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NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON NUCLEAR WASTE (ACNW)

146TH MEETING

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WEDNESDAY,

OCTOBER 22, 2003

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ROCKVILLE, MARYLAND

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The meeting convened in Conference Room T-2B3 of the Nuclear Regulatory Commission, 2 White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., B. John Garrick, Chairman, presiding.

MEMBERS PRESENT:

B. JOHN GARRICK	Chairman, ACNW
MICHAEL T. RYAN	Vice Chairman, ACNW
GEORGE M. HORNBERGER	ACNW
RUTH F. WEINER	ACNW

ACNW STAFF PRESENT:

JOHN T. LARKINS	Executive Director, ACRS/ACNW, Designated Federal Official
SHER BAHADUR	Associate Director, ACRS/ACNW
NEIL M. COLEMAN	ACNW
HOWARD J. LARSON	Special Assistant, ACRS/ACNW
MICHAEL LEE	ACNW
RICHARD K. MAJOR	ACNW

ALSO PRESENT:

HANS ARLT	NMSS/DWM/HLWB
ROLAND BENKE	NMSS
TAMARA BLOOMER	NMSS/HLWB
MARK P. BOARD	BSC
JOHN BRADBURG	DWM
ANDY CAMPBELL	NRC/NMSS/DWM/PA
ASADUL H. CHOWDHURY	CNWRA
KEITH COMPTON	NRC/NMSS/DWM/PA
BISWAJIT DASGUPTA	CNWRA
DIANA DIAZ	NRC/NMSS/DWM/PA
NICK DINUNZIO	DOE
DAVID ESH	NMSS/DWM/EPAB
CHRIS GROSSMAN	NMSS/DWM
DOUG GUTE	CNWRA
LAHIF HAMDON	NMSS/DWM

ALSO PRESENT:

CAROL HANLON	DOE
GREG HATCHEY	NMSS/DWM/HLWB
NORMAN HENDERSON	Bechtel SAIC Company
BANAD JAGANNATH	NMSS/DWM/HLWB
ROBERT K. JOHNSON	NMSS/DWM/EPAB/PA
PHILIP JUSTUS	NMSS/WM/HLW
JOHN KESSLER	EPRI
YONG S. KIM	NRR/DE/EMEB
TIM KOBETZ	NMSS/DWM
PATRICK LAPLANTE	NWTRB
BRET LESLIE	NRC/NMSS/DWM/PA
TIM MCCARTIN	NMSS/DWM
ROD MCCULLEN	NEI
SITAKANTA MOHANTY	CNWRA
MYSORE NATARAJA	NMSS/DWM
GOODLUCK I. OFOEGBU	CNWRA
WES PATRICK	CNWRA
JOHN PECKENPAUGH	NRC/DWM
DAVID PICKETT	CNWRA
JOHN H. PYE	NWTRB
DANIEL ROM	NMSS/DWM/HLWB
JAMES RUBENSTONE	NMSS/DWM
CHRISTOPHER RYDER	NMSS/DWM/EPAB/PA
JIM SHIFFIN	MTS

ALSO PRESENT:

KING STABLEIN	NMSS/DWM/HLWB
OMID TABATAB	NMSS/DWM/HLWB
E. TIESENHAUSEN	CCCP
GORDON WITTMEYER	CNWRA
MITZI YOUNG	OGC

I-N-D-E-X

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

(8:33 a.m.)

CHAIRMAN GARRICK: Good morning. Our meeting will come to order. This is the second day of the 146th meeting of the Advisory Committee on Nuclear Waste.

My name is John Garrick, Chairman of the ACNW. The other members of the committee present are: Mike Ryan, Vice Chair; George Hornberger; and Ruth Weiner.

Today the committee will hear from the NRC staff on Yucca Mountain preclosure safety and drift degradation issues. We will hear from the staff on the updated staff performance assessment code. We intend to discuss the plan for ACNW review of NRC waste management-related safety research to review our proposed presentation for tomorrow's public meeting with the Commission.

Richard Major is the designated federal official for today's initial session. The meeting is being conducted in accordance with the provisions of the Federal Advisory Committee Act.

We have received no written comments or requests for time to make oral statements from members of the public regarding today's sessions. Should anyone wish to address the committee, please make your wishes known to one of the committee staff. And it is requested that the speakers use one of the microphones, identify themselves, and speak clearly and loudly, so that we can hear you.

Our first topic is going to be the Yucca Mountain preclosure safety and drift-degradation issues. The committee had some briefing on the methodology that's being proposed on this some time ago. In fact, it was a joint subcommittee of the ACRS and ACNW that wrote a report in January of 2002, and that report had three or four comments in it that were of great interest to the committee.

One comment had to do with both committees favoring more of a PRA approach than what was at that time described as the integrated safety analysis or safety assessment approach. We also suggested that the ISA, as changes are made in it, that those changes be structured in such a way that it allowed evolution to more of a risk-based approach to safety analysis.

The committees -- both committees expressed some concern about the capability of the integrated safety assessment methodology to address dependent events, dependent failures. And we also raised questions about the insights that the ISA would provide with respect to the aggregated risk, because the version we saw -- there was considerable emphasis on specific scenarios but not on aggregating the risk, so to speak.

So we're looking forward to an update. Of course, we're talking about Yucca Mountain applications now. At that time we were just pretty much talking about the methodology itself. I think that the presentation today is something we are extremely anxious to hear.

And I understand that Raj Nataraja is going to start off and will introduce all of the other speakers.

Raj?

MR. NATARAJA: Good morning. Can you hear me?

My name is Raj Nataraja, and I am the technical lead for the repository design and thermal mechanical effects key technical issue, which consists of both preclosure and postclosure aspects.

And my presentation is going to be quite brief. Basically, I'm going to set the stage for this morning's presentation, which has actually three major presentations but made by four different people.

The title for today's -- this morning's

presentation is preclosure safety analysis methodology and drift-degradation evaluation. And what I would like to do this morning is go over the objective and scope of this morning's presentation, talk a little bit about the risk significance of the topics that we have chosen for presentation, and then I will introduce the speakers who are going to make quite detailed presentations.

So we are going to cover a lot of ground this morning, and it ranges between the safety aspects that imply -- that are affecting the preclosure period as well as the postclosure period.

As I mentioned, the staff has been working on mostly postclosure aspects for quite some time, and have started paying attention to preclosure only in the last couple of years. That was because the work structure was developed in that way, and all of our focus was on the postclosure aspect.

However, the first topic that we are going to discuss today is to provide an update on the preclosure safety analysis. We have a tool -- what we call PCSA tool. As you know, the rule requires the Department of Energy to conduct a detailed safety assessment, and the term used there is integrated safety assessment, which basically you have correctly observed consists of the same steps that the PRA has -- what can go wrong, how likely is it, what are the consequences.

And the PCSA tool that we have developed, we have given you a methodology. We'll give you an update today about the application with a specific example.

And the second part of the presentation will talk about the long-term effects of drift-degradation, which is a fairly important issue. As a matter of fact, the -- most of the agreements that we have with DOE deal with either the stability during the preclosure or long-term impacts of instability.

So the second part of the presentation will focus on how to predict the long-term behavior and its impacts on the design and performance of the engineered barrier system.

Just to give some reasons for why we picked up these two topics, as you know, the PCSA is our tool and our methodology that we use to evaluate DOE's design and assess the risk significance of various structure systems and components. And that's how we determine whether the performance objectives are met.

And also, DOE will come up with a list of structure systems and components as part of the safety analysis based on their integrated safety assessment, and we will do some selective review of certain risk significant structure systems and components. And the way in which we determine which will be the focus of a review is based on the work that we do using the PCSA tool.

And as far as the drift-degradation issue, there is one technical issue that we have ranked as high, potentially high, in terms of risk under the RDTME KTI. And that is because there is a potential for the impact of the drift-degradation being severe enough to impact a large number of waste packages, if the load is transferred from the rock falling on top of the drip shields. And if the drip shields buckle and transfer the load to the waste package, there is a potential impact on the waste packages.

The first presentation on the PCSA will be done by two people. The first part of the presentation, which covers the methodology part, is done by Robert Johnson of the Performance Assessment Branch, NRC staff. And he will be followed by Dr. Bis Dasgupta from the Center. He will go into some details of the application of the two and give a specific example or examples. They may be real or not, but they show how we use the PCSA tool to evaluate DOE designs.

And one important thing that I might add here is that the structure systems and components important to safety as defined will consistent of both an evaluation of the public dose as well as the dose to workers. And it looks like that the dose to public is not a big concern here. Dose to workers is probably the more important and more definite result of the operations. So the two will show examples of how it is applied to both cases.

And then, the second part of the presentation will consist of two parts. The first part will be presented by Dr. Goodluck. He will talk about the empirical relationships and some analytical calculations that were used to predict the long-term behavior of an emplacement drift.

Actually, this work was initiated as a result of the Department of Energy's assumptions in the SAR performance assessment, which basically made an assumption that an emplacement drift will remain open for 10,000 years. We did not believe there was sufficient technical basis to make such an assumption.

So we looked at other possibilities, and a recent report prepared by the Center actually went into some details and came up with some alternative possibilities. And that's what we will hear in the first part, and the second part will take the output from that analysis and use it as input to the design of the waste package. Actually, we have not come to the waste package part yet. We are looking at the drip shield right now.

And we looked at one of the current designs, or at least the designs that we looked at were current at the time when we started this work. And that -- the impact of the rock fall on the drift-degradation and the static and dynamic loads on the drip shield is looked at. And that presentation will be made by Dr. Doug Gute from the Center also.

I just have two more slides. I don't want to spend too much time on that. The reason for this is more or less like a backup slide. We haven't talked to some of the new members, so they might not know exactly what the RDTME KTI is all about.

It's a mouthful. It takes into account the design and construction of operation -- construction and operation of the geologic repository operations area. The word -- if we simply say "repository," you know, discussions, we refer to geologic repository operations area as defined in the

Part 63.

And this particular KTI covers both preclosure and postclosure performance objectives, as I mentioned earlier. And we have to worry about the coupled processes and long-term impacts of thermal loading and seismic loading.

We have two aspects of seismic loading -- the design basis seismic loads that will be used for the preclosure part, and then there are the seismic events that occur during the 10,000-year period, which might impact the long-term behavior of the emplacement drifts and the EBS.

And then, the construction and operations sub-issues are also covered under RDTME KTI, but mainly their impacts are during preclosure and the -- if they are factored in appropriately for design, then they can be factored appropriately for postclosure performance assessment.

We have looked at -- if you have read some of our earlier versions of the IRSRs, you will see that RDTME KTI had four subissues -- design control process, seismic design, thermal mechanical effects, and seals.

Actually, design control process was looked at under this KTI simply because we did not have another place to put it in. We were not actively doing QA at that time. Actually, it belongs under quality assurance.

Currently, we have closed that subissue, because the subissue was generated as a result of some of the observations we made during the ESF construction -- design construction and operation. But the same issues might, you know, crop up again when we start thinking about design construction and operation of the repository itself. But apparently that subissue is closed.

And the last one -- seals -- is also closed, because that was not relevant to the system that we are in.

And most of the agreements that we have which are still being open and looked at are the seismic design and thermal mechanical effects. And there is some duplication here in the sense that this DS and CLST also have lots of common issues and agreements.

And, finally, there's a lot of information here which I'm not going to go through, but this is simply to show that we are looking at -- for convenience, we are looking at preclosure.

