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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE AND MATERIALS

(ACNW&M)

184th MEETING

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TUESDAY,

NOVEMBER 13, 2007

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VOLUME I

The meeting was convened in Room T-2B3 of Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 10:00 a.m., Dr. Michael T. Ryan, Chairman, presiding.

MEMBERS PRESENT:

MICHAEL T. RYAN	Chair
ALLEN G. CROFF	Vice Chair
JAMES H. CLARKE	Member
WILLIAM J. HINZE	Member
RUTH F. WEINER	Member

NRC STAFF PRESENT:

LATIF HAMDAN

NEIL M. COLEMAN

DEREK WIDMAYER

MYSORE NATARAJA

JIM RUBINSTONE

TIM McCARTIN

BUCK IBRAHIM

BRITT HILL

ALSO PRESENT:

JOHN PYE

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P-R-O-C-E-E-D-I-N-G-S

10:00 a.m.

CHAIR RYAN: The meeting will come to order. This is the first day of the 184th meeting of the Advisory Committee on Nuclear waste and materials. During today's meeting, the committee will drift degradation and a staff review approach and capability and a discussion of ACNW letter reports, actually W&M letter reports. Neil Coleman is the designated federal official for today's session.

We have received no written comments or request 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. It's also requested that if you have cell phones or pagers that you kindly turn them off at this time.

Feedback forms are available at the back of the room for anybody that would like to provide us with his or her comments about the meeting. I hear that we have some folks on the bridge line. Would you please introduce yourselves and we have a video hookup with you as well. It said mute on the far end.

(Telephone participants introduce themselves not audible)

CHAIR RYAN: All right, thank you very much. We appreciate your participation with us today. Are there any other participants on the bridge line?

(No audible response)

CHAIR RYAN: Without further ado, I will turn this session over to our cognizant member. It showed my initials on the agenda, but in fact, it will be Professor Hinze that will leading us in this session so without further ado, Professor Hinze.

DR. HINZE: Thank you very much, Dr. Ryan. The Committee has had a long-term interest in this issue of drift degradation at the proposed repository and has written a letter to the Commission on this topic. As I understand it, we have not had a briefing from the NRC staff for about four years on this topic. So it is appropriate that we bring ourselves up to date.

There has been significant activity at the Center and at DOE and DOE/NRC interaction on this issue as well as a report that has been issued by the Center. This issue has been specified as of medium significance and the Risk Insight Baseline Report and so this is an important topic to us. Some of the important questions that we may consider is the cover question of what is the potential risk from drift degradation. We are also interested in what are the relative role of the seismic ground motion, the thermal stress as well as the gradual weakening of the material of a rock around the opening with time.

And we are very much interested in the timing and the rate of progress of drift degradation. The risk, of course, is controlled by what eventually happens to the drip shields as well as the waste canisters and so we're interested in learning more about that. Unfortunately, DOE has decided not to support this meeting, but representatives of the Committee attended a DOE/NRC Appendix 7 meeting on this topic last month. A report has been written on that by the representatives attending that meeting and the Committee has a copy of that report.

That report explains that there are considerable differences, potential differences, between the DOE and the NRC and hopefully, we'll be hearing something -- about some of that from the staff today. In addition, we have learned that the Electric Power Research Institute has recently issued a report on drift degradation associated especially with thermal mechanical effects and stresses and we will be hearing a report on that at our next meeting and we look forward to learning what their views are as well.

Today we have joining us John Pye, an expert on rock mechanics, who is a staff member of the Nuclear Waste Technical Review Board and we thank the Board for permitted John to participate with us and we thank you, John, for coming and lending your expertise and background on this topic to us. With that, I will turn it over to whoever I should turn it over to, Jim or to Mysore Nataraja and Raj, you're becoming a familiar face to us. You were prominent here at our last meeting and we welcome you here and look forward to your comments, briefing on this topic. Thank you.

MR. NATARAJA: Good morning. I'm becoming too frequent here. I don't know whether it's good or bad but I certainly I'll be fulfilling my obligation of meeting the objectives of this presentation. I would like to first of all acknowledge my colleagues at the Center. Two prominent members of my team, Dr. Goodluck Ofoegbu, I don't think he is present there, I can't see him, and Luis -- Dr. Luis Ibarra, are the two key members who have contributed to our current understanding of this subject of drift degradation.

And what happened to the slides? So I have mentioned the names of those two people but there are many other people. I'm going to be showing you during the course of my presentation, the various disciplines and it's a fairly complex topic. There are numerous people, you know, both here as well as at the Center who have helped us over the years to crystalize our thought process on the issue of drift degradation.

I'd like to mention at the outset that we are going to present this more as what our approach is rather than comparing and contrasting with what's going on with DOE, although we are very familiar with the published reports and the contents thereof. So I'd ask for your indulgence in trying to understand this process and how we are going to review this complex topic when we receive a license application.

As you can see, in the outline, there is a fair amount of material that I would be covering today. I'm going to first explain the purpose of my briefing and then I will provide some context in the form of background material and there is a fair amount of history for this particular topic. I'm going into the significance of drift degradation process. I'll discuss some staff activities later to the license application review preparation and I'll describe what our current understanding is of the -- this particular process of drift degradation how DOE has addressed it in its documents and whatever documents that have been available to us in public domain. I would then discuss the process, as we understand it based on some of our own limited independent analysis, focused analysis, then talk about our approach, the staff approach for the review of any analysis that we might see as -- in support of DOE's claims and conclusions. I'll briefly touch upon our capability to conduct this review in an efficient and risk informed manner and finally, I'll conclude my presentation.

I'm on Slide 3 now. I have identified two broad objectives forming our presentation today. First, to present our current understanding of this process, drift degradation process and then in the context of the mechanical performance of engineered value system because we are not going to look at just the process of drift degradation in isolation. We need to see what its impact is on the mechanical performance of the primary barriers and how that might impact the overall performance of the system.

And second, I'll try and describe an approach that we have developed to review the contents of reviewing license application. Okay, now, I'm on slide 4, the background. And under this background, I have about I guess seven or eight slides and this somewhat long background discussion is actually the body of the discussion. We thought this was necessary to bring everybody to the same level of understanding so that you can better appreciate our approach for the review that we have developed.

So I will take you to where we have been in the past and where we are today and where we want to be when we receive the license application and I will be touching upon some of the past activities, really into the past, like maybe a decade or so but briefly and then I'll get into some of the recent activities and I'll mention all the disciplines involved and I'll go into some of the uncertainties and in the context of what we know as the current conceptual design of the underground facility.

I will try to make a distinction between the pre-closure aspects of this -- where this impact is pre-closure and where post-closure comes into the picture and my focus today is the post-closure part. And I'll only mention pre-closure to help you to make sure that we do understand there is an impact but we're not calling it a investment impact. I will define some terms so that we can all be on the same page when we talk about this issue of drift degradation and I'll also say that we're going to be at a fairly high level at this presentation intentionally to keep this from going over the objectives of our presentation rather than going through specific details of some of the studies that we have conducted.

Okay, I would like to mention as a part of this background something about the key technical issues. If you'll follow the family of what we used to call KTIs and the -- I want to make sure I'm on the right slide. Yeah, I'm on Slide 4 still. The -- if you remember, the key technical issues, there are a number of KTIs that had a relationship with this issue of drift degradation and its impacts on the EBS. One of them was the containment life and source term. The other one was the various activity and there was the faulting ans seismicity issues and criticality also came in the picture although in a minor fashion.

All the agreements related to this particular topic and what the staff did and what source of information was requested and how the information was supplied to us to close the agreements, they've all been documented in what we call the IRSR, the Issue Resolution Status Reports. I'm sure you're familiar with those. And most of the technical discussions related to the -- what we call drift degradation today used to take place under the RDTME, Repository Design Thermal Mechanical Effects TKI. And we did not make a distinction at that time between pre and post-closure. Both those aspects were handled under RDTME and in the `90s there were numerous discussions between NRC and DOE both formal as well as informal and most of those questions that were raised had to do with the importance of the data from the site characteristics, lab testing and modeling. And then in the 2000 and 2001 time frame, we documented all these agreements and the resolutions in the IRSRs and I think Dr. Hinze was present in one of those meetings where we came up with numerous agreements and later to the topic.

And after that, the next phase was what was called the AMRs, the Analysis and Model Reports and there was a major effort by the Department of Energy in writing a voluminous document on this issue of drift degradation in 2002/2003 time frame. And I believe it was in 2003/2004 that we -- the staff both here as well as at the Center, spent an enormous amount of time reviewing this particular AMR and we were -- in fact, we spent about two weeks concentrated time at the Department of Energy looking at this particular AMR and documenting our comments in great detail.

