we should know from the more complicated models, you know, assuming they're adequate.

And that's my comment.

DR. GARRICK: Good. Good. AS Einstein said, make it simpler, but no symptom -- what did he say? Make it simpler but no simpler.

Okay. We'll be here at 8:30 in the morning, and with that we'll adjourn.

Thank you very much.

(Whereupon, at 5:35 p.m. the hearing was adjourned, to reconvene tomorrow morning at 8:30 p.m.)