When I said RDTME KTI itself, I already

said that preclosure and postclosure are both part of it. But the reason why we have put preclosure separately here is the KTI structure did not cover the preclosure part.

So we are looking at the preclosure aspects under 10 topics, which I believe we made a detailed presentation to you. I think it was at the 127th ACNW meeting. We told you what the 10 topics were, and what are some of the issues under each one of those.

As you can see, we have right now based on the interactions with DOE we have nine agreements there, two agreements on the identification of hazards and initiating events, which is part of PCSA, and two on identification of structure systems and components, which is also the result of PCSA, and five agreements on the design of structure systems and components.

But there are a number of preclosure topics we haven't really touched on yet, so we will probably have more issues that come up later.

And under the RDTME KTI itself, as I mentioned, the subissues one and four are closed. And we have a total of 23 agreements currently we are looking at. And as you can see, many of these agreements deal with the stability of underground openings as it impacts the preclosure operations as well as the impacts on the postclosure performance because of the potential impacts of instability of the emplacement drifts.

So, in summary, we chose two topics which we thought were risk significant, one for preclosure and one for postclosure. And we will make some detailed discussions on all of those topics. If you have any quick preliminary questions, I'll be happy to answer. Otherwise, we can move on to the first presentation.

CHAIRMAN GARRICK: Any questions at this point? Would you comment on the impact that the absence of a detailed design has had on any of these analyses?

MR. NATARAJA: Well, that's been one of our problems all along. And the nature of the repository investigation itself has been one of iterative -- it has to be iterative out of necessity, because they will not know all of the information in advance. So they did the site characterization to the extent they could, and then the more information comes in they keep making revisions.

And we have had some difficulties, yes, because we cannot pinpoint any defect in an unknown design. We can only work on a generic concept. So far we have not seen a final design. But I think it has matured enough for us to raise a number of questions.

CHAIRMAN GARRICK: But has the absence of a detailed design maybe made you go in a more conservative direction than you might if you had?

MR. NATARAJA: I don't know whether it would be more conservative, but we would like to look at too many possibilities. And some of those possibilities and alternatives might not be realistic simply because we cannot just eliminate it at this stage.

CHAIRMAN GARRICK: Yes. Thank you.

Any questions? Okay. Thank you.

MR. NATARAJA: So Robert Johnson.

MR. JOHNSON: Okay. Good morning. My name is Robert Johnson. I'll be ready in a second. I'm with the Performance Assessment Section, as Raj mentioned. Bear with me.

Okay. Again, my name is Robert Johnson. I'm with the Performance Assessment Section in the Environmental Performance Assessment Branch in NMSS. I will be presenting today with persons that have already been introduced.

The key or the purpose or the reason that we're here is to brief you guys about the development, the methodology, and the capabilities of the PCSA tool and to discuss the simplified conceptual analysis that we've started.

Thank you.

Okay. Once again, the reason we're here is to discuss or brief you guys on the development, methodology, and capabilities of the PCSA tool, as well as discuss the simplified conceptual analysis that we've started to do.

The next -- we're also going to provide you a glimpse or some insights on where we're headed with the tool, and some of the things that we need to do to bring it up to speed.

Before I get any further, I need to recognize some additional contributors -- Roland Benke at the Center. I didn't mention, Bis is with the Center. In addition, additional contributors are Tony Ebaugh, who is in the High-Level Waste Branch, and Banad Jagannath, and there are a lot of people who have worked along over the course of the development of the tool, a lot of other people.

That leads me to the overview. Like I said, I'm going to be presenting the first part of the presentation today, which is going to provide some background -- the relevant background information and methodology, including relevant requirements, the preclosure safety analysis or safety review strategy, and then outline some of the capabilities of the tool, and then step through the first part of the example problem and the capabilities of the tool.

Bis will be up next. He's going to actually provide more detailed information on the conceptual analysis that -- or the example problem that we have put together. He'll outline the future work, and he will provide a summary.

Okay. So I'm going to take a minute or two just to step through some of the requirements, just to put it in perspective, so we can better understand what we're doing with the tool. So I'm going to start off the -- okay. Bear with me.

Okay. Part 63 defines the preclosure safety analysis as a systematic examination of the site design, potential hazards, initiating events, and the resulting sequences -- event sequences, and the potential dose consequences to both the public and workers.

63-112 further defines the preclosure safety analysis as an identification and systematic analysis of the naturally-occurring and human-induced hazards at the repository, including a comprehensive identification of potential event sequences.

The next important point to mention here is the -- that the preclosure safety analysis has to demonstrate compliance with the regulatory performance objectives. And for Category 1 event sequences, which are those that have -- those event sequences that are expected to occur one or more times during the preclosure period. There's a public annual dose limit of 15 millirem, and then the worker dose limits are identified in Part 20 -- are 100 millirem.

The Category 2 event sequences, which are those event sequences that are expected to occur at least one time in 10,000 before public -- during the preclosure operation period, has a public dose limit of five millirem per event sequence in the organ dose -- this is just a summary.

The preclosure safety analysis is required to identify and analyze SSCs that are important to safety. This analysis should also describe the controls that are relied on to limit or prevent event sequences or mitigate their consequences.

It also identifies measures to ensure the availability of the safety systems, and it's also going to include information on the design basis and design criteria that satisfies the regulatory performance objectives that we discussed up here.

Okay. This side provides an overview of the staff's strategy for reviewing a preclosure safety analysis that would be submitted as part of the license application. It's important to note that DOE is required to submit the preclosure safety analysis that meets the requirements that we just discussed.

DOE must demonstrate through its preclosure safety analysis that the repository will be designed, constructed, and operated to meet regulatory performance objectives throughout the preclosure period. Key elements of the preclosure review strategy include the fact that the staff will be using the Yucca Mountain review plan to review the license application.

Specifically, with respect to DOE's preclosure safety analysis, the staff will use the preclosure safety analysis tool to conduct an independent confirmatory analysis where necessary and to evaluate the preclosure -- DOE's preclosure safety analysis.

The staff will focus their review on the important SSCs, or SSCs that are identified as important to safety, in the context of their ability to meet the preclosure safety objectives. It's important to note that the PCSA tool also -- or is not the only tool that is going to be used to identify SSCs that are important to safety.

There is a whole list in 112 that identifies a minimum of 13 other aspects that are going to be considered when they're determining what SSCs are important to safety. Examples of that -- means to limit concentration of radioactive material in the air, means to prevent and control criticality. Another example is the ability of SSCs to perform their intended safety functions, assuming that the event sequences occur.

The last point here is that staff will look at risk insights for multiple sources. We are first going to be looking at DOE's preclosure safety analysis to make -- to get some risk insights to see it from their perspective.

We have our tool, which allows us to independently look at selected portions of a repository or to look at specific systems. We have other similar regulated facilities. We've got -- there are multiple sources of input for risk insights. And as I mentioned, one of the main things is that the tool provides some capability in this area.

Okay. The next slide outlines key capabilities of the preclosure safety analysis tool itself. The tool provides independent review capability in that it allows the staff to evaluate the completeness of DOE's preclosure safety analysis, including the identification of hazards, initiating events, the development of event sequences, and consequence analysis, and the identification of SSCs important to safety.

It also allows the staff to evaluate selected portions of DOE's preclosure safety analysis, their assumptions, their data, as warranted.

Okay. Use of the tool also enhances the staff understanding of DOE's preclosure safety analysis by giving the staff an integrated tool that provides the capability to conduct preclosure safety analyses for part of all of the facilities, as I've mentioned -- selected sections, if we need to, or we can -- we have the capability to do a more exhaustive analysis.

It allows us to perform independent safety -- an independent safety assessment. It allows us to look at the event sequences and independently identify SSCs important to safety. It allows us, as I mentioned, to develop preclosure risk insights, perform sensitivity and importance analysis, provide -- and one of the main things is that it provides a framework -- the staff with a framework for systematically documenting our review.

Okay. This slide is a graphical representation of the staff's preclosure safety analysis review methodology as described in the Yucca Mountain review plan. Each of the individual boxes which are kind of hard to read here are -- they represent particular elements of the staff's review included in the YMRP, in the reference sections of the YMRP. I tried to identify which sections related to it in each of the boxes, so it's easy to understand.

Okay. To illustrate the relationship between the preclosure review methodology and the PCSA tool, I further grouped the review methods. Okay. The first box actually represents the inputs to the PCSA tool, the things that we're going to be inputting into the tool itself.

That includes a site description, facility design and operations, the SSC design bases that we'll have, and identify inputs from naturally-occurring and human-induced hazard analyses.

Okay. The next grouping actually

represents the functions that are going to be taken care of in the PCSA tool, or the PCSA tool functions themselves and how they relate to the review method. These include operational hazards, event sequence analysis, and categorization consequence analysis, compliance assessment for Category 1 and Category 2 events, and the identification of SSCs important to safety.

And the last grouping represents the objectives of the preclosure safety analysis itself, and that includes, again, the compliance assessment for Cat. 1 and 2 event sequences, and the identification of SSCs important to safety, as well as a review of design basis and design criteria, and a review of ALARA requirements 20 for Cat. 1 event sequences.

Okay. This slide provides a brief introduction, a simplified conceptual analysis that we have been working on, or the example problem. There has been a recent increase in staff emphasis on both the preclosure safety analysis itself and the preclosure safety analysis tool. And one of the results is the analysis that Bis is going to discuss.

Activities that were performed as part of that analysis include we went through and created a conceptual dry transfer facility. In the absence of real design information, we actually laid out what we expected to be in the facility and started from there.

We went through and identified applicable functional areas. We performed hazard analyses, FMEAs, and what-if type analyses, developed event trees, assigned hypothetical probabilities for initiating and top events in the event trees. We went through and identified Category 1 and Category 2 event sequences.

And then, with the results, we compared the doses from each of the Category 1 and Category 2 event sequences to their respective performance objectives in 63-111. We identified some hypothetical SSCs that are important to safety and performed a limited risk analysis, because the scope of this analysis was relatively small.

One thing to understand here -- the list that I just went through is not intended as a -- or it's intended as a higher level discussion to lay the foundation for the more detailed discussion that's going to be coming.

And the last point is that the staff is going to be using a similar approach to review DOE's preclosure safety analysis.

Now, we can transition or we can take questions. Yes, ma'am.

MEMBER WEINER: At what point -- if you go back to your last slide with the boxes --

MR. JOHNSON: Yes, ma'am.

MEMBER WEINER: -- at what point do you introduce the notion of probability or risk in your -- in the blue box in the tool itself?

MR. JOHNSON: Okay. In the tool itself, the concept of risk is identified. First, we go through and there's sort of a qualitative approach. You start out the process and go through the operational hazard analyses themselves.

Then, you're going to identify event sequences that are within -- or I should say you determine the probability of the event sequences that you've identified here to determine whether they fit within the -- if they are beyond consideration or whether they are Category 1 or Category 2 event sequences.

And then, the consequences are determined for each of the event sequences that fit into each of the Cat. 1 and Cat. 2 event sequences, and the combination of the two is I think what you're looking for.

MEMBER WEINER: Do you introduce probability into your -- or do you associate your event sequences or any component of them with probabilities?

MR. JOHNSON: Yes, ma'am.

MEMBER WEINER: I suppose I'll see that in the example.

MR. JOHNSON: Yes.