Because of the complex nature of this issue, we decided that we also should conduct some independent analysis if our own to develop an understanding of this process and how this process might impact the performance of the engineered barrier system so over the period of last 10, 15 years, we have probably written a dozen reports that we have developed on the various topics related to the subject. Slide 5, please.

In addition to the independent analysis

that we performed, there was -- it was clear to us that we needed to look at this particular topic in an integrated fashion. So we arranged for an internal workshop between the NRC and the Center Staff and we spent about three days on all effected ISIs, when I say ISI it would be Integrated sub-issues and we had moved from KTI to ISI in that time frame. So all the effected ISI teams participated in this particular workshop and then as a result of those discussions during those three days, we developed a common understanding and that information has been documented in a report which is publicly available, you probably have seen that. And that's the summary of current understanding of the drift degradation process.

And that workshop was held in March of 2006. And in addition to looking at the rock mechanics aspects of the thermal mechanical impacts of drift degradation, we also looked at the structural performance of the engineered barrier system. We started off with what sorts of loads might be expected and what might be the impacts of those loads on the mechanical and structural performance of drip shields and would the drip shields perform as intended. If not, what would be the impact? Would the failure --

potential failure of drip shields have an impact on the performance of the base package. So we did a lot of work and there are a number of reports related to the mechanical performance of the engineered barrier system.

And the last thing we have done is the abstraction of all this information into the performance assessment exercises that we are doing internally and in the last presentation both Chris and Britt made presentations to you and gave examples of how drift degradation is handled in the TPA.

Finally, the most recent activity in this particular issue is an informal discussion we had with the Department of Energy. This was just last month and ACNW representatives were present in that meeting where we heard some information which we had not been exposed to. So there is recent information out there and some of which has become public information now. We have just started looking at the Supplemental Environmental Impact Statement. Some of the discussions we heard in that Appendix 7 meeting in October has been summarized in the Supplemental EIS, so it has become public information and also there is a consequences, a seismic consequences document which is also now available but what I'm trying to impress upon you is that there's a fair amount of review that we have done of the publicly available documents and there is a fair amount of history of discussion and interactions between NRC and DOE on this topic dating back to more than a decade and even in the recent past, like in the last month, we have had a discussion, informal discussion with the Department where we heard the most recent information.

And I'm not going to claim that we have digested all the information that is out there because there's still quite a bit of information we have to review but we have a reasonable level of understanding of what has been done to date. Slide 6. This is just basically to give you an idea about the various disciplines involved; geology, seismology, rock mechanics, structural mechanics, mining engineer, earthquake engineering, material finds and performance assessment. And each one of these disciplines has its own unique way of dealing with uncertainty. So you have to realize that when you come to the last level of the performance assessment, you have received inputs from various disciplines which deal with uncertainties in their own unique fashion and then we have to integrate all that and look at it in the overall context of what this might mean to the performance of the engineer barrier system and the depository as a whole.

Now, let's get into Slide 7. What I will do is I will skip Slide 7. I'm trying to look at 7 and 8 and we have one screen here. It is better to go to eight but I'll use the description on the seven to look at what we have there. This is basically one of the figures that we have taken from one of the viewing documents. This is probably a picture that you have seen in many of the conceptual designs. Some details here could change, but, you know, it's not -- it's not going to really factor a discussion if the spacing between the waste packages changes a little bit, the spacing between the -- the clearance between the waste package and the drip shield increased or decreases, but this is probably current information but it's sufficient for our discussions today here.

As you can see there, you've got a 5.5 meter diameter excavation. You do not see the excavation here. What you see is the inner most skin after the excavation is complete and that is -- that consists of a perforated sheet that is part of the ground support system as designed today for the underground facility for the emplacement drifts. What you don't see here is also the radially placed bolts, the rock bolts that go radially into the rock which will be the first thing that that they place and then the perforated sheet that you see, which is a continuous sheet basically to prevent any rock pieces from falling onto the EDS or to protect the workers and also for the safe operation of the early pre-closure period. And these drifts are about 81 meters center to center which is an important piece of information for calculating the heat load, et cetera.

Now, the -- what you're seeing here is the as-built, fresh immediately after installation of the ground support system. However, you have to realize that the blue thing which is the drip shield, would be the last thing to be placed after the -- you know, after the decision is made to close the repository. Just before the closure the drip shield would be placed unless a decision is made that the requirements are being met and you don't have to do any more operations there. So between the actual construction of the initial phase of the emplacement there's going to be a long gap for the emplacement of the drip shields. So there could be improvement, changes to the design, et cetera in the field, so we have to keep that in mind.

So now let's look at the -- Slide 9 now. Yeah, okay. All right, now what I would like to explain here is a little bit of what might happen to the drip with time. Now, keep this figure in mind. I'll go to the next slide and then come back to this slide again. Let's go to -- all right, what happens when we construct a repository is you first start off with a 5.5 meter diameter hole excavated in the rock, using a TBM, which is the tunnel-boring machine. So as you know, that before you do anything to the rock, the rock is in equilibrium and it is under some kind of in-situ stresses like what we refer to as the in-situ stresses. There is a horizontal component, a vertical component.

Normally the vertical stresses are higher than horizontal stresses and there are exceptions but they are very few, but in any case, the rock -- you take the tunnel boring machine, make a hole and then you disturb the condition. As a result of this disturbance, these places are going to be redistributed and this is what we call the mechanical effects of the construction so the redistributed stresses what we call the excavation induced or the mechanical stresses, are now superimposed upon the redistributed existing stresses.

Then you go back and put in the waste and the emplacement bolt, that starts generating heat. There's going to be conduction, convection, radiation and so no and so forth. It starts heating the rock and generates the thermal stresses. That's what I call the heat or the thermal stresses and this causes a gradient and this is superimposed on all the rocks that are heated in the near vicinity of waste emplacement hole.

Then at which time there could be some random seismic events that take place of different magnitudes and they, in turn, induce what we call the seismic stresses and there's going to be a combination of mechanical of the excavation induced stresses, thermally induced stresses. On top of it you may have some transitory migratory motion and then because of that there are seismic stresses. Now, any one of these stresses by itself can cause failure in the rock. And in combination, definitely there is potential for rock failure and I would like to loosely define when I say failure we are talking about two possibilities. One is we have something called a rock strength where you take a small sample in the laboratory and measure the strength of the rock and assign that as the rock strength and that strength is not necessarily representative of what happens in the field so there is conversion from the lab to the field behavior but there is what we call an all strength, and if the rock strength is exceeded by any one of these stresses or a combination of these stresses, we term it as failure.

This does not necessarily mean that the rock will come tumbling down. It means that the rock has been heavily stressed. But that could also be because the nature of the rock, the jointed nature of the rock and discontinuities and so no and so forth there could be excess of information in the placement of the hole and then we can term that as failure either due to the strength being exceeded or due to the mix of information. That's what we loosely call a rock free nuclear. Now, let's go back to Slide 9. What you see in the first figure there is a pictorial representation of what could be an ideal condition. The perforated ground support along with the rock bores will keep the opening stable and then you have the in place waste inside and covered by a drip shield whose function is to prevent the rocks from falling onto the waste package and damaging it and also from the water dripping onto the waste package.

And with time, the roof support, the ground support system, loses it's effectiveness and then the stresses that I just explained, the combinations of those stresses will create some kind of effect, the strip condition which will start failing the rocks. As I said, the rock failure could be excessive deformation on individual rocks falling. We'll come to that in a couple of minutes. But I've shown two configurations there.

The middle one is what we call the trapezoidal type of failure, deformed shape of the emplacement drift and the last figure is like what we referred to as the chimney shape where you have the vertical elliptic final configuration at the emplacement hole as a result of degradation.

Now, the biggest thing here, we have to admit is when does this happen, how long does it take and what would be the extent of this degradation and how -- what would be the rate of this rubble accumulation around the value system. And now let's go to number 11. Okay, I just wanted to bring in a few terms here so that these are normally used in different context but what we mean by rock fall is basically individual pieces of rocks. They could be small, they could be large. In fact, they could be as small as an inch or two in size. They could be several feet in length. It could be regular shape. It could be irregular shape and it could be even pointy. You know, you could have a very sharp edged rock which has got the capability to punch into the barrier system. And that's what we mean by rock fall. We refer to the individual pieces falling in.

And when we talk about drift collapse, we're talking about massive volumes of rock, several linear feed of the emplacement cliff coming down, bringing in tons and tons of material, which could happen as a result of some very strong motions during seismic events. And the third point there, we're talking about the drift degradation which is normally -- is referred to the gradual change that takes place as a result of accumulation of rubble over a period of time, generally as a result of thermal stresses being immediate layers which are exposed to heat can spall in small layers and accumulate around and near the barrier system and they could, of course, be made worse by seismic checking and thermal dumping and on and so forth.

But the most important message here is that regardless of whether it is due to rock fall or to drift collapse or drift degradation due to thermal loading, we have rubble accumulation taking place on a continuous basis until it is prevented from happening somehow. Okay, now, let's come to Slide 12. So what's significance now. So we need to look at the significance of the drip regulation in general. That would be from the pre-closure perspective as well as for the post-closure perspective. We are going to be, as I said, focusing only on post-closure today but I just wanted to make sure that we also understand that there could be some implications during pre-closure but there are regulatory requirements both NRC regulations as well as DOE's own regulations for safe operations. So there would be ground support system and we would know the design of the ground support system as a part of the license application and the adequacy of the design itself would be determined in the context of the pre-closure safety assessment and the pre-closure performance objectives.

In any case, from the discussions that we are talking about today, it is important to note that DOE does not take any credit for the performance of the ground support system in the post-closure period. Slide 13, please. Now, Slide 13. All right, now, the -- in Slide 9 we saw the conditions, the initial condition and two possible conditions and we all know that it is not possible to precisely calculate when a shape would be in a particular form. So we have to look at a range of possibilities. And all these predictions are based on some analytical methods and numerical models which all carry their own assumptions. And the -- as a result of the rock failure, there's going to be accumulation of rubble and this accumulated rubble could actually behave like a backfill around the engineered barrier system and therefore, it could change the temperature conditions and the near-field enlightenment and all that. So it has, in fact, the -- the unit, if it does not fail, the engineered barrier system, the system mechanically, it has an impact as a result of the changes in temperature and effluent chemistry but the more important one is if it has an impact, if it structurally collapses the drip shield is what we are discussing here today as the mechanical performance. So our objective in this particular ISI at the -- when we are looking at the mechanical disruption of the engineered barrier system, that's in the context of that we are looking at the process of drift degradation our objective is to see what could be the extent of the log as a result of this accumulation of rubble and what might that do to the mechanical and structural performance of the engineered barrier system.

So it has an impact both in terms of the effluent chemistry, the temperature and the environment, what it might do to the corrosion characteristics and so on and so forth and would there be sustained loading which would impact on the creep behavior, and, if course, the impact of individuals rocks that might punch into the engineered barrier system. So the -- that is the context and that's the reason why we believe there is going to be a significance of the drift degradation process in the context of the overall performance of the engineered barrier system.

So before we exclude or include it we will have to have a technical basis to understand the process level so that we can transfer that into the abstractions in the performance assessment. Okay, now we're on Slide 14. What have we done as -- with all this understanding? I'm just trying to touch upon some of the activities.

As I mentioned earlier, we have had a long history of interactions with the Department of Energy and we have reviewed the reports that are available to us. And we have done our own independent analysis as I mentioned, to see if there is any specific aspects of the facts that we would like to focus on in our reviews. And the most important thing that we have come up with is that there is even in the limited analysis that we have done, you'll see that there is potential uncertainty both in how we take the information from the site characteristics and the data that are available to us from reviewing the reports, therefore, we have concluded that it's necessary to look at the range of parameters when we do the independent analysis and factor these into the performance assessment.

And the last bullet there on this slide talks about the topic that was discussed in the last briefing to you by performance assessment team, so again, I'm not going to discuss in detail about that today. All right, now let's look at Slides 15. Okay, based on the reviews that we have conducted to date, what we have seen is that the understanding considerations of drift regulation in their analysis suggests that the emplacement drifts would remain stable for a long time under expected mechanical and thermal conditions.

I explained to you the mechanical stresses which would result -- which are excavation induced, super-imposed on top of the existing central conditions and then on top of it you have the thermal stresses. This -- their analysis, what we have reviewed, shows that there would be some degradation but it is not significant but it would continue with the -- the drifts would essentially continue to be stable for a very long period of time under those loads. And then the -- we also have learned that their conclusions are that the drifts may collapse under strong seismic events, so they have taken into account several seismic e rings of different magnitudes which would cause different degrees of collapse of the emplacement drift as a function of time.

And then the third blip, the drip shields can potentially withstand the impacts that are due to the static loading. In other words, the accumulated static loading by itself is not sufficient to failure of the drip sheets. That's one of the things that we are seeing. However, they do account for the thinning of the material due to generalized corrosion as a function of time. And in Number 18, and continuing to summarize our understanding of DOE's conclusions, they have analysis which suggested the drip shields may collapse and mechanically interact with waste packages under strong seismic events. However, their main failure mechanism that they considered is from interaction between these packages and a stable drip shield condition. The drip shield has not collapsed. There is space and the waste packages are free to move around during strong motion, up and down, laterally and hit against each other and also interact with the supporting -- if we go back to the design picture that -- can we go back to the -- no -- yeah, this one. You can see the waste packages are resting on pedestals and then the whole thing is resting on what we call the inert and there could be banging of these packages against each other and they could have an effect of waste package jumping up and hitting against some of the sharp objects of the supports. So they have looked at the potential damage under strong seismic motion but it is under a condition where the drip sheet is in tact.

So what do we understand from our own alternate modeling scenarios? That's on Number 17. As I said, we have employed numerical models and used the DOE data and does some of our own independent interpretations of the parameters, strength parameters, analyze the strength stress characters so on and so forth. And what we have concluded, you know, in all independent studies is that the thermal stresses could be strong enough over a period of time to generate stresses and stress gradients in the exposed layers of the rock. And those stresses could be large enough to exceed the strength in which case the thin layers of rocks could fail or spall and start falling. And once that layer of rock fails and spalls, the next layer of rock gets heated up. As long as there is heat source, this process continues and the thermal degradation continues and the accumulation of rock rubble continues. And of course, there is going to be an addition of degradation due to intermittent seismic damage.

So you have this accumulated rock rubble could generate sufficient static loading on the drip shield sufficient to fail the drip sheet as designed. I have to emphasize the fact that we have looked at the current design and as I said, the design is, you know, subject to change. But the current design under several distributions of loads, you have to understand that the load distribution is pretty complex. It is not just a particular load. A load could be unsymmetrical, it could be on one side if the drip shield, on both sides. It could be different in different sections of emplacement drifts and it could be different heights of rubble accumulated at different parts. It's not going to be uniform because there are four of five categories of rocks in the repository and two major rock types like the lithophysal rocks versus the non-lithophysal rocks. The lithophysal rocks are characterized by cavities and the non-lithophysal rocks are jointed rocks which have -- are characterized by the fracture characteristics or joined characteristics.

So there's going to be a wide ranging possibly some load conditions but we have looked at several conditions under several loading conditions. We believe that the drip shields could collapse as designed and those drip shields could interact with the waste package and there could be a load transfer. In other words, a large amount of static loading is sitting on top of the drip shield, which is sitting on top of the waste packing, transferring the load through a lateral -- a sharp edge of one of those members and has a potential effect of stress concentration starting some kind of a damage process of the waste package surface. Does it mean that it's going to breach the waste package? No, I'm not saying that but it could start the process of accelerated corrosion and there could be surface damage as a matter of -- as a function of time later on.

So we also have concluded in our limited studies that we have potentials for waste package surface damage due to strong motions as a result of the entire assembly now moving up and down. Now you have waste package sitting on top of a drip shield and on top of it is accumulated static loading. So you have to look at this entire thing, up and down or laterally or whatever. Under those conditions there could be some potential damage to the surface.

All right, Number 18, there are other additional considerations in the second part of -- I already covered the first dash. Under the second dash, there is the sustained lower and the creep effects and the -- also there is a generalized condition that is also taking place with time. And the temperature impacts on the material properties themselves with time could also have an impact. These could be secondary considerations but some considerations that need to be looked at. And there's also the issue of the degradation of the pallet itself on which the waste packages are supported. All materials which are subjected to degradation as a function of time.

So now, under Slide 19, based on the review that we have conducted to date and based on the independent analyses that we have conducted to develop our own insights to this process and its potential impact on the mechanical performance and eventually on the performance of the DBS as a whole, we have started developing a review approach and in this review approach and in this review approach, basically what we would like to do is we have not looked at the entire story that the Department of Energy has put together in support of its claims or conclusions.

We have seen it in bits and pieces and hopefully in the license application we will see an integrated story and when we do that, our approach would be to check to see if DOE appropriately considers the site characteristics. When I say this, we're talking about the joints, the fractures, the voids, the material properties and how the laboratory properties have been extrapolated to the field conditions and how the strength parameters have been interpreted so on and so forth for the rocks, of the various types there.

This does not necessarily mean that we expect that every joint will be discontinued to be modeled, only to the extent that it has an impact on the overall performance. That's what we would be looking at. And we would also be looking at whether appropriate models have been used by the lithophysal and non-lithophysal type of rocks in coming up with the relation process itself and appropriate models have been used for the structural mechanics part of the analysis of the drip shield and the waste package.

And whether they looked at alternate possibilities, alternate concepts, not necessarily sticking to one particular model but look at different types of models and see whether we can come to the same conclusions based on various analysis.