MEMBER WEINER: Thank you.

MR. JOHNSON: Were there other questions?

MEMBER HORNBERGER: Do we know how DOE is going to do their analysis for the preclosure case?

MR. JOHNSON: At this point, we know that -- we have some understanding. They've put out a preclosure safety analysis guide. It's my understanding that there's going to be a revision to that coming up or coming out in the near future. I'm not sure when that's coming out.

Do you have anything maybe to add to that?

DR. DASGUPTA: Well, we have seen their --

MEMBER HORNBERGER: You have to use a microphone.

DR. DASGUPTA: This is Bis Dasgupta. We had a glimpse of their analysis for the IRSR design, but their change of the design and the new analysis we haven't yet seen.

MEMBER HORNBERGER: So based on what you know, how similar or different do you anticipate that the DOE safety case would be from your method of analysis, your PCSA tool for example?

DR. DASGUPTA: DOE -- we have this tool to review DOE's preclosure --

MEMBER HORNBERGER: Yes, I realize that.

DR. DASGUPTA: -- analysis. And they can present their -- I mean, their analysis the way we'd like. And we have our own approach to review that.

MEMBER HORNBERGER: Right.

DR. DASGUPTA: Hopefully, it's all in the same direction. But today what I'm going to talk to you about, how we are going to approach that.

MEMBER HORNBERGER: Okay. So I realize everything that you just said, and I accept it. But what I was trying to gain some understanding of is whether your anticipation is that there will be any major differences between the way DOE approaches the building of their safety case and the way you have organized to review the safety case.

DR. DASGUPTA: As far as the IRSR design, we don't think that there will be -- whatever we do from the IRSR design analysis, I think we are headed in the right direction. But I do not know if they are changing their methodology for future analysis.

MR. JAGANNATH: Banad Jagannath, staff. We reviewed the PSA guidance document, which is related to the staff guidance document, and what we have seen we are in kind of -- same considerations, same logic. We have not seen any detail, but my general impression is we are in agreement.

CHAIRMAN GARRICK: Let me ask about an overall strategy here. Has the strategy in developing a PCSA methodology been one of how to review somebody else's safety case or safety assessment, or has it been almost 100 percent an independent method of doing safety assessment? Because the role here is one of satisfying yourself that their analysis is a credible one and has addressed the issues correctly.

Can somebody comment on whether or not that -- because we have seen in the performance assessment there is quite a bit of attention given to the perspective of being a reviewer rather than just an independent -- developing just an independent capability to do safety assessment.

MR. JOHNSON: That's a good question, and I've got a good answer.

(Laughter.)

The tool, first and foremost, is designed as a review tool. But it actually allows the staff the capability and the framework to actually do a full-blown analysis.

So it's -- we have to review what DOE provides us, the preclosure safety analysis that they provide us. The tool we think is headed in the right direction to allow us to look at their -- the direction that they're headed with the preclosure safety analysis, the methodology document.

But the key here is that it actually -- the tool gives a little more flexibility. It gives the ability to do the analysis, and then we also can consider some elements of risk. We can go through and incorporate all of the capabilities of SAPHIRE. It allows us to review what they're going to provide, and we -- and actually do an analysis, either a selected portion if it's necessary or a full-blown analysis.

CHAIRMAN GARRICK: Okay.

MR. JOHNSON: Does that take care of your question?

CHAIRMAN GARRICK: Yes, thank you.

Do you have any questions? Any other questions at this point? Okay. Thank you.

DR. DASGUPTA: Good morning. My name is

Bis Dasgupta. The objective of this part of the presentation is to provide you -- provide through an example the overview of the PCSA tool capabilities and how it relates to the review sections that you have seen in the earlier flowchart. I'll go back and forth on that one.

To put into perspective, the basic functions of the PCSA tool is to store information and data systematically, conduct wide-ranging qualitative and quantitative analysis, and produce a focused result to determine the compliance with respect to the performance objectives and also to gain risk insight.

Now, the structure of the PCSA tool and its module is given in the backup slide, and I believe it's in the slides 4 and 5. The tool actually puts together many analysis techniques, methodologies, and tools in a combined and integrated software. But the tool is very comprehensive, and it has the flexibility to -- with a built-in flexibility to review -- to do review of the preclosure safety analysis, and as well as conduct independent uncertainty, sensitivity, and importance analysis.

The staff has conducted a limited preclosure safety analysis on a conceptual dry transfer facility. We looked into -- the focus of this analysis was to gain experience over the preclosure safety analysis tool, and we looked into the transfer of the assemblies and the canisters in the hot cell, the canister in this hot cell, and also the transfer -- or the handling operations of the waste packages in the welding area. And this is indicated by this circle.

Now, the overall conceptual surface facility that we have used in the analysis is given in the backup slide 6. This is the -- this slide shows the operations that have been used in the conceptual analysis. On the left it is -- a bridge crane is used to lift the canisters out of the transportation cask, and before it's put inside the waste package is put temporarily in the staging rack. And then, from the staging rack it is put in the waste package.

There is -- an assembly transfer machine has been visualized over here kind of to transfer the assemblies one at a time from the transportation cask. The spent fuel is in place from the transportation cask and put directly into the waste package.

Now, over here the layout and the operations in this conceptual analysis is in this -- you know, the data that was -- the layout and the operations is totally conceptual. And the data required for this analysis was either assumed or it was taken from the DOE's site recommendation design.

Now, the way the preclosure safety analysis tool, or the PCSA tool, would work is that the first -- the whole facility is divided into several functional areas in order to focus our attention on that particular analysis.

And that's why you see these different numbers. We give different numbers to these functional areas. That helps us to kind of identify which are we are really agreeing on conducting our analysis.

The information for this analysis really comes from the review of these two boxes in the Yucca Mountain review plan sections, such as associated design and operations and associated design basis. The Yucca Mountain review plan in its sections -- site description, facility design, and operations -- we review the information and try to find out the sufficiency and adequacy of the information to conduct a preclosure safety analysis.

After having done that, after we are satisfied that we have enough information, those information are abstracted and put inside the -- as an input to the PCSA tool.

Now, after that information has been put in, then we get into the analysis in -- the preclosure safety analysis. That means address the risk triplets, the three sections of the risk triplets.

The first one -- the first risk triplet is the operational hazard analysis. The tool has three or four methodologies. These are primarily qualitative techniques, like what if analysis techniques, the failure modes and effects analysis technique, and the -- there is the energy checklist method, and also a human reliability analysis technique has been written. So that the primary aim is to find out the gaps in the identification of hazards and initiating events.

Now, for natural and human-induced hazards, these are reviewed outside the tool, but the credible hazards are primarily -- the information on the credible hazards, primarily the frequencies are put inside the tool as an input, so that that can be used for further analysis.

MEMBER WEINER: Excuse me.

DR. DASGUPTA: Yes.

MEMBER WEINER: Could you identify as you go through this where you have hardwired something into the tool and where it is a user input? Just for my information, if that's not too much trouble.

DR. DASGUPTA: Oh, no. Yes. Probably I'll -- that's the basic -- I mean, that's the objective of this sort of talk, to kind of go hand in hand and to show you what we have done in the tool and how the tool relates to the review process and what we are going to input that.

Okay. To go back to answer your question, the first thing is to -- that we have, we first have to input the information in the tool that comes from the review of these high description facility design operation and SSCs design basis. The tool has gone -- first, the system description component, and included -- in addition to that, the types and the quantity of the nuclear material that's going to be sort of used in that particular functional area.

So the first is all divided into functional areas, and information for each functional area then comes through from the review of this process again.

The tool takes this information, and then the first step of the tool is to conduct a hazard analysis. And I just said that -- what are these different hazard analysis techniques that we have built into the tool?

So the tool has the capability of conducting the total hazard analysis. But, of course, we will get from DOE a list of hazards. The idea over here is to find the gaps in their hazard analysis and to identify whether they have not included some of the hazards and analyzed them in the -- you know, further analyzed them to determine the compliance and the risk.

So now the -- in this example, the hazard analysis was conducted, and I think the backup slide number 7 shows you the list of hazards that has been identified for this simple conceptual facility.

The primary hazard that we have identified over here are the assembly drop and the canister drop, because of the failure of the bridge crane or the assembly transfer machine, or due to the human errors.

Okay. After the hazard analysis -- after the identification of the hazards, the next step in the -- the next component of the risk triplets is the event sequence analysis and categorization. The tool -- that means over here the tool now does its own analysis, which means tries to develop the scenarios, event scenarios. For doing this analysis, we need the event scenarios.

Event scenarios are defined as the

initiating events and the subsequent failure of layers of protective and mitigative safety systems that have been designed to protect the workers and the public from getting the radiological dose.

So which means now -- I think I can turn this off. Which means the scenarios are then developed into event trees, and the tool has the SAPHIRE software to do the event tree and the fault tree analysis that we were required to use as the probability data that I think a little while ago you have been talking about.

Okay. The example that we saw has got -- the scenarios have been identified in slide number 10, I think, in the backup slides. And over here what I'm showing is just an example of one scenario, which deals with the failure of a bridge crane, which drops the canister, and the canister can breach if it has got an initial defect of certain probability.

And after that breach, the public can either get the dose, which is the unmitigated dose, the particulates and the noble gas, or if the HEPA is working the public can still get the mitigated dose, which is coming from the noble gas.

MEMBER WEINER: Where do you get -- I assume these numbers are just for your example.

DR. DASGUPTA: Right.

MEMBER WEINER: But where will you get these probability numbers from?

DR. DASGUPTA: Okay. For this initiating event, we have given -- in this example, we had done some assumptions, and also some -- have also conducted some analysis. For this particular event scenario, the bridge crane failure rate, we got it.

We have done independent fault tree analysis, in which we kind of looked into the failures of different components -- electrical and mechanical components, developed a fault tree, and tried to develop the failure rates of the bridge crane. And then we know how many operations are going to be there in that particular --

CHAIRMAN GARRICK: Bis, is this for a particular category of bridge cranes, or is this bridge cranes?

DR. DASGUPTA: It's a bridge crane. You know, the heavy-duty, because the canisters are primarily the very heavy -- you know, it's a heavy-duty bridge crane, yes.

VICE CHAIRMAN RYAN: Just a quick question, too. These are point values for probabilities in this example. Can you also handle --

DR. DASGUPTA: Right.

VICE CHAIRMAN RYAN: -- distributed values or --

DR. DASGUPTA: Exactly.

VICE CHAIRMAN RYAN: -- probability functions?

DR. DASGUPTA: Right.

VICE CHAIRMAN RYAN: Yes, okay. Thanks.

DR. DASGUPTA: The SAPHIRE software can handle distributions for each of these probabilities, and it can propagate to uncertainties all the way through.

And for the canister breach, we have assumed this value of 10^{-3} as, you know, initial defects in the canister. The HEPA is -- again, we have assumed it, but it is kind of in the ballpark figure that we -- we see the values in the literature.

But all of these values will be looked into in details when the license application comes, or between -- between the license application comes and now we will get into more details in these values.

So after we -- this event sequence, although this is a very simple one, but we can use SAPHIRE software to do this analysis. And we will get these event frequencies for each branches of this event tree.

Okay. The next step of the -- of this analysis, of the risk triplets, is to evaluate the consequence, radiological consequence. We use -- in the tool we use RSAC software to do the radiological consequence. And also we use the MELCOR software.