And of course, we are going to look at the issue of calibration of these models that have been used with the information that is available to us in terms of the laboratory tests and as you know, there is a large scale heater test already done. So models that are used for this purpose can be used to calibrate the final events and also to validate the models to some extent, but I'm going to be extremely careful when I say validation because it's not going to be possible to validate our predictions or analysis for thousands of years. That's, you know, unreasonable and unrealistic to expect that, but having said that, we can do certain things with the available test data both the large scale as well as the lab scale to calibrate and we'll be checking to see whether the models used are calibrated appropriately and validated to the extent reasonable.

And we would also -- the most important thing we would be looking at is whether the uncertainty has been factored at various stages for the parameters and for the characters fix. And when we do that, I think we'll be in a fairly good position to either support or question the conclusions made by any analysis, like 20 years.

So what are some of the review considerations now for the process level as well as the TPA abstractions level? Based on our understanding of -- I jotted down a few important ones. At the process level, we know that there is potential for degradation both due to thermal loading and due to seismic motion. And we know that as a result of this there is going to be accumulation of rubble with time and even though we may not be able to exactly say what would be the height of load on that, we do have some idea of the ranges of possible static loading that can occur as a result of accumulation and using that loading and the input from the seismic hazard, we would be able to analyze the potential for buckling of drip shields. That's a potential failure mode of the drip shields because we have seen as designed the drip shields have the potential for buckle under static load and definitely under combination of static and laboratory motion.

And since there is that potential for buckling of the drip shield, we do know that the dip shields in some cases may not function as intended and the second thing we will know -- we also know is that there could be interaction between the drip shield and the waste package and as a result of that, there could be surface damage to waste package. So we are going to look at where these things have been analyzed and they have been abstracted into the TPA in analyzing the long term impact of the drip degradation.

The Department of Energy could exclude or include this and if the exclude, we expect them to provide a technical basis for why it was excluded and we would have a basis based on our own understanding either to agree with their finding or to ask further questions.

Now, let's look at Slide 21. In addition to the primary considerations, there are some secondary considerations. You have looked at these and we have looked at these also. For example, could the drip shields separate themselves and because of that reason allow water to seep in and drip onto the waste packages? That's one of the potential failure modes due to either -- mostly due to seismic motion or it could be due to unsymmetrical failures, one part of the drip shield failing and the other on not failing and separating the two off. And then the other consideration is of individual rock blocks. In fact, several years ago, we used to think that this was a very major issue, huge rock blocks falling and damaging the EBS. Over a period of time that concern has reduced in comparison to what might happen as a result of accumulated rubble over a period of time. But still that is something that needs to be considered because there could be some huge rocks impacting on the EBS performance but that could be limited in extent. It could be here and there rather than a continuous number of drip shields failing in the individual rock blocks.

And there is the issue of the faulting. It has been considered and considered as a very low probability thing and even if it does happen, it is supposed to be limited to that particular area where the faulting takes place and so it's going to impact a limited number of waste packages. But these are secondary considerations and we'll be looking for these in our reviews as well.

So I'd like to summarize my review

approach in Slide 22. It's an approach that has resulted from a number of years of interactions amongst ourselves, amongst various disciplines within the staff here as well as in the Center. So we do believe that there's going to be a rod degradation as a result of problem loading and also it will be made worse by intermittent seismic loading and there is going to be some sort of rubble accumulation as a result of this. And now, we have to have some estimate of what sort of load distribution we might have as a result of this rubble accumulation on top of which there could be intermittent seismic load.

And then we look at the consequence of this rubble accumulation and potential damage to the structural performance or the mechanical performance of the drip shield which leads to the drip shield not doing what it is supposed to do which is to protect the waste package from rock fall as well as from water dripping on. And then the potential load transfer, if there is a failure, is that a potential load transfer and how many cases and what might that do and is there a consequence?

And that is the last step. I'm not going to discuss that issue here because that's part of the performance assessment discussions we already heard. And as far as for that review approach and the plans that we have, what kind of review capability do we have within the staff as well as our Center support. I believe that we have extensive knowledge and experience, both field experience and analytical knowledge both from modeling, not only analytical modeling but also numerical modeling of continuous and discontinuous media. We have expertise in geologic engineering, mining engineering, structural mechanics, and also we have a number of years of combined experience in licensing reviews and hearings. So I feel confident that we have a team that is well-prepared and knowledgeable and experienced and has quite a bit of engineering judgment to apply to make sure that this review is risk informed. And I'd like to recap in Slide 24, this is basically the old saying that you can tell them what you're going to tell them, tell them, tell them what you told them.

I have some liquidity but you know, I went into a log background of the history of this going back to a couple of decades and how this issue has been discussed as an isolated piece of rock mechanics issue and then as an integrated sub-issue under the mechanical disruption of the barrier system. And I talked about the significance of drift degradation both for pre-closure and post-closure and mentioned that the particular aspects would be looked at in the context of PCSA to the extent necessary. But the -- we have to remember that DOE has not taken any credit for the performance of the ground support system in its post-closure analysis and we discussed the significance during post-closure as a result of the accumulation of rubble and we summarized current understanding of what DOE has done in its approach to considering this in its PA and we also discussed some of the highlights from our own independent analysis and based on all this, I gave you a review approach that the staff has developed so that when we do the receive the license application, we are in a good position to approach this in a rational and risk informed manner.

In summary, my last slide, we understand DOE's approach. We believe based on what we have seen, but that doesn't mean that we have seen everything, there is new information coming in as we speak and we haven't been able to review all that yet. And hopefully between now and the license application arrival we will have time to review those, especially the latest information of the seismic consequence analysis and the staff continues to perform independent limited analysis because we have questions of our own how important is this process to the overall performance of the engineered barrier system so we continue to sharpen our pencils and continue to do more analysis as needed and we have the capability, we have the modeling capability as well as the analytical capability to continue that.

The most important thing I'd like to leave as a message here is that we have a fairly flexible review approach. So whatever the Department of Energy presents, we are ready to review that with an open mind. We have no positions why we have technical basis for raising questions if there are significant differences between our understanding and the understanding that will be submitted in the license application. And with that, I think I'll conclude and take any questions and I have a number of people here to help me if I get into trouble.

DR. HINZE: Well, Dr. Nataraja, let me congratulate you on a very clear and well-organized presentation. I think your focus upon the staff review approach is very helpful to the Committee, while you also provided us with a lot of technical details and all of that is extremely helpful. It's an excellent presentation in my view.

With that, I will ask the Committee if they have any questions for Raj. Allen?

VICE CHAIR CROFF: Yes, I've got maybe a couple. If I understood what you said or at least implied, your understanding of DOE's approach is that you expect the drifts to remain intact under mechanical and thermal conditions but seismic could cause some difficulty; whereas, in your analysis, if I understood the implication, the thermal stresses you feel are more likely to cause degradation or collapse of some kind. Can you elaborate? I mean, there's, I guess, fairly apparent to me some difference in the two analyses. Can you be more specific on where the differences are, I mean, in terms of models or assumptions or whatever?

MR. NATARAJA: Well, our analysis is based on a assumption that the rocks are going to behave in a linear elastic fashion. It's a very simplified model and we have a relationship between the strength of the material and the elastic models. So this is based on the laboratory testings that the Department has performed. So we use that data to input the elastic models in our analysis which basically calculates the stresses as a function of thermal input.

So it's a very simple and straightforward analysis. You input thermal load and there's a stress characteristic based on various information and based on the models that we input to the various elements of the rock within the vicinity of the placement drift, the stresses are much higher than strength values. This is a kind of factors in geotechnical engineering and rock mechanics.

If the stress is higher than the strength, we assume failure but where failure is vaguely used many times, it may or may not mean that the rock will break up when it starts falling. In some cases, it does, in some cases may not, depending upon the joints and other things, you know, that may prevent. There may be high stress -- small areas of high stresses but there may be no score for the formation because of the way it in which it is arranged and may prevent it from happening. But there is no basis to quantify that other than to say if the stresses are greater than the strength, and if there is no support, the rock is going to spall and we can see this. In fact, we used to use this methodology in developing countries. In India and China, they use it even today. You heat a brittle rock with a lot of charcoal and wood or something for several days, remove that and then full cold because the thermal gradient develops quick. So this is not imagination or something. If there is sufficient gradient due to thermal stresses, but that's a drastic example that I'm giving.

You're not having such a drastic gradient here but you do have thermal gradient because you have this high heat source that is giving up the first layer of rock and it becomes smaller and smaller as it goes inside. So that first layer of rock when it is completely over-stressed and if the strength is exceeded and there is no support, it's logical to expect that the thermal spalling cannot go and that's what we are calling failure here. It's a slow process but it's a continuous process that goes on as long as there is a heat source which is the process of 1,000 years plus.

VICE CHAIR CROFF: Why doesn't DOE's analysis show a similar effect?

MR. NATARAJA: DOE's model is slightly different. What they have done is they described the rock as made up of polygons of different shapes and those polygons are connected by joints and they sort of manipulate the properties of those joints using some sort of a calibration process, comparing it with laboratory testing to simulate what might happen in a test and use that in the large scale.

Depending upon the properties that you have for those joints, even though the stress might be higher, it does not allow you to fail. In other words, the individual blocks cannot separate and fall down because of the assumptions they have made. So it's a slightly different analytical technique about which we have some questions about the validity of the assumptions and the conditions and so on and so forth. These are the questions that we have raised and it is a topic that is of a continuing discussion.

So you can model it using different approaches. They used this approach because they believe that they can represent the voids using these different polygons you can represent the lithophyte and then do a laboratory test and reproduce that laboratory test with some assumed stress strength characteristics of the joints and cohesion and friction characteristics and then you reproduce, try to reproduce the laboratory results and say it's now representing what happens, but whether that happens in reality or not is somewhat questionable.

Again, I'm not saying that any one particular model gives you an accurate prediction of what happens. We have to use a number of models and we have to use our judgment to see what are the various possibilities. If you use simply the analytical techniques, you can see that trapezoidal type of opening ending up with rock falling on either side or you can have an elliptic shape and all that. Again, you have to make assumptions and these are theoretical calculations which cannot be verified immediately. It will take place over a period of time. And there is also the nature itself has got its joints and characteristics in such a way which may prevent some failures from occurring. So, they will make some analysis and they will make some conclusions and we have made some analysis and we have made some conclusions, but again, we are not going to say that we are going to compare our results with their results and then say that they're wrong, they're right or anything like that. All we are going to say is, okay, have we factored all the uncertainties of the characteristics into the analysis and have we come up with a conclusion which represents a range of possibilities based on the range of possibilities of characteristics and material properties and the ultimate conceptual models.

VICE CHAIR CROFF: Okay, the second question, a couple of slides you mentioned, I think this is under DOE's approach, strong seismic events can cause failure. How strong? I mean, it is --

MR. NATARAJA: 10^{-5} probably would be the exceedance and beyond they have collapses. Definitely 10^{-6} it's total collapse. 10^{-5} it starts happening, so they are pretty large acceleration values and large velocity values.

VICE CHAIR CROFF: Okay, but fairly improbable.

MR. NATARAJA: Well, I don't know how to say improbable. We have a hazard curve the goes up to 10^{-8} and 10^{-4} and beyond is based on some extrapolation. If I get into trouble here, I have friends here to help me out with that, but they looked at the accelerations from the hazard curve and the velocities corresponding to those accelerations from the hazard code and did the -- they've done the analysis and 10^{-5} and beyond they expect large collapses to occur but they occur very infrequently but you know, that is factored into the analysis.

VICE CHAIR CROFF: Okay, thank you.

DR. HINZE: Dr. Ryan?

CHAIRMAN RYAN: Raj, thanks for the presentation. It's -- you know, I guess one question on certainty analysis. I think about, you know, a PRA where you've got a whole bunch of processes and you treat them typically statistically or probabilistically. Have you done that sort of analysis or are you really relying on what I take away from your talk as more deterministic and judgment informed modules?

MR. NATARAJA: We would do parameter studies but I don't know whether that would be the same as what you're talking about but we --

CHAIRMAN RYAN: I'm talking about where you have a bunch of inputs that you vary somehow with a statistical model or some kind of a function that's appropriate for those parameters and then do a -- you know, a multiple kind of analysis where you get a range of results.

MR. NATARAJA: It's done more at the PA level than at the process level. It's more the abstraction of the parameters. There we have a range of parameters and distributions which have input into the Performance Assessment models.

CHAIRMAN RYAN: So at the end of the day how likely is it a package fails? That's what I'm reaching for.

MR. NATARAJA: Right, that is done in the PA and I don't know if anybody wants to help me.

CHAIRMAN RYAN: Are all the parameters from your modeling structure analyzed in the PA, probabilistically? Is that right? Tim, can you help me with that?

MR. McCARTIN: Well, you're correct that there's a range of effects in the performance assessment case in that -- I mean, are you getting at are there a lot of realizations where you have seismic induced failures of the waste package?

CHAIRMAN RYAN: Yeah, that's what I meant.

MR. McCARTIN: And I think that -- you know, and I'll say my memory is you know, if you had an average, you're looking at around 10 percent of the waste packages fail due to seismic drift collapse scenario, on that order.

CHAIRMAN RYAN: And again, I'm way out of my element technically but what I'm trying to get at here is that your judgmental abstractions, which I don't challenge on their merit at all, how do you get from that kind of a professional judgment circumstance to where you've got you know, sort of a probabilistic treatment of that in the TPA?

MR. NATARAJA: That's where we have the range of possibilities of the height of accumulated rubble. So with the varying heights of accumulated rubble possible and also different types of the solutions has a different impact on the structural mechanics and the structural collapse of the drip shield. And if the drip shield fails, then there is an interaction between the drip shield and the waste package.

CHAIRMAN RYAN: Also that's one of the possible outcomes.

MR. NATARAJA: Right.

CHAIRMAN RYAN: You're capturing all those ranges of possibilities in the assessment.

MR. McCARTIN: Correct, the 10 percent is due to in some cases you know, the extent of the collapses is smaller than other cases and when it happens, et cetera. There's a lot of factors that come into play.

MR. RUBINSTONE: One answer might be we're not explicitly in the TPA modeling each drift collapsing per se. What we're capturing, as Raj said, by looking at ranges of possible rubble accumulation and metric configurations of the tape.

CHAIRMAN RYAN: So when you do a TPA run, you're capturing one version of that.

MR. RUBINSTONE: Right, so you have to have a distribution of rubble to sample that in TPA.

CHAIRMAN RYAN: And that's what you're doing?

MR. RUBINSTONE: I think that's fair to say.

CHAIRMAN RYAN: Okay.

MR. McCARTIN: Yeah, and dependent also obviously, a particular run would have certain seismic events.

CHAIRMAN RYAN: Right and again, you're going through many, many, many realizations and over that hopefully sample the distributions appropriately and check well, that what you do anyway and so forth.

MR. McCARTIN: Right, right.

CHAIRMAN RYAN: So okay, thanks. But, you know, again, the engineering aspects you're talking about are fascinating to me but I just want to make sure that we're not setting a deterministic result from that module and then having that go in deterministically in the TPA. It sounds like we are not.

MR. McCARTIN: Correct, when I was saying on the order of 10 percent was an average over all the realizations, all the runs, what do you see.

CHAIRMAN RYAN: And that could range from some --

MR. McCARTIN: Some are zero, some are large -- you know, it's a spectrum.

CHAIRMAN RYAN: Fair enough. Thank you. Thanks, that answers my question.

DR. HINZE: Dr. Weiner?

DR. WEINER: First of all, I also want to thank you for a very thorough presentation and I want to point out the obvious, I'm certainly not an expert in this area. This is way outside of my expertise but so you can consider my questions in that context. If

I ask you something dumb, just tell me.

Your Slide 19, you used the words "appropriately considering site characteristics and reasonably calibrated back validated models". Considering the fact that your model is completely different from that of the Department of Energy, and that the views that NRC staff and the Center have on drift degradation are almost diametrically opposed to those of the Department of Energy, what do you really mean by the words "appropriately"? How are you going to make that judgment?

MR. NATARAJA: Well, these words are coming from basically our overall look. We have a review approach so these are basically, I mean, we may not have a precise definition of what appropriately is but when a rock mechanic, a geological engineer or a mining engineering depending upon the field, when he or she looks at an analysis, will be able to determine whether it is appropriate or not because we are all equally knowledgeable in the state of the art and what can be done, what cannot be done as far as the modeling approach is concerned.

And then when I say appropriately, first we go back to the level of site characterization itself. It starts with dividing the entire block into two major blocks which is one is the lithophysal, the other one is the non-lithophysal. Lithophysal is about 85 percent. Non-lithophysal is only about 15. So we would be more interested in the dominating 85 percent in terms of overall performance, not that we are going to ignore the 15. And then the type of characterization for the 85 percent is different because it's the dikes that control the behavior of the rocks. And then the jointed, the factor within is a different kind of characterization, so we are going to -- our experts look at the site characterization and the results.

For example, all the mapping that was done in the ESF and how that information was translated into the models. Kevin Smart spent two weeks along with us looking at this kind of information. So that's where we determine whether the site characteristics have been appropriately factored into the models.