The RSAC software calculates the atmospheric dispersion, and the MELCOR is used to estimate the building retention of release of the airborne material, which means it calculates the release fraction. They use a fraction of the release that really goes out to the public. I mean, we are trying to make this analysis more realistic as possible.

The tool has the capability to do both point estimate as well as probabilistic analysis of the consequence. And in the probabilistic analysis, the two samples -- a wide range of input parameters like meteorological data, the release fractions, source term event tree, the inhalation ingestions and submersion data, and then the tool uses the RSAC for deterministic analysis for the -- for all of the realizations for different -- for each realization.

And ultimately, the tool will produce this kind of results. It will give you complimentary cumulative distribution function, and this shows -- on the left-hand side it shows the different pathways -- the inhalation ingestions for the internal dose and the ground surface and submersion for the external dose and the TDE, the total dose equivalent for the mean dose over here. And we use the mean dose to do a compliance analysis, which you will find over here.

Coming back to this one, these are the mean doses that comes from the consequence analysis. We have one step before that. First of all, after we get these frequencies, the frequency needs to be categorized as to the definitions of the Part 63 in which Robert has talked to you about. And these are the categories of the frequency -- Category 1 and 2 of the particular event scenario.

MEMBER WEINER: Are you -- I'm unclear as to what you are assuming about the release fractions and the size of stuff that's released and the division between gas and volatile, and so on. Is that somewhere in your code, or do you -- how do you determine that?

DR. DASGUPTA: Well, the code as such is -- this is the input that -- you will have to give it to the court.

MEMBER WEINER: Yes. But is there a place that you input, for example, different deposition velocities for your particles, different types of physical or chemical properties of whatever is released?

DR. DASGUPTA: Right. And I think if Roland Benke, who is actually -- who is our HB help over there, if you can elaborate on that, Roland.

MEMBER WEINER: Okay.

MR. BENKE: Sure. This is Roland Benke, CNWRA staff. The answer is yes. Specifically, deposition velocities would be an input to the RSAC code. That would be atmospheric dispersion calculations. The other question that you asked about particle sizes, that is an input for the MELCOR code that's used for building retention fraction, or it's commonly called as leak path factor.

Do you have any further questions?

MEMBER WEINER: Oh, I will from time to time.

(Laughter.)

MEMBER HORNBERGER: So that's, of course, the calculation once you have a release. So somewhere in here you've dropped the cask. Tell me how -- what the assumptions are about how much of the material gets released.

DR. DASGUPTA: Did you get that, Roland?

MR. BENKE: Oh, okay. Roland Benke again. Sure, yes, I'll -- Roland Benke, CNWRA staff. Starting with the assumption that there is a breach of the cask, we are going to have to pick a release fraction from the spent nuclear fuel that's damaged.

In general, we've done a literature search and gathered information from both American National Standards on release fractions for non-reactor facilities, as well as NRC guidance, such as Spent Fuel Project Office Interim Staff Guidance 5, and other NUREG guidance documents.

Those release fractions from the guidance documents tend to be conservative. In general, we say for a consequence analysis we use best estimates where possible. Releases from containers, without knowing the impact forces and amount of damage, are certainly generic in these analyses today that you've seen.

MEMBER WEINER: Do you use -- I'm not familiar with RSAC. Is that just a gaussian dispersion code?

MR. BENKE: Yes, that's correct.

MEMBER WEINER: What do you do about the area where the workers would be? Because most gaussian dispersion codes blow up as you get close to the source. What do you do about the near field?

MR. BENKE: Right. Very good point. We are not relying on atmospheric dispersion to give us involved worker doses. Our current plans are to perform calculations offline specific to that worker dose scenario.

There is, you know, in general -- if you have a facility that is a number of kilometers away from a member of the public, the atmospheric dispersion can be used for a variety of releases within the building, because obviously they need to be transported through the air and atmosphere to get to the receptor.

Now, if the receptor is a worker, then geometry of where the worker is, are they outside an operating gallery, are they inside a hot cell, are they wearing respiration, are they shielding walls that need to be considered. All of those things are more complex and more unique for each scenario.

So what the tool capability will be is establishing the links and areas where information can be stored for offline worker dose calculations. We do not foresee the capability to imagine all scenarios and stylized calculations, so that the tool is doing the numbers -- number-crunching on those.

We imagine analyses that can be tracked as -- together for a worker safety compliance at the end using the tool.

DR. DASGUPTA: I'd like to add right at this point we don't have the capability to do worker dose, and that's why you see in this column that they are not calculated. But this is in our next -- I mean, this is the next part of the development that we are working on, to introduce the worker dose calculations into the tool.

Any questions on this one?

MEMBER WEINER: What kind of assumptions are you making when you calculate the public dose? What kind of assumptions are you making about things like breathing rate? And are those user input to the code, or are those hard-wired in the code?

CHAIRMAN GARRICK: Or are they offline? Yes.

MEMBER WEINER: Or are they offline? Yes.

DR. DASGUPTA: Yes. No, these are input to the code, you know, so -- so it's -- the tool is very flexible. We did as minimum as possible hardwiring in the code. So that even -- even with the release fraction, as Roland said, that -- that we didn't hardwire that, and it depends upon what are the release fractions or other data that we get -- and review them, and then put that into the code, into the analysis.

Now, this was a snapshot of just one example of the different event scenarios that I have listed in the backup slide, which is slide 9. So, similarly, we go through this analysis, and for each of these event scenarios the initiating event frequencies and the other probabilities -- you know, particularly the initiating event frequencies -- are given in slide number 10.

So we go through this analysis. The tool goes through this entire analysis, and for different functional areas -- and then the results of all the event sequences, the frequencies, and the consequences, are all put together from the entire repository, and they are collected in one place.

This slide shows the only -- the Category 1 event sequences. They are kind of soldered -- all of the Category 1 event sequences. And here is the compliance analysis that the tool performs.

First of all, I think Roland has touched upon the different compliance assessments that we go through. Number one is that individual event sequences should not be greater than 15 millirem.

Okay? That's number one compliance assessment.

The second one is the annualized dose or the frequency weighted dose should not exceed, again, 15 millirem per year.

And the third one is the -- some of the dose from combination of events in a single year also should not exceed 15 millirem.

I did not show that analysis, but the tool has the capability to do the combination of events over here, so you hit -- when this calculation is done, it gives all different possible combinations of different -- of Category 1 event sequences and the dose. So we comply and look at the compliance from that perspective.

This is the compliance analysis for Category 1 event sequences. Category 2 is quite simple -- that their regulation says that each individual event sequence should not exceed five rem dose criterion. So -- you know, so we don't need to do any further analysis to that one.

The next is the example of SSC important to safety. This feature is not fully functional in the tool, but this is the methodology that probably you will use. This is based on our take-away approach, take-away analysis approach.

Again, coming back to the same example, this is what we do -- what we will do. We will take this baseline event tree, and then take away the safety system one by one and look at the -- and perform the compliance assessment once again.

And then, if the compliance assessments show that it exceeds the regulatory dose limit, then that particular safety system is important to safety. So this is the process of analysis that we will be using to identify SSCs important to safety.

Risk analysis. The tool provides the capability to evaluate system risk. Now, this is -- this capability has been introduced to gain risk insight.

Okay. The tool performs both point estimate and probabilistic risk analysis. A sample result from this risk analysis is given in -- I think in slide -- backup slide 12.

What do we expect from this risk analysis, and how do we want to gain risk insight? First of all, the tool evaluates the total risk. It considers all Category 1 and Category 2 event sequences are beyond design basis, so it doesn't distinguish the Category 1 or Category 2. It takes all of the event sequences, and then the total risk calculation is performed.

This result from the risk analysis --

MEMBER WEINER: Excuse me. How do you -- do you multiply the probability times the consequence and then add them all up? Or how do you do that?

DR. DASGUPTA: Well, it's -- I think I will have to again defer to Roland Benke. But we do in a probabilistic space. It's not just multiplication of our frequency times the dose. It's -- we do this calculation in the probabilistic space, and find out the outcome of each event -- occurring and non-occurring -- and combinations of those different events occurring. So you would get a big list of different combinations of events.

Roland, do you want to add anything to that?

MR. BENKE: Yes. Roland Benke, CNWRA staff. At this time, I think we should probably finish the presentation. I could probably talk a while on that, but I don't think it's appropriate right now.

What you could do is point them to the paper that's mentioned at the bottom of slide 16 that outlines the methodology. You summarized it well.

Thanks.

DR. DASGUPTA: Thanks, Roland.

So after obtaining the risk, the -- we try to analyze this and find out what are the largest -- what is the risk insight, to try to understand what are the largest contributors of the total risk. It could be based on some certain SSCs functioning or not functioning, or it could be certain functional areas that have a high risk significance.

Or it could be any hazards or operations that could be risk significant. I think that information we will get from the risk analysis capabilities.

We come to future work. The tool development is not complete. The Version 3 is our target version for -- to be used for the license -- for review of the license application. As we have already talked about, the worker dose capability has not been introduced yet, but we are working towards it.

Primarily, the worker dose calculation will be done offline, but the tool will develop the input data for dose analysis. And then, the tool will also have the linkages that will come out of the worker dose calculations to do the compliance analysis of the event sequences, and also the SSCs important to safety related to the worker dose calculations for all of the performance like the tool.

We are expecting to use, for the external dose softwares like MCMP, the Monte Carlo software, and also use the dose -- for the internal dose, we'd like -- we probably will use the guidance given in Part 20. So the Part 20 will be heavily used for assessing worker dose calculations.

The tool -- our next goal is to do software verification of the PCSA tool. Each individual external softwares will be -- also will be verified, and also the entire process. The PCSA tool itself will be verified.

And we would like to continue the safety analysis in the next fiscal year, expand the analysis that we have done, the conceptual design, which means -- analyze the other functional areas or -- and bring in the other hazards, like the external hazards, which has not been analyzed in this particular analysis.

In summary, as you can see from the backup slides and all of these discussions that the tool is pretty complex. And it's also very comprehensive. And this tool -- but it had got enough flexibility to do the review, to do its independent analysis, to do reviews.

The tool can do uncertainty sensitivity and importance analysis, and it -- you know, it combines so many different methodologies and the tools and the techniques that makes this tool kind of unique for it to use in the Yucca Mountain -- to review the preclosure safety analysis for the Yucca Mountain facility.

And the rest of the summaries are like we will continue -- the staff will continue using the tool in the next fiscal year to gain more experience and also to gain more risk insight. And as more and more details that we receive from DOE, probably we will iterate through that process and analyze them to get ourselves a -- to get insight into the facility operations and design.

I think that's all I had.

CHAIRMAN GARRICK: Okay. Bis, what is not included in the methodology that would make it a full-fledged PRA tool?

DR. DASGUPTA: That's a good question. And we looked hard into it and tried to compare every time what is there in the PRA methodologies and what we didn't have in the tool. My assessment is that we have almost all ingredients that the PRA uses that we have over here.

This tool, although I did not mention, could use -- you know, look at the dependent or common cause failures. This is all built into the kind of scenarios or event scenarios that you can use.

Sensitivity uncertainty analyses are all part of this -- you know, the tool functionality over here. So to me, you know, I don't see very much of the difference between the PRA and the total function. We are -- in this tool, we are looking into all aspects of the risk triplets. And that's the sense of both PRA as well as the PCSA tool.

But that's my sort of assessment. If anybody else has --

CHAIRMAN GARRICK: So, well, we didn't see any examples of common cause or real --

DR. DASGUPTA: Right.

CHAIRMAN GARRICK: -- dependent failure analysis or uncertainty analysis or human reliability component or --

DR. DASGUPTA: Right. But --

CHAIRMAN GARRICK: -- what have you. But you're saying that you could introduce a top event, for example, in your event tree that would account for human --

DR. DASGUPTA: Right.

CHAIRMAN GARRICK: -- reliability, and you could accommodate the split fractions in the event tree with probability distributions, etcetera, etcetera.

DR. DASGUPTA: Exactly. And, in fact, we have introduced the human reliability or the human error effects into -- in our example problem. Some of the examples that we had, the human could make an error in trying to lift the canister or the assemblies. While they are lifting it and putting it down, there could be several different ways the human can drop the load. And it's all like error of commission. And that's what he had tried to do that in a very simplified manner in this example itself.

The tool -- I did not mention, of course, the tool has a database of different failure probabilities, okay, we gathered from different sources, and the tool has a database of the failure rates, including wherever we could get any information on the uncertainties.

And also, it has got the HEP -- or the human error probability generator. It's apparently from the Swain and Goodman's methodology that we have introduced in the tool, so any time people can -- want to evaluate the human error probability they could go ahead and do it.

And the other aspects of trying to identify if human could be an initiator -- we have a qualitative methodology in a hazard analysis technique. We have a process that -- where, you know, the user can go through and evaluate or find the human errors that can initiate events. Or if human error could be used in the fault tree or event tree analysis, you know, it's all built into that.

CHAIRMAN GARRICK: Now, how about data updating such as the use of Bayesian methods to account for new data.

DR. DASGUPTA: Right.

CHAIRMAN GARRICK: Are there any algorithms for that?

DR. DASGUPTA: No. Right now, we don't have, but we have plans to work on that. We do -- because that's our next step in the steps that we will be following in this coming fiscal year.

CHAIRMAN GARRICK: Ruth.

MEMBER WEINER: I have two questions right now. One is, how do you do -- you said you can propagate a distribution of any input variable. How do you sample on that distribution? And do you allow the user to choose a sampling method -- Monte Carlo, SAPHIRE, and so on?

DR. DASGUPTA: Yes. For the frequency analysis, the SAPHIRE does that and the SAPHIRE has got both these methodologies -- Monte Carlo and LHS -- so, you know, the user can choose whichever sampling process they can use.

MEMBER WEINER: The other question is: did you -- when you chose SAPHIRE, did you look at a variety of software tools that could accomplish this? Because just -- I don't really know much about your tool, obviously, since this is the first time I've seen it.

But it seems to me that Analytica, for example, can do most of what your tool does without a lot of extra design. I just wondered if you had done a survey of software before settling on this particular approach.

DR. DASGUPTA: Yes. And there were two criterias for it. One was research. We looked into different software. And the other -- while doing that, we found out that SAPHIRE is kind of in a very developed stage compared to, you know, a couple of -- even a couple of years back. And SAPHIRE is actually developed for NRC. So SAPHIRE is software NRC uses quite a lot and NRC has confidence in.

CHAIRMAN GARRICK: The normal approach that is taken in most PRA work is that you -- of course, once you get the scenarios and the likelihoods of the scenarios in whatever form you have them, either as frequencies or probabilities or probability of frequencies, or whatever, you often do this just on the basis of point estimates.

And then, when you see which of the scenarios are the most interesting from the standpoint of contributing to risk, then you magnify the level of the analysis considerably on those particular ones, and including probably the invoking of a bona fide uncertainty analysis.

Is that something -- is that a practice that you would tend to follow?

DR. DASGUPTA: Yes. Yes. That's exactly -- and the tool actually has that flexibility. Why I'm saying this is supposing we chose one particular event scenario, and we went through this point estimate analysis. So that's the first pass of the analysis.

And after the analysis has been conducted, and if you want to do sensitivity on that particular event scenario, the tool does not -- I mean, you don't have to delete that scenario from that. And you could still develop another parallel scenario, do the analysis, and use the new analysis for your compliance assessment.

And in that one, we could bring in the uncertainties and sensitivity and all other different parameters that we know of. And this is the kind of risk insight is that we are planning -- hoping to gain from this tool.

So as of now, we have tried to build in as much as we can think of. And probably in the next year when we do more analysis, and as we go through this process, there may be certain changes we need to make. But to exactly sort of keep these flexibilities --

CHAIRMAN GARRICK: I think the important thing is to make sure that the analysis only is as complicated as it needs to be. There's a lot of scenarios associated with this kind of a system that you can eliminate in a very quick hurry, just by looking at the scenarios in many instances.

And you certainly don't want to employ the full rigor of the process on each of the scenarios, and I'm assuming that that's how you will -- how you would use it.

DR. DASGUPTA: Right. I mean, yes, the

level of --

CHAIRMAN GARRICK: The exercise of going through and developing the scenarios very often is the most valuable exercise in terms of relating the model to the physical characteristics of the facility. Once you do that, generally a lot of things become pretty obvious and you can narrow the scope of the problem.

Doing it in phases like that is extremely valuable, and I assume that's what you will do. You won't apply all of the rigor of your software to each scenario.

DR. DASGUPTA: You are right, and that will be built into the tool, not to go to all -- for example, we may not want to do a rigorous hazard analysis if we know there's only a handful of hazards that we need to look at.

CHAIRMAN GARRICK: Yes.

DR. DASGUPTA: Okay. So the tool -- you don't have to go from one end of the analysis to the other end. You can get in, develop your event scenarios, you can just go in and do your sequence analysis, but all -- at the end, the tool allows you to systematically put this data in a place, so that ultimately you can do your compliance assessment.

I hope I answered your question.

CHAIRMAN GARRICK: Yes. Any other -- this is an unfair question to close out this discussion on, but I'll ask it anyhow. Given that you have now taken basically the ISA thought process and evolved it into what appears to be almost a PRA format, if you had it all to do over again would you not consider just starting with a PRA established model?

DR. DASGUPTA: Well, to me, the only component of the ISA, as far as I understand about ISA, is the hazard identification part that we have --

CHAIRMAN GARRICK: Yes. But that's part of my point, Bis.

DR. DASGUPTA: Yes. And, in fact, when the PRA -- it's my understanding, I mean -- I came to this line much later, but my understanding is that when PRA was started, ISA or these hazard analysis techniques were not there. They came later on, primarily with the chemical industry.

And so we have added this facility. I mean, it's not that -- we kind of added this capability to do this qualitative hazard analysis to identify certain hazards. So beyond that, all of the analysis is primarily PRA-based in the tool. So that's the only part that we really borrowed from the ISA.

CHAIRMAN GARRICK: All right. Well, you can't help but ask the question given that this is kind of the founding agency for PRA, and there was an established legacy of methodology that was not only available but demonstrated with numerous applications, including fuel cycle applications. And I was just curious as to whether or not, if you had it to do over, you would maybe start from a different point than going to the chemical industry and pulling from that resource.

DR. DASGUPTA: Yes. Tim has something.

MR. McCARTIN: Yes. Tim McCartin, NRC staff. I guess when we put ISA in the rule, in our proposed rule, we weren't implying a suggestion that we were looking at ISA -- a term as a very broad class of analyses. PRA would be considered in that broad class. It was getting more -- and we probably made a mistake, and we -- obviously we did change the name in the final rule.

CHAIRMAN GARRICK: I'm sure glad of that.

(Laughter.)

MR. McCARTIN: Because we weren't -- there was not -- we were not trying to indicate a particular analysis but trying to identify a broad class. And consistent with what you were saying before, you need to do an analysis appropriate to the complexity of what you're dealing with, and there wasn't an attempt to exclude it.

And as Bis has explained, really this particular methodology has really, you know, pretty much all the elements of a PRA in many different ways. So, you know --

CHAIRMAN GARRICK: Well, that's enough. Thanks, Tim. I understand, and I just had to needle it a little bit.

(Laughter.)

Wake people up, you know.

All right. Are you finished, then?

DR. DASGUPTA: If you don't have any further questions.

CHAIRMAN GARRICK: Are there any more questions from staff? From anybody?

Okay. Is this a good time, Raj, to have a break?

DR. DASGUPTA: Yes.

CHAIRMAN GARRICK: Okay. Let's take a 15-minute break.

(Whereupon, the proceedings in the foregoing matter went off the record at 10:02 a.m. and went back on the record at

10:20 a.m.)

CHAIRMAN GARRICK: Okay. Let's see if we can resume. I have been informed that Mark Board wants to make a comment following these next series of presentations, and we want to be sure and allow him time to do that. So we have that on the agenda now.

I think I'm going to ask Committee Member, our token geoscientist, George Hornberger, to take the lead on these next presentations. George.

MR. HORNBERGER: Thanks, John. So we're going to proceed, and as Raj introduced, we're going to move in now to talk about some engineered barrier performance aspects. And, Goodluck, I think you're up first; is that right?

DR. OFOEGBU: Yes.

MR. HORNBERGER: Please proceed.

DR. OFOEGBU: My name is Goodluck Ofoegbu. I'm here to talk about the evolution of rockfall effects for input to performance and assessment calculations. The approach that I'm going to present today has been implemented in the MECHFAIL module of the TPA 5.0 code that will be described later in the afternoon. I'm not going to talk about MECHFAIL because there's a second presentation that will deal with that, only to point out that rockfall loading of the engineered barrier components is one of the quantities evaluated in the MECHFAIL code, and the objective in this presentation will be to explain the basis for the evaluation of rockfall that is documented in the -- I mean that is implemented in the MECHFAIL code and documented in their Company report.

The first thing I want to do is to explain that there are two aspects of rockfall evaluation. The pre-closure aspect focuses on the stability of the emplacement drifts. We'll look at information available for engineering design of the openings, a combination of some kind of inspection -- to determine if the openings will be sufficiently stable to support the pre-closure operations. And this information will be used as the input in pre-closure safety analysis. And that aspect -- this aspect -- the rockfall aspect of pre-closure safety analysis is not going to be discussed in this presentation. Our focus in this presentation is to look at the evaluation of rock fall to provide input to post-closure.

The difference, an important difference between post-closure and pre-closure is that, one. the repository is closed. The openings would no longer be available for any kind of engineering intervention. And any ground support provided during the pre-closure period would degrade with time and would ultimately lose its effectiveness and suspect that a part of the rock mass surrounding the opening would thereafter likely break into blocks. Some of these blocks would fall into the openings and slowly accumulate as rock rubble. Individual blocks falling into the opening strike the engineer by their components, which are the drip shield, and may deliver some dynamic loading to the component. The components have to be evaluated against their ability to withstand what they will do when subjected to that kind of loading.

The dead weight of the accumulated rock -- the dead weight of any accumulated rock will wear on the engineered by their components, and their capability to support such dead weight also needs to be evaluated. As the rocks break up from the roof area, they change the geometry of the roof, and as they accumulate in the opening, they also change the geometry. So, ultimately, what's the data say? Opening with an empty space with components may evolve into a mass of rubble, a mass or rubble, and this change in the configuration of the emplacement drifts need to be considered in the calculation of parameters of the near field environment, such as temperature, such as the flow of moisture and maybe other aspects.

So my intention with this one is to explain how we calculate the rock fall inputs into these aspects of performance assessment.