And then the laboratory tests and the interpretations going from the small scale unconfined compression to table-top to the in-situ inter-test. How the data has been interpreted and used in stress strength characteristics and parameters. The same thing comes in the materials aspects. We have -- of course we looked at the creep and corrosion aspects and there were things which are factored into the analysis. So at every stage, that's why I said, I gave the list of the disciplines involved and each discipline has its own unique way and uncertainty and that's what we do. We look at how this uncertainty has been factored and once they use all the data, give it sufficient weight and then use a representative distribution, that's appropriate in my mind.

So I don't know that I can precisely say with some criteria, saying that if I check one, two, three, four inappropriately, I don't think it will be possible. We need to look at the entire, the integrated claim of the safety case that we make. Supposing they have such a wonderful design for the drip shield which never fails under any expected conditions. We are worrying way too much about some of the details. So that's -- the real why we're varying is we did some independent analysis, how the drip shields are potentially could collapse under some conditions.

Supposing we found out at that point that neither the seismic nor the static loading would do anything to the drip shields, then we're done because drip shields will do what they're supposed to do and protect the waste packages and rock fall and water dripping and so on and so forth. So the question of the waste package damage becomes less and less critical.

But if that's not the case -- now, we have to look at what happens as a result of the accumulated rock, have they factored that into their near-field chemistry and the water flow and temperature effects and so on and so forth? I think by the combined intelligence of the review team, they would be able to make a determination whether it's appropriate or not.

DR. WEINER: Thanks. That's very helpful that illumination. Are there any natural analogues for the lithophysal drift degradation that you are -- that you're studying? I mean, there are caves all over the place. Clearly you don't have any analogues for drip shields and waste packages. But you do have — there are caves everywhere. What has been observed?

MR. NATARAJA: We don't have thermal load is the problem. If it was just simply the integral conditions and super-position of laboratory we do have plenty of examples and in fact, there are studies which document the cases where the case of the underground facilities, tunnels, et cetera, failed under certain (inaudible), but you know, you don't have analogue for heat. So it's extremely difficult to come up with an analogue that is really meaningful and representative of what happens at the risk replacement form. The nearest example right now is the in-situ heater test. That may or may not be in the right one but at least it is in the tough (phonetic) and it is heated and we have data to look at. The least we can do is use those models to see whether our models similarly -- what is happening in the near -- the vicinity of the in-situ test. We have that.

There's the heater which is the dummy for the waste canisters and we have the emplacement head and that's something that is not done yet. A real composite of the model predictions to the extent of degradation because unfortunately they have different kinds of supports. It is not unsupported. We've got steam, we've got all kinds of things and there probably may be some locations without any support, I'm not sure, with some mesh and you can see grass coming down there.

So we have evidence to the fact that if you heat up the rock it is going to spall but the question is, how much? What is the extent of this degradation and how long does it continue, what are the final -- when does it stop and what will be the height of the rubble? That is an extremely difficult question to answer and I don't think any model will give you that, the correct answer and you shouldn't expect it.

So we should definitely base our judgment on possible means. Look at what happens and if that doesn't have a major factor and consequence, then you're okay. That's the approach we're taking.

DR. WEINER: But you certainly -- what I take it from your response is that you will incorporate the results that you have had from the heater test because those heater tests have been going on for some time.

MR. NATARAJA: Yeah, we've asked DOE this question and --

MR. RUBINSTONE: One of the problems with the heater test is they'd shut it off and they did an initial entry into the tunnel, but then they've suspended most of the site operations, so they're not doing the full decommissioning of the heater test. There's cameras in there now to observe it but they haven't pulled out the heaters, they haven't taken down the mesh and looked at how much material has fallen.

MR. COLEMAN: You need to identify yourself.

MR. RUBINSTONE: I'm sorry, Jim Rubinstone, NRC.

DR. WEINER: But what I understand from what Raj is saying, you can observe a certain amount of rock fall starting to take place.

MR. RUBINSTONE: Yeah, the fall is the best you can do at this point because they haven't done the full decommissioning of the tunnel there.

MR. NATARAJA: And that's only in a small limited exposure. You know, you have that entire thing to support it, so it's not exactly --

DR. WEINER: But I suppose --

MR. RUBINSTONE: It's the best we can get.

DR. WEINER: I suppose real data is always better than just suppositions that you put in your model. Could you go to your Slide 9, the one with the figures with the rocks? Yeah, that one. Okay, let's suppose one of these scenarios, one of these -- yeah, the one with all the rocks falling and sparking things.

Let's suppose that one of these two scenarios on the right does take place. Since the end product of all of this is the movement of radionuclides to the accessible environment, if that were to happen, wouldn't you get dust along with rock fall of course. Wouldn't you get retardation of movement of radionuclides by a variety of mechanisms, absorption onto rock surfaces and so absorption in the dust and so on? Would that have any effect of retarding the motion of radionuclides?

MR. NATARAJA: I think I'm going to ask for help here. This is way beyond my comprehension, but I'm pretty sure that if -- there is a way to handle that in our analysis. Tim, do you want to --

MR. McCARTIN: I mean, well, certainly if water and radionuclides are moving around rock, I mean, there is a potential for some retardation. I mean, if it's rubble and you're moving around the rock, there wouldn't -- it would be more like a fracture movement and there might not be as much retardation. The dust, I guess there's a possibility for some there. In our TPA code certainly, we do have the invert properties and we do account for the potential for retardation through the invert. One could, you know, possibly enhance the retardation, the invert, if one felt the properties of the rubble were enough that it would be -- enhance that in a significant way.

I mean, the biggest problem -- if it's true like sort of a like a gravely or rubbley thing, it would be -- the water would most likely -- well, it's always hard to say but the potential would be for it to move around the rock rather than through it and more like a fracture flow than a porous media flow, but you know, there's certainly -- it is a possibility that there's some retardation.

DR. WEINER: But you're looking at incorporation of this into any performance assessment that is done. In other words, this has been -- is being considered in performance assessment. You know, volcanic tuff when it breaks up does produce a lot of fairly fine large surface area particles.

MR. McCARTIN: Right, well, I don't want

to mislead you that it's -- I'm saying that we have an ability to consider retardation in the invert if there was a potential for a lot of retardation through the rubble then I think, yes, we could incorporate in the code, but I -- there really -- right now we've looked at some of the potential for that rubble more to effect how water might get to the package rather than retardation of radionuclides away but there is a recognition that, yes, if you have a collapse drip there's rubble and how might that effect some of the processes. So it's an interesting suggestion, retardation that it's worth putting in the mix.

DR. WEINER: Thank you very much for that, Tim. I have one other question. To what extent have you and to what extent can you determine that DOE has included references from the peer reviewed literature in the modeling of drift degradation? In other words, the reference you refer to in your slides are Center reports but has there been any general literature search or general peer reviewed backup of your model, of the DOE's model, as far as you know?

MR. NATARAJA: Yes, our models are standard models which are used by all the people in the field. It's not -- nothing is generated for this purpose.

DR. WEINER: Thank you.

MR. NATARAJA: And Center staff who have done the work have published numerous papers in referred journals and so they are standard what we are using as well as what DOE is using. They're all standard models, state of the art and they have experts in that field. In fact, the people who are doing the modeling for DOE are the people who have developed a number of models in this field, people from ITASCA (phonetic) if you're familiar with that.

They're at the cutting edge of the American modeling for rock mechanics and mining. So they are being in use and they're continuously being tested. So I don't have any question about the model itself but a model does what you tell the model to do, depending upon what you import. You know, you might get some crazy results some times. So you -- that's where we have to be able to review them carefully. I'm sure they have been internal experts reviewing that. It's not like some information here is being sent out with the actual review or anything like that.

DR. WEINER: Thank you. That's it.

DR. HINZE: Dr. Clarke?

DR. CLARKE: I do have one question and it's a question that's probably better addressed to the DOE but you're here and I'm interested in your response. As I listen to the discussion on the different kinds of failures that could result, in inter-relationships between the two, I found myself thinking about failure in general and also wondering if there's a role for performance confirmation here. And what I mean by that is organizing the analysis and I don't know what's the best way to do it, event trees or logic diagrams or some analytical framework where you could possibly identify precursors to failure, things that might suggest that they be monitored during a time the repository is open.

MR. NATARAJA: I'm positive that performance confirmation has taken into account that program. I don't remember all the details but --

DR. CLARKE: So this is being --

MR. NATARAJA: Drift stability is one of the things there which comes in. But through the precursor period this is continuously maintained, at least that's the claim. Now we can have safe pre-closure operations, the government support is maintained for that period.

DR. CLARKE: I understand. Nevertheless, things might be observed that could be useful to know.

MR. NATARAJA: I'm positive there will be sections of the facility which will be dedicated to observing the behavior of the underground -- you know, holes.

MR. RUBINSTONE: I don't know if this will make it in the DOE's final performance confirmation plan but an earlier version did I believe call for having one drip loaded early and little hotter than average and have strain meters and such monitoring the rock around it. That was in an early version. Like I said, we'll see what we get with the LA in terms of the PC plan, but I think they're thinking the same way that you were with that comment.