And to do that we're going to go through a number of topics. I don't want to dwell on them. I'll go right straight to the first one, which is dynamic rock-block impact on drip shield. Now, the interest in evaluating dynamic rock-block impact is to look at the potential for rock blocks that are large enough to cause damage to the drip shield, striking the drip shield. And the -- because of this in the lower lithophysal stratigraphic unit, which represents the bulk of the rock types that are likely to be encountered in the repository, it has been determined that the rock blocks that would form -- that are likely to form are individually too small to cause any damage as an individual dynamic impact. So because of that, dynamic impact on drip shield is not considered a concern for the lower lithophysal area of the repository.

But for the middle nonlithophysal area, there is potential for individual block -- rock blocks that can cause damage. An analysis of the block size distribution of the rock based on fractured data indicates that about 60 percent of the blocks will be less than one cubic meter. Considering the density of the rock, that's about 60 percent less than 2.5 metric tons. But there is 40 percent that is greater than that, and these need to be considered. About 35 percent lie in between 2.5 and about five metric tons.

MR. HORNBERGER: Goodluck, the basis of that is just fracture spacing?

DR. OFOEGBU: Yes. That is -- well --

MR. HORNBERGER: So is there any empirical evidence that blocks of this size actually do fall from openings like this?

DR. OFOEGBU: Yes. There is empirical evidence. There have been observations at the site, but we haven't -- the openings that have been there haven't been long enough to contribute the information that can be used to make this a definite number. In the geological engineering field, that's often the approach that is used to estimate block sizes. You look at the fracture distribution, try to take the two dimensional fracture that are collected from openings from outcrops, generalize them into three-dimensional models and try to calculate the size of blocks that would come from such models. So it is a model information, but it is done in a way consistent with the now practice.

CHAIRMAN GARRICK: I guess the key here is the breakaway frequency -- I'll call it breakaway, I don't know what the proper term is. But is there the kind of the evidence that would allow you to even with uncertainty to come up with some sort of a breakaway frequency of rocks as a function of size or size ranges?

DR. OFOEGBU: At Yucca Mountain that hasn't been done in practice other than looking at fracture model, but I thought of size before I looked at maybe a place where rock is blasted or something, measure sizes and come up with size distributions.

CHAIRMAN GARRICK: Okay. Thank you.

DR. OFOEGBU: Okay. But there are two important mitigating factors for dynamic rock-block impact in the middle nonlithophysal area. One of them is the percentage of repository that needs to be in this rock pipe, about 15 to 25 percent at this point, but the information indicates it's going to be less than about 30 percent of the repository that would be -- 30 percent of the emplacement drifts that would encounter this kind of rock.

The second one is that the rock blocks would accumulate in the opening, and once the drip shield is buried under the rock rubble, then any of the rock blocks falling will be falling on top of the rubble and would not be able to transfer significant impact to the drip shield. So because of these mitigating factors, we believe that dynamic rock-block impact needs to be studied but it does not deserve as much emphasis as the next assessment of the part of accumulated rock which we'll go into next.

And in looking at all the information available, the drifts -- our observation is that the drifts would be expected to experience rock form and eventually rubble will accumulate in the drifts. And this information is -- this observation is based on an analysis of empirical information from engineering experience and a computation of analysis that has been conducted based on these available designs from the repository.

Our engineering experience is that on the ground fractured rock needs ground support system and maintenance of the ground support system to keep them stable and prevent or reduce the appearance of rock fall. And when openings can no longer be provided with the ground support, with the maintained ground support system, such as abandoned mine openings, the experience is that after a certain amount of time such openings collapse. So this forms one of the contributing basis for the expectation that the emplacement drifts after they are abandoned are likely to collapse and fill with rubble. There have been analysis conducted that also supports the view that ground support systems will be needed to maintain the emplacement drifts in a stable condition, but that can only be done during the pre-closure period. So after post-closure, the expectation is that after an amount of time the openings will go through this experience. There is also DOE information that supports a similar conclusion, a similar observation.

MR. HORNBERGER: So these empirical observations, say, in abandoned mines, can you give me an indication of what the empirical data show with respect to, let's say, what fraction of a drift -- would nearly 100 percent of the drift be expected to collapse or just in sections?

DR. OFOEGBU: Well, the percentage is difficult to estimate based on that experience. And the problem with this is that on the ground rock engineering has primarily been concerned with stable openings. We try to prevent collapse of openings, and once the operation is finished, like in the case of mining, the opening is abandoned. And the only reason people have gone back is where collapse of the opening has produced a surface expression, such as sinkhole or something or where the opening did not collapse, in which case people can location it like ancient temples in some countries that can locationally go in. But this is only a fraction of the openings that have been constructed, and they don't give information that can be translated in terms of probability.

MR. HORNBERGER: Okay. And the second question that occurred to me is, again, in terms of the empirical evidence, is there empirical evidence as to the rates of degradation of the supports, whatever they may be, rock faults in this kind of fractured rock?

DR. OFOEGBU: There is empirical evidence, and let's talk about that when we -- I have maybe one or two slides on rates of degradation.

MR. PATRICK: If I could interject, Goodluck.

DR. OFOEGBU: Yes.

MR. PATRICK: This is Wes Patrick, Center Staff. I am probably among the most rank of the rank empiricists, Dr. Hornberger, so I appreciate the comments that you're bringing in on the importance of looking at the empirical evidence. But one of the things -- while encouraging our staff to look at the empirical evidence and analogs to the proposed repository, one of the problems that we confront immediately is that none of the examples we can find have had the type of thermal cycle that is of interest here. And that is driving this more and more in the direction of while not ignoring the empirical evidence that might be available, for instance, even evidence from the Nevada test site that might be applicable, we're also putting a very strong caution on the use of empirical information because uniquely in the case of Yucca Mountain there will be a cycle where stresses are increased due to a thermal pulse, and then those stresses will decrease over time. And we're going to have to rely more heavily on calculations there I think than we might otherwise like to do, those of us who do tend to take a more empirical approach.

DR. OFOEGBU: Okay. Having said that, we have to also take a look at the available empirical evidence and what they tell us about behavior of underground openings in fractured rock, and one of them is being presented here. This was compiled by Barton and a group before this, and what it looks like these openings that are stable, that are known to be stable. The dark circles -- the man-made openings and some of the squares where a few natural openings that were observed in the study. And this information is plotted against a rating of the rock mass quality. The lowest numbers indicates rock that are badly fractured, and the highest numbers indicates rocks that are less fractured. And what this led to was a kind of line that says that, okay, let me explain this. This one, this panel, the opening is really any dimension of the opening. In the case of a tunnel, for instance, there will be two spans. There will be the diameter of the tunnel and then the length of the tunnel. And considering all those, the information will be issued here and say that the stable openings tend to fall below a certain relationship line between span and rock mass quality.

The DOE people have indicated that they're going to use a -- they're likely to use a different approach for evaluating the mechanical quality of Yucca Mountain rock. So because of that, we don't expect that this will be directly applicable, but based on information we have up to the site recommendation analysis, most of that coming from the ESF paper, the rock -- the queue value for the Yucca Mountain rock would fall approximately between one and 15, and this is based on taking fractures along the ESF and looking at conditions at every five meter average or something like that, which would suggest that the maximum span of unsupported opening that one would expect based on this chart would be less than 20 meters.

The same kind of information, this one, I think, was compiled by Biezenoski based on South African experience and experience from other parts of the world and eventually this matured into a cog that was used for design of underground openings basically to determine at what point do you have to stop construction, go back and install support and then continue, because it's looking at the maximum standard time given a certain span, a certain unsupported span. And this, again, is plotted in terms of rock mass quality. The quality in this is Biezenoski rock mass, which the relationship can be related to the queue values that we showed in the previous chart. But the lower values represent rocks that are highly fractured, and the high values represent rocks that are less fractured. And here the standard time decreases as the span increases. It decreases along the lines such as those board lines. Again, the Yucca Mountain rock would have fallen in the poor rock to fair rock region, maybe a little bit in the good rock. And based on that, the standard time for an unsupported span of, let's say, two to ten meters, the standard time would be on the order of -- anticipated standard time would be on the order of months and years.

This information here, as I said, is often considered conservative, that a number of openings have survived beyond that, but if you were using and constructing a tunnel, for instance, and your concern is providing support so that the rock doesn't fall to hurt people, if you don't have any of that information, it will be considered very somewhat bold to try to go beyond what this chart recommends. But of course the more information you have about your site, then the more able you might be to try to extend beyond what is provided in this design chart.

Now, there is an example from a collapse of abandoned mine openings. This study was conducted I think in Bulgaria, was done by a master's degree student, and what they did was look at I think there were 79 occurrences of sinkholes in that area. And how the sinkhole develops this shows schematically on the figure on the right. The figure shows a coal seam and the number of rock layers above and below the coal seam. And, typically, in mining they will cut a section of the coal seam and extract it for economic purposes, and so when the mining is completed that's what the opening would look like. Then eventually when the mining is done they abandoned the openings and go. The material above the opening will begin to collapse into the opening, and the gradual collapse may at times work its way depending on certain property breaking characteristics of this rock, as we will talk about later. This may work its way to various heights.

In this particular case, there is a loose fragment of material above the coal area. And the fragmented material falls into the opening created by the collapse of the abandoned mine opening and eventually produces a surface expression that is called a sinkhole, and it's a problem for highways and buildings and others. So this is why this was -- this phenomenon is of interest and was studied. If it wasn't for the occurrence of the sinkhole, most likely there would be no information about the collapse of the mine.

But judging from the time of occurrence of the sinkhole relative to the time that the mine was known to be abandoned, this individual found that the majority of the sinkholes occurred -- about 70 percent of the sinkholes occurred about 60 years after the mine was abandoned, and about ten percent of the sinkholes occurred about 70 years after the mine was abandoned. So just in this case the occurrence of the sinkholes happened between 60 and 70 years after the mine was abandoned. Now, the occurrence of sinkhole may have been much -- may have been later, I shouldn't say much later. It's possible it occurred at the same time as the collapse of the opening, but it's also possible that it took a long time after that. So what this figure -- this is empirical evidence that suggests to us that the collapse of openings in this kind of rock will take a few tens of years at most. We have to acknowledge that these are not tunnels, these are mine openings. They have a geometry that increases space concentration and makes a geometry that is less stable than the -- geometry, but more important they are also quite large compared to the -- the openings are quite large compared to the mine area. So there are factors about these that will make them more susceptible to collapse than other kinds of openings. They haven't said that this is a piece of empirical evidence to go by and if one wants to go beyond these, then the person needs to come up with additional analysis or additional evidence to support extending the time of collapse beyond what is suggested by this kind of information.

MR. HORNBERGER: Goodluck, just so I understand this stuff, the study by Dyne, the 79 cases -- this frequency that you have here refers to 79 observed sinkholes; is that correct?

DR. OFOEGBU: That is correct.

MR. HORNBERGER: So we don't know anything about the population of openings that didn't exhibit sinkholes.

DR. OFOEGBU: Well, actually, the population of openings in this area has received a lot of study. We're just showing a sample from a study that was available to us. Unfortunately, this kind of study is not often made available, but there is -- the experience with these kinds of openings and this kind of rock is that they collapse. They are expected to collapse. There may be one or two that survive. Maybe instead of one or two let's say a small percentage that survive, but those are departures from the expected behavior. The expected behavior is that when this opening is abandoned they will collapse and they do -- they may progress to the surface and develop a surface expression. In fact, put the other way, it's only those that develop a surface expression that we are going to see.