DR. CLARKE: Very good, thank you.

DR. HINZE: Thank you, Jim. John Pye?

MR. PYE: Yes, an excellent presentation, Raj.

MR. NATARAJA: Thank you.

MR. PYE: Do you think several mechanical models, numerical models capture all the processes that lead to drift degradation?

MR. NATARAJA: When you say all the

processes, it's very difficult for me to say yes, but if you would give me three or four of the bigger ones then I'll say yes or no.

MR. PYE: Well, you threw out some empirical terms, rubbling, spalling. There are other terms we use in mining and geotechnical engineering that do lead to different modes of drift degradation. Do you think the models that DOE and the NRC are using capture all those processes?

MR. NATARAJA: I would say there is a serious attempt to capture all the processes. I mean, the model doesn't distinguish between rubbling, you know, displacing or breaking up and all that. The only thing you can get in the model is you have a stress/strength relationship and the value. You input certain load which translates itself into stress and the composite to whatever you assign as strength based on the stress/strength curve, and you define failure. If you define failure as exceeding the strength, that's serves our intent here. But in the DOE's case, they have a slightly different arrangement where they have these polygons which are attached to each other and they are free to fall if they can detach themselves from the main mass and that happens based on the friction and the cohesion characteristics of the joints, the interfacial connections between one polygon and the other.

So again, that's another way of defining the strength being exceeded. Not only the strength instead of the main element, you know the strength of the joint. So the strength of the joint is exceeded, that polygon, if it's geometrically possible to detach itself, it will detach itself. But that model chose that. So if you can try various possible shapes and sizes of these polygons, you can probably look at the various things like the spalling, rubbling, et cetera, et cetera.

MR. PYE: All right, you talk about thermal hydrological process ultimately effecting the end drift environment but you sort of separate thermal mechanical and see thermal hydrological as a consequence. If you put thermal hydrological and mechanical together, for example, the project asserts that there's capillary diversion. Well, if there's capillary diversion, there's going to be water close to the drift profile. Do you see that as having an impact on drift stability or drift degradation?

MR. NATARAJA: I probably -- I don't know if I answered the question not having done an analysis of that kind but I think it presents -- you're talking about massive amounts of water flow or just some --

MR. PYE: Not massive, just joints that are close to saturation.

MR. NATARAJA: Well, if the joints are saturated with water, definitely it's going to reduce the friction. So I expect under those conditions, it would be easier for those different polygons to detach themselves from the main body and fall off. But again, I'm speculating here. I don't really -- it is a very complicated problem. If you want a model, thermal mechanical hydrological all together, it's extremely difficult to.

MR. PYE: Okay, picking up some of the earlier comments, it seems the conceptually that you have quite a different model from DOE. You, essentially, at this point using the same data sets although you're going to re-investigate those. My question is, what value do parametric sensitivity studies provide you with if you're going to compare them with DOE if conceptually, you have different models? When you talk about uncertainty, you're just talking about parametric uncertainty.

MR. NATARAJA: Well, first of all, we have to agree on whether the model itself is applicable to the situation that is being analyzed. That's the first question. Now, if you don't agree with the model itself, then there's no point in looking at uncertainty.

MR. PYE: Oh, I agree.

MR. NATARAJA: So I'm making the assumption here that this model will be acceptable because it is the state of the art model being developed by experts in the field unless we find some fundamental flaw in it. I haven't seen any such thing. I'd probably leave it to the other experts in the modeling area to make that comment, but having said that, the -- there's always going to be questions about the boundary conditions, the actual values that you use for the parameter, such as the cohesion and friction and the strength of the material itself. Those things can be reviewed and questioned if we don't agree with them.

MR. PYE: Okay, you talked about your staff's approach. It's a multi-discipline approach and it needs to be integrated. You touched on thermal hydrological issues in the context of these environments may cause corrosion of the waste package and drift shield. If I look at Slide 6, where will the issue of in-drift environment be addressed? Which discipline will address those conditions?

MR. NATARAJA: The material science people will provide us the inputs for the thinning of the metal with time.

MR. PYE: In corrosion issues there are always two aspects. You ask the corrosion engineer how long will the structure with this material, this configuration, last and he will ask what's the environment? So it's on that issue, who is going to tell you what the environment is? You've got to debris that. You're going to have a film of conductivity. You're going to have conditions with respect to heat transfer in those piles of debris. Where will that information come from and how will it be integrated?

MR. NATARAJA: We have one group who we call Murphy (phonetic) chemistry people. That's the group responsible for some of the things that you mentioned. And we also have a hydrology group which -- thermal hydrology that are models at the Center that have been used to calculate the very things that you just mentioned. So we have integration between -- I didn't specifically mention thermal hydrology as a separate group but there are activities going on looking at just those kinds of things.

MR. PYE: All right, thank you.

DR. HINZE: That's it? Just a few questions, Raj. The assumption that the ground support, the stainless steel ground supports will disappear at pre-closure, at end of pre-closure, how conservative is this and is this possible to be handled in a probabilistic manner in the assessment rather than in a deterministic that's just gone?

MR. NATARAJA: Well, it is definitely conservative to assume that it just vanishes at the end of pre-closure period. It doesn't happen. It's not like T equals 100, it just vanishes, but I don't know wether we have a rational way of calculating the effectiveness of -- this is meant to be a pre-closure support system and it is designed with that life in mind. It's not designed to withstand for hundreds and hundreds of years. Probably 100 years is what they would use as the base case, but I'm not sure.

But it is conservative in the sense that there is going to be some drift support in some parts.

But I think for your point of view, I think it is reasonable to assume that it is not there. I mean, if you use that, I don't think it is overly conservative but I can't quantify --

DR. HINZE: Are there tests and evaluation and laboratory work done to support this, the fact that it will essentially for the end repository?

MR. NATARAJA: If you take credit for that, then we will have a need to do that kind of analysis. If they don't I don't see any -- I mean, it's -- it is a conservative assumption but how conservative it is and, you know, what does it do to the overall performance, I don't think I can quantify that.

MR. RUBINSTONE: This is DOE's choice to not take credit for that ground support serving any purpose after -- or during the post-closure analysis. If they decide they want to take credit and they have a basis for it, we'll evaluate it. It's not our position to tell them to take credit for things that they don't think they should take credit for.

DR. HINZE: And you have not evaluated it at this point. Let me ask about setback distances. We all know that there are quite extensive fracture zones associated with some portions of some faults. And as I understand it, there is a certain setback distance that DOE will assess to their -- to the repository. Are you -- do you have any feeling for how large the setback distances should be around any fault, around any specific fault? How are you handling the analysis of the setback distances?

MR. NATARAJA: I'll have to request some help here but all I can say here is that if there is a fault, they're going to avoid that. That's the first thing they're going to do. You know, they're not going to emplace waste knowing full well there is.

DR. HINZE: Right, but some of those extend for meters.

MR. NATARAJA: Right, but they have a criterion for these circumstances. If there is somebody from geology or seismology that wants to answer that question, there is a subtract distance that they have assigned.

MR. IBRAHIM: Earlier we -- Marcus Ibrahim. We have a setback 15 meters from the fault. That's what we mentioned in one of the reports.

DR. HINZE: And that's regardless of what fracturing might be found?

MR. IBRAHIM: It depends what you call fracture and what you call fault. So fracture is completely different issue than faulting. And when we talk about faulting that's a major displacement along the fault which can cause an eruption to the waste package.

DR. HINZE: Ten meters?

MR. IBRAHIM: Fifteen meters.

DR. HINZE: Fifteen? Going back to some of the previous questions regarding analogues, the drift scale heater test is potentially a very important test to this entire problem of what -- of which model is correct and which parameters are being evaluated and I understand that you've not incorporated that and I didn't understand that until Jim explained that, that this is because of the fact that it has not been totally decommissioned.

MR. NATARAJA: That's right.

DR. HINZE: You know, looking up there, you see those slabs are pretty thin but we don't -- we haven't looked at them all. What -- are we going to have that information and if so, when are we going to have that information and will you incorporate it to test your models at that point?

MR. NATARAJA: I don't know that answer to when it is going to be available and if it is going to be available but we have raised the issue of they have calibrated their models using results of the field test that they have collected. I don't think that we are going to subject ourselves to that condition of -- it's DOE's responsibility to calibrate their models to the extent they can with the available information.

And we have raised that question. As far as our model is concerned, our model is a much simplified model compared to theirs and our model shows there's going to be spalling and whatever leaking we can see there, we see spalling. To every extent we have some calibration of our own model but I'm not going to take credit for that and say that, you know --

DR. HINZE: It would seem that validation of the modeling that you're doing should be of pretty high significance to the NRC.

MR. HILL: Britt Hill, NRC staff. I'd like to provide a clarifying comment on this.