MR. HORNBERGER: That's correct.

DR. OFOEGBU: The majority of them will probably end up here and maybe have a stiff material here.

MR. HORNBERGER: Right.

DR. OFOEGBU: So the surface expression doesn't develop.

MR. HORNBERGER: Right. But in this case am I right in assuming that these are sort of pothole sinkholes and not linear features? That is, that the whole drift here that collapses a very long segment or is just a surface expression of a part of a drift?

DR. OFOEGBU: This is a surface -- well, now, let's learn something. The figure to the right is also schematic explaining how this type of thing develops. The actual study is on the left, and that study doesn't really explain. What happened in this case is that a large mine or a large area over a large mine and these sinkholes usually occur as isolated holes within that area.

Okay. Now, going into analytical work, this is an analysis that we conducted a few years ago on pre-closure to try to estimate pre-closure stability. The information used for the analysis was taken from information that DOE -- was derived from information that DOE used to support its site recommendation. The design is the EDA design, EDA II design, which the drifts are 85 meters center to center from each other, and the diameter is 5.5 meters. The drifts are located at a depth of about 250 meters below the ground surface. So this analysis was extended to a time of 150 years. The only significance of the time here is the rate of decay of heat produced by nuclear waste.

We also looked at the effect of decreasing -- the rock mass strength here has two components: The cohesive component and the frictional component. We looked at the effect of decreasing the cohesive component along a hypothetical time decay occurs, from 100 percent of its value at time zero to about 50 percent of its value at time in 150 years. The time scale here really is not significant. It is the amount of decay that we were interested in.

Now, what this shows is that -- now, let me explain. This analysis is a continuing type of analysis and it was done using a continuum model of the rock mass. And continuing models such as this are enough to identify the onset of failure but they are not really known for calculating the extent of failure. Typically, these kind of analyses are used to determine the need for ground support systems, because the experience is that if you support that rock that is shown to have -- to be likely to fall, then if you can prevent failure of that, then it would attend the rest of the rock mass. On the other hand, the failure of that rock is not prevented, then the failure is likely to progress layer by layer and eat its way into the rock mass. That progressive growth is not shown here. The model used for this analysis is not capable of calculating that.

Wherever we see an inelastic strain it indicates where fracture in rock, and that's an interpretation, fracture in rock is likely to occur. And the common interpretation that usually comes out of this kind of analysis is to say, okay, we need ground support extending into the rock in certain circumstance in order to prevent failure of the fracture zone that was observed in the model. And because of that, the conclusion we can draw from this analysis is that ground support will be needed to maintain stable openings for this particular design and set of properties that we looked at. And the other conclusion, of course, is that when it is no longer possible to provide and maintain ground support system, then we should expect the openings to experience rock fall and the accumulation of rock insight.

There is another example from DOE analysis. This is a different kind of modeling. It tries to represent the rock mass using a set of polygons, and the contacts of the different polygons is assigned a strength and stiffness, and this is sort of tuned such that the overall behavior of the rock model is similar to the expected overall behavior of the rock mass. And a measure -- one important advantage of this kind of approach is that it's able to model failure, it's able to look at progressive failure and you're able to see the extent of failure and extent of failure calculated from the model and also the accumulation of rock within the opening.

In this particular case, what DOE was looking at again is the effect of decreasing cohesion to look at potential rock degradation. The rock strength is again represented -- the rock strength has two components -- The cohesive component, the frictional component. And they decrease the cohesive component from each -- one represent of each value in stats of 20 percent. By that it's 80 percent, 60 percent, 40 percent, 20 percent and zero percent cohesion. And they looked at the accumulation of rock in the opening. The one conclusion that we can draw from this study is that as the rock degrades we should expect the openings to experience rock fall and expect rock to accumulate inside the openings.

Now, having going through all these calculations, we've reached an expectation that the openings over time will collapse. But what we really need is a way to calculate the amount of rock that can accumulate in the openings and the rate at which this accumulation would occur. Each of -- I show several models -- well, examples from different model calculations. Here are several of the examples. And each of them is able to calculate something that others are not able to calculate. So it's -- taking the information directly from a single model, it's often not a way to do this. You need to draw some conclusions and try to represent those conclusions in an abstracted model that is then used to calculate the quantities that are needed.

Doing geomechanics modeling is like looking into a big house through a window. Each view -- each window gives a view of the house, and still the challenge is putting several views together to develop an image of what interior of the house will look like. If one relies on one view, it's quite possible to come up with a calculation that may be in error. So we've made the observation that openings are likely to collapse. We need to calculate rate of collapse and the amount of material accumulated as an important property of broken rubble that can be used, that when a piece of rocks breaks from the roof and falls, that it's likely -- not one piece of rock but a collection of rock pieces, they are likely to occupy more volume than they occupied within the rock mass. And this -- so as the material falls, more space is created, but the amount of space that the fallen rock occupies increases faster than the new space -- the amount of new space being created. So, ultimately, this increase in volume behavior or bulking behavior of rock has a property of arresting the progressive failure. Because when there is no space for rock to go into, the failure process has been stopped. So by using that, we are able to develop a mass balance approach that simply says that the mass of rock in the rock mass is equal to the mass of rubble that has fallen and apply this volumetric relationship and we are able to calculate the volume of material that can develop if this failure process were to progress to completion.

Another important input to that

calculation is the shape of the failure zone. There are several types of shapes that can occur. The elliptical shape -- hello? Did somebody say something? Okay. Not to us.

MR. HORNBERGER: One of your colleagues.

PARTICIPANT: Inadvertently.

DR. OFOEGBU: Okay. Yes. The elliptical shape is used often in rock engineering because the stress condition that develops at the apex of the equilibrium comprehensive stress date. So that once the opening has progressed to that shape, they tend to equilibrate and stop the growth. So there are other shapes, as we'll see later on, but using the elliptical shape and using the bulking behavior of rock and looking at the ranges of bulking factors from 1.1 to 1.5, we calculate a distribution of potential highs of the failure zone, which means potential amounts of loading transmitted to the engineered barrier system. I need to point out that the --

MR. HORNBERGER: Wouldn't a bulking factor of 1.1 almost require a stone mason to go in there and organize those?

DR. OFOEGBU: Yes. It's quite low but -- lower values. There is a paper we looked at recently that in fact did lower values, a value of 1.05, for --

MR. HORNBERGER: In broken rock? In broken rock? In rock like this?

DR. OFOEGBU: Yes. Yes. This was for a coal mine, and what we speculated is that maybe because of the stratified nature of the rock, maybe they were looking at plug failure in most of the cases. But the low values can occur. But, generally, we think this field of engineering the values are expected to lie in the 1.25 to 1.35 range. So when we chose 1.1 to 1.5, it is to try to target an average in that range. But I need to point out that the lithophysal nature of the lower lithophysal rock may actually, again, this is speculating, but it may lead to lower values for bulking factor than the nonlithophysal area.

Okay. DOE has looked at several ways of doing this. They've done something similar to what we did here. They said the shapes -- they looked at two types of shapes. We think that shapes should really progress to the elliptical geometry, both of them, but they do represent two range -- a range of shapes that one could call permissible in this kind of analysis. They also plotted numbers from the numerical model calculations, the volume model that I shared earlier.

We think that the numbers taken directly from the numerical model are smaller than the numbers from the analytical model because of action. Action is a process that developed because of the sheer strength of rock particles. If you have a large number of particles falling at the same time, they tend to -- they can at times develop particle arrangements that is much more open than events from what you would expect from particles that have been -- that are deposited in thin layers or that have experienced a long history.

But the thing is that action is an attestable state. It's an equilibrium state that depends on transient variables, one of them being the stress on the contact of the particles, and also the strength of the -- the potential for particles to share against each other. So that over time because of creep of particle contacts and because of ground vibration, the action would disappear and eventually the look at any point in the granular mass would approach the steady state value which is a product of the unit width and height of the -- the column height of the material.

Now, having said that, one has to acknowledge that action can occur, but you have to look at it -- it needs to be looked at as the relationship between the steady state value, the constant load, and slowly decreasing -- slowing increasing value because of decreasing action. So if somebody wants to take advantage of action to reduce the load in a granular mass, it becomes necessary to describe -- to characterize the transient nature of the action so that ultimately the loading approaches the steady state value. We think it's easier to just use the steady state value, but if one can come up with a function that describes the transient nature of action, consider the effects of creep on particles, effect of seismic potential and ground vibration from seismicity, then such a transient cover would definitely be one of the things that can be looked at.

The changing geometry of openings is an area we have a lot of interest because of potential effect on performance assessment. The effect on the loading, mechanical loading of the engineered barriers will be discussed in the next staff but we noticed that the people that calculate heat flow and moisture flow in the repository environment tend to use only this geometry that we believe will only occur during the pre-closure period. During the post-closure, the openings are going to transition. They're expected to transition from this geometry to that geometry, and we believe that that transition will take relatively short time. I will get a slide on that. So that the people that do performance assessment calculations need to ensure that the models they use take into consideration this change in geometry of the emplacement drifts.

It is expected that the changing geometry, that the accumulation of rock will occur within a few hundred years after the openings have been abandoned, that's after cessation of drift maintenance. And this is an order of my estimate. It's not built on model calculation, it's built on interpretation of available empirical data. It's believed that the ground support that is -- any ground support left in the openings will degrade and within a few tens of years will lose its effectiveness and will no longer be able to prevent fall of blocks from the roof area. And the information we presented earlier suggests that there will be additional tens of years for the openings to transition from the initial geometry to the anticipated long-term geometry. And in order of magnitude calculation such as this, we consider two stacks of tens of years that will lead you to a collapse time of approximately a few hundred years.

There is effort being made at DOE to

improve this calculation approach and that effort is sort of described briefly here. And what DOE intends to do is to do a static fatigue testing on rocks, rock samples from Yucca Mountain and try to use that information to somehow calculate the rate of drift degradation. Static fatigue has been -- rocks have been subjected to this kind of testing for a long time. What it is is you take -- in the standard compression testing of rocks, a rock is taken and the load is applied rapidly, and within a matter of a few seconds to a few minutes the rock fails. The standard of strength value obtained.

The value of rock strength obtained under this rapid loading condition is often not appropriate for calculating the behavior of rock underground openings instituted. A very good example of this was the Atomic Energy of Canada mined by experiment. They completed an opening, I think, about 420 meters below the plant surface in the underground research laboratory, and we did a few months notch at the opening, at the roof, roof failure. And several attempts were made to try to rebuke this notch using the continuum base models and the rock strengths derived from the conventional laboratory test where a rock is loaded and failed within a few seconds or minutes. And the experience was that we could not; in fact, that was my first exposure to static fatigue test.

We found that there was this work done by a group of people at the University of Winnipeg that indicated that if the rock is loaded slowly over an order of this kind of time scale, ranging from maybe one day to about ten days, that the strength of them would be between 60 and 70 percent of the strength that was obtained in the rapid loading condition. And by using this reduced strength, we could get results that somewhat resembled the observed notch. And later on a group of people at ITOSCA did analysis with a micromechanics model and this is the simulated behavior, static behavior is this here. And using that they were able to predict the notch that occurred in a few months. In fact, it was developed within two months of the construction of the opening.