DR. HINZE: All right, Britt.

MR. HILL: There are some limitations to the analogy from the heater test. First, the total was mined for the heater test using Alpine mining techniques, so it's not quite the same surface configuration, if you will, as what we would potentially be seeing for the emplacement drifts at Yucca Mountain. There also is a fairly large stainless -- or a large support mesh sitting on the roof of the heater test that is keeping any of the spalling rock up in contact or very close to contact with the ceiling itself. It's providing insulating barrier and effecting the thermal gradient that you would expect to see under a condition where all the rock rubble was allowed to fall down.

So it does provide some useful insights on the model or any potential model for drift degradation, but it doesn't provide a good basis for model validation. At best, we're getting some avenues of support for some of the processes that were being captured.

DR. HINZE: That's helpful, Britt. Let me ask you then Britt, do we know that properties of the added where the drift scale, the heater tests are being conducted? Do we know those in detail so we can relate to physical properties through the extent of the spalling?

MR. NATARAJA: Yeah, I think that failure has been entirely characterized and the properties so that --

DR. HINZE: In detail so that that can be related.

MR. HILL: But let's be clear though. The models are not using a parameterization that explicitly represents a specific set of rock conditions. You're not looking at this exact fracture density or fracture orientation. You're abstracting that into a rock characteristic. So I don't want to over-play the -- any individual segment of a drift may behave very differently from the corresponding segment because of these sorts of variations in rock characteristic.

MR. RUBINSTONE: Another thing to remember is that the models that the center has done and that DOE has done are two-dimensional models on a cross-section of a drift and in the repository drifts, those will be bored out and will be relatively uniform with slight variations in the rock height alone along the strike of a drift. The drift scale heater test, I think has much more heterogeneity in the types of support that was put in and because of the tendency of the outlying mine, so that the two-dimensional models may be less representative of that alcove than they would be of a drift.

DR. HINZE: Speaking about analogues, in terms of the effect of seismic, of ground motion on drift degradation, as I recall I believe the 1992 Little Skull Mountain earthquake which was in the upper crust was right underneath the X tunnel which was cut into basalt, which of course, has not -- which is more akin to the non-lithophysals rocks, but I recall going into that and shortly after the earthquake occurred, and could see no evidence of degradation of the drift of the X tunnel from the seismic activity.

Have you look at other analogues that might be useful in terms of understanding the effect of seismic ground motion?

MR. NATARAJA: We have not looked at the particular analogue, of any other analogue other than look at the potential review. In the literature we have got, somebody took the trouble (inaudible) somebody had not ventured a guess. Number one, papers have come in after that. Basically, what they've done is they've looked at number of mines, number of tunnels, number of underground facilities. They have documented what happened, did they fail, what was the extent of failure, small amount of failure, large amount of failure, intermediate, like that. They have got a graph. I think it's Professor Downing and somebody else, Jude or someone.

Anyway, that is the compiled history of number of facilities and number of different drop types. That is what is generally used as an indication of under what acceleration you might expect failure. So there are some threshold values after which you expect failure to take place, but then you don't know the extent, how to take that average thing that is based on number of rock types and number of facilities, built using different techniques and all that. When you use that, it gives you some idea but you cannot exactly say, "This is what happens." But I think we have some indication of damage, under a given vibratory motion especially when it comes to 10^{-5} and beyond.

DR. HINZE: Let me ask -- our time is very short here, but let me ask one final question and you talked about your workshop at the Center where all of the disciplines would get together to discuss their impact upon the ISIs and so forth. Can you tell me how the coupling of drift degradation with seepage and with igneous activity were brought together and folded in for information to be put into the total performance assessment.

MR. NATARAJA: Seepage, yeah, definitely we had participation by people from thermal hydrology group and in fact, they were represented in every one of our discussions, not only in that workshop but also in our interactions with DOE. So they've been following -- I think what we're doing is first we are looking at is there a potential for degradation and if there is degradation, is there an impact on mechanical performance? And is there an impact on the flow into the drift.

DR. HINZE: How has that been incorporated into the DPA? Have you given the parameters and so forth, that will permit --

MR. NATARAJA: I think there is a section which deals with the opening shapes and the in-flow. I think Tim probably might be the better person to answer that question.

MR. McCARTIN: In a fairly abstracted manner, there are certain parameters to account for how infiltration eventually ends up as seepage and then ends up getting into the waste package and there was some looking at say what seepage through rubble piles might do in terms of getting into a waste package. And so it just -- there's a -- there is some flow parameters, yes.

DR. HINZE: How about the igneous activity?

MR. McCARTIN: Igneous activity, we haven't done much with respect to altering infiltration into say damaged waste packages for the intrusion. The focus has primarily been in the extrusive case where just because of the nature of the probabilities and the releases, there's just -- in the way it's modeled in TPA, the extrusive tends to be a much more significant release.

DR. HINZE: But have you incorporated any of the drift degradation into the intrusive scenarios?

MR. McCARTIN: Well, one can do it -- there's parameters to adjust that but have we done explicit modeling to say okay, after a certain amount of time, if intrusion occurred, and there was drift collapse, it wouldn't occur, we haven't been -- we haven't done the explicit modeling. It could be done, though.

DR. HINZE: I think -- is the flexibility built into the TPA to provide the because as I understand it, you have --

MR. McCARTIN: For the smart user, I would say. For the -- in that there isn't -- there isn't --

DR. HINZE: Excuse me, but the TPA is being distributed to the world.

MR. McCARTIN: Right, with a user's manual that explains all the things you can and can't do. There is -- there's not a direct coupling of say drift collapse which -- and if you had an igneous intrusion, and now the drift collapse would change the nature of the intrusion, there is not an explicit coupling in the TPA code for that. But you could do it with the parameters that are in there for the intrusion case. But you would have to look at the inputs and think through the problem how you want to represent it and you could represent it.

DR. HINZE: Dr. Hill would like to make a comment.

DR. HILL: Thank you, Dr. Hinze, Britt Hill, NRC staff. I just want to stress that the TPA code is a review tool for staff and that we have a range of alternative conceptual models that have to be considered for igneous activity. As you've seen in Raj's presentation, the information that our staff is using would show that drift degradation may occur early during the post-closure performance. In that case, if you wanted to use the NRC's TPA tool, you would adjust the parameter that's used for the igneous scenario for intrusive to show a limited range of waste package interactions with magma.

However from what we've seen from the available DOE information, their models would have the drift staying open for potentially a very long period of time. So we need that flexibility to have both an adjusted parameter for limited interactions as well as no interactions with a collapsed or partially collapsed drifts.

DR. HINZE: Thank you very much. We -- it is now one minute to 12:00 if I read that clock right.

CHAIRMAN RYAN: No, it's one minute after 12:00.

DR. HINZE: I read it the other way.

(Laughter)

DR. HINZE: Are there any other questions? John?

MR. PYE: Empirical design methods, Cal Carzigi (phonetic) in the 20s and 30s came up with some empirical estimates of loosening load about tunnel structures. Did you take those into account? Did you compare them with your modeling estimates?

MR. NATARAJA: Yes, we did. Actually, in calculating the static loading and estimating the height of the rubble, and translating that into a load, you might have seen in both the DOE's as well as in our report, there are two curves, and there are a number of points from the analytical models. One of those curves represents the design view. So we have taken that into account in the empirical calculations.

MR. PYE: Well, in hard rock conditions as opposed to non-cohesive material, near surface tunnel structures, what are we looking at, 1.5 or 2B, the width of the excavation in terms of extent or where are your models putting the extent of loosening, 2B, 3B or --

MR. NATARAJA: I would have to request -- who would like to answer that question but I think what we have looked at is the two cases of one trapezoidal shape, other one is a chimney elliptic shape and I think vertical elliptic shape, if you look at the h-max here, I don't have the actual number of it, it at least is -- if this is clear it is at least three times the diameter or something but I'm not sure whether it is to scale. Maybe Goodluck wants to elaborate on that.

DR. HINZE: Can we make is extremely brief?

MR. OFOEBU: Yes, Raj, the difference in the shape of the collapsed (inaudible) you end up making with the tunnel the largest laterally and vertically and that is you try (inaudible). Then the other option of course, is a tunnel that grows like a chimney but it (inaudible) and that's you know, we got (inaudible).

DR. HINZE: Thank you very much. I think we're going to have to cut it off at that point. Since there are no other indications that there is a burning question, I will pass it off to you, Dr. Ryan and four minutes early?

CHAIRMAN RYAN: No, in geologic space perhaps. Raj, thank you, it's been an interesting discussion and presentation. So we really appreciate your time this morning and thank you very much and with that, we'll adjourn the morning session and reconvene for our letter writing at 1:00 o'clock.

(Whereupon, at 12:04 p.m. the above-entitled matter recessed, to reconvene at 1:00 p.m. the same day.)