Now, what we need to see here is that the order of seconds information was found inappropriate for calculating an order of one's behavior. And we needed an order of this information to predict a matter of months behavior accurately enough. So this raises a concern about using the static fatigue test, which is order of days information, to try to predict behavior that may be developed within an order of maybe hundreds of years or even thousands of years. The question we asked in there is whether the time scale of the test is applicable to the time scale of the calculation, and this question needs to be addressed in order to apply the static fatigue test in order to rely on drift degradation estimates that were calculated based on the static fatigue model.

And there are several ways that this can be approached. Maybe use -- apply the same model to existing critical cases where openings are known to have histories extending over tens of years like the example I showed in the coal mines. There are also openings at the Nevada test site that probably have the same time scale type of history. So somehow that combines this empirical information and maybe combining the modeling it might be possible to develop the information that can be used to address the scale effect, the time scale difference between the static fatigue test and the calculation time scale.

Well, to conclude, I need to point out that there are areas where NRC staff views are very similar to the DOE views in dynamic rock-block impact on drip shield. I think there seems to be a common understanding that this is not a concern in the lower lithophysal area. It is a concern in the middle nonlith area but the concern has a number of important mitigations. We believe that there is a common understanding that drifts will be expected to degrade and rubble will accumulate within the drifts within the 10,000-year period of regulatory concern.

Where there are differences is, first of all, regarding the amount of the static load from accumulated rubble. Really, the difference here is that the DOE hasn't said what it intends to do. They presented a range of different ways of looking at the problem, and, as I described earlier, we're kind of saying don't use -- we don't believe that using the information from the -- numerical information from the volume model would be an appropriate way to go because those have one big drawback is the action, unless somehow the characterization of the action -- time effects of action is included in the analysis and the appropriate technical basis provided for such characterization.

Now, on time of degradation I've already discussed. DOE intends to use a static fatigue test, and we believe that's a step in the right direction, but there are concerns that need to be addressed in using that approach. Then representation of drift degradation in the performance assessment, good. The site recommendation analysis did not include drift degradation. We've looked at DOE's nominal scenario in the TSPA-LA Methods and Approach document and the suggestion there again is that drift degradation is not included, but we are still discussing this. Thank you very much.

MR. HORNBERGER: Thank you, Goodluck. Questions from the Committee? Mike? John?

CHAIRMAN GARRICK: Has there been any back-of-the-envelope calculations or any type of analysis done that would indicate the effect on overall performance of increased drift degradation?

DR. OFOEGBU: Back of the envelope, no. People have speculated on things. There are a number of effects. One is on mechanical behavior of the engineered barrier system. How would the drip shield and waste package respond to that loading, and our group is going to discuss that in the next presentation. There is also a calculation on heat flow that shows with the accumulated rubble accounted for the temperature of the waste package will be higher than predicted. And this is from calculations done at the Center as well as an interpretation of backfill case calculations that DOE did a few years ago. So that has been done, but that increase in temperature, the implication of that on behavior of the engineered barrier system and behavior of the near -- space of near field has not been evaluated.

Then another area is seepage. In the seepage calculation, there is this assumption of calculated around the opening and that's predicated on the existence of an opening that we believe would not be there within a short time after closure of the repository. So we think that that needs to be modified and its effect on the calculation examined. Back of the envelope, it's not easy to do for this kind of thing.

CHAIRMAN GARRICK: Big envelope.

(Laughter.)

DR. OFOEGBU: Yes. Okay.

CHAIRMAN GARRICK: The other question is when you survey existing unsupported openings, what does the survey consist of? Is there monitoring equipment, degradation transducers of some sort or is it just an observation?

DR. OFOEGBU: Well, for openings that are currently used, there is usually monitoring equipment, but those openings also are usually supported. I mean they have ground support on them so they are not exactly applicable, but the information there can be used. But for openings that have been abandoned, no. In rare cases there might be, but usually there is not monitoring equipment. It's just going into observe.

CHAIRMAN GARRICK: Is it possible to monitor something like this in terms of how close you are to really having a rock falling situation?

DR. OFOEGBU: It is possible, and we believe that this is one of the approaches that DOE may use for the pre-closure period. For post-closure, because the time is so long, I don't know if --

CHAIRMAN GARRICK: Yes. Okay. Thank you.

DR. OFOEGBU: Thank you.

MR. HORNBERGER: Ruth?

MS. WEINER: This is a question asked out of complete ignorance of this entire process. When the rocks -- when the drifts degrade and the rocks fall, how much dust do you get? What percentage or what by some measure do you get dust, very fine particles accumulating in the interstices?

DR. OFOEGBU: There is dust. There is usually dust. I can't say how much. I don't know what the particle distribution would be, but there will be a certain amount of dust.

MR. HORNBERGER: Other questions? Staff?

Neil?

MR. COLEMAN: Neil Coleman, ACNW staff. I've had a chance to see or to enter tunnels at the site that have been isolated for a period of time, for many months, six to nine months, and something I noticed going in you do see debris that has fallen down, and what I saw ranged from sand size particles up to maybe a few centimeters. Over say 100 meters of tunnel it might add up to a kilo or two of material. But I don't know if this is a rate that's continuous, but I guess it tends to support the idea of -- this area is very well supported by steel sets and rock bolts. This is the ERCB east-west drift.

DR. OFOEGBU: Yes. For supported openings, the behavior will be different. For unsupported openings, you may see a similar behavior but what we need to point out is that these openings have a very short history so far, and often people see something and say, "Oh, that's a minor rock fall," but that is the beginning of rock fall. If it stops there, yes, it's minor, but if it progresses, as it's expected to be, then it's really the beginning of what may be much more important.

MR. HORNBERGER: Okay. Thanks very much, Goodluck, and I guess we'll go on to our next presentation on MECHFAIL. And, Doug, you going to do that?

DR. GUTE: Okay. Can you hear me? Okay. And I'll do my best to stick to the 30 minutes as best I can. As Goodluck just presented, he spent a lot of time going over the basis for the rockfall loads that we're assessing within the MECHFAIL module. Here we're going to get a little better of an -- better idea of the overview of what MECHFAIL does because we do assess other mechanical types of loads other than rock fall, in particular seismicity and some other issues that come into play when we want to assess the potential effects of mechanical damage on the engineered barrier system.

The presentation, I'm going to try to go quickly over the objective of MECHFAIL module, and overview of the EBS components that we're concerned about, some risk insights that have been done, and this kind of goes to your back-of-the-envelope calculation question earlier about how bad can it potentially be, then an overview of how we implement the MECHFAIL module, a characterization of mechanical loads, and Dr. Ofoegbu already discussed the stack and dynamic rockfall characterization aspects of the talk, so I'm just going to focus on seismicity in a very short way. Drip shield response to the mechanical loads. I want to point out and emphasize that the drip shield we have evaluated, or that has been evaluated, was released by the DOE in 1999. Since that time, we have had several discussions and technical exchanges in Appendix 70 and were able to convey that there were certain things that were overlooked in their original design analysis and assessment. They've gone back and looked at it, and they are in the process of reevaluating, reinforcing their designs or trying to take appropriate measures to improve the performance of the engineered barrier system components. We'll also look quickly at the waste package response to mechanical loads. We don't have a whole lot of detailed information here. It's more of where we're going in our analysis process at this time. And we'll have some closing observations.

The objective of the MECHFAIL module, though, is to approximate the temporal and spatial variations of the mechanical loads, in particular seismic and rockfall loading conditions. We want to assess accumulated damage because up to this point, historically, people have only focused on those one-time scenarios, what could potentially breach the drip shield and/or waste package as a one-time event? What happens when I have much higher frequency events that contribute a little bit of damage to the EBS system as you go along and as time progresses has enough of these higher probability events occurred to the point where I do ultimately still end up reaching the drip shield and/or waste package? So it has to do with the aspect of assessing the effect of accumulated damage on the system, and then try to identify the risk significant failure mechanisms that we should focus our review on.

The engineered barrier system components are the waste package, the drip shield, invert to the waste package pallet support. Some people say that the nuclear fuel cladding is not being taken credit for as an engineered barrier. It depends on which particular document you might be reading and how old it might be, but I've included in the list anyway because it does have an effect on the release of radionuclides, ultimately. And some people would argue because of the capillary diversion credit given to the drift, that the drift itself is also an engineered barrier.

From a risk insight perspective, we want to get kind of a sense of how bad it can be, your back-of-the-envelope calculation that you mentioned earlier. What they found is that if we take the drip shield or if the drip shield is taken out of the system, that the expected dose is only increased by roughly 75 percent. It doesn't seem to have a significant effect on overall repository performance, and that's taking the drip shield out of the system at the time of closure.

Okay. But the TPA code currently does not have the ability to assess the waste package response to direct rockfall loads at the present time, and we also don't consider the increased temperatures and potential seepage that may enter the drift as a result of the drift degradation processes. So what was looked at next was to take out both the drip shield and the waste package closure and see what effect it would have on the overall dose, and it was shown that the dose increases by approximately two orders of magnitude relative to the nominal scenario. But in both cases, the potential seepage and increased temperatures was not considered in the TPA analysis.

To assess mechanical failure in the TPA code, several things need to be assessed: The number of seismic events that could occur over the regulatory period, the temporal and spatial distributions of rockfall loads, both static and dynamic, the mechanical effects of these loads on the engineered barrier system, including potential interactions between them, and the applicable failure mechanisms and their respective failure criteria. Analyses have shown that the drip shield is prone to buckling, or the older design of the drip shield is prone to buckling. Also, do we need to look at fracture mechanics failure approach as opposed to the standard continuum mechanics failure criteria or methodology? That oftentimes is load- and material-dependent.

And also creep. It turns out that creep at elevated temperatures -- even though the indirect temperatures I think with in place backfill the maximum expected is around 350 degrees C, which may not seem to be that high of a temperature when you consider metals in typical applications, especially boiler pressure vessel type of applications. Turns out that titanium is highly susceptible to creep at relatively low temperatures, and for the titanium alloys that are being used in the construction of a drip shield the mechanical strength is also degraded quite significantly even at temperatures of 100 degrees C, let alone 330 degrees C, and I'll expand on that here in a little bit.

What has been already screened out from

the MECHFAIL module has been faulting as a potential significant mechanical loading condition or scenario. A lot of work's been done in this area. It's not expected to cause significant drip shield and waste package damage. The DOE is already committed to the fault-setback distance. If there are faults that they encounter during the boring of the drifts and so on and so forth and they know where faults are at, they will make sure that the drip shields and waste packages are a certain amount of distance away from there so as not to be directly affected by those faults. And when you go through and do a detailed analysis, you find that a very small percentage of drip shields and waste packages could potentially be affected by this type of mechanical loading mechanism.

Igneous intrusion, which is also under the mechanical disruption of engineered barriers ISI, which is really what we're trying to encompass within the MECHFAIL module, igneous intrusion also falls under that umbrella, but we have left that to the volcanologists to deal with in their own code modules and we're not going to go there.

One of the things I need to point out in the abstractions that have been developed for the MECHFAIL module we have not considered any of the material degradation or corrosion processes that could affect, ultimately affect, the structural performance capabilities of the engineered component system. For example, stress corrosion cracking can come into play, fabrication flaws and so on and so forth. I've got them listed here. We're working closely with the CLST people to try to incorporate these effects into the MECHFAIL module if we find that they are in fact risk significant. There's a lot of uncertainty still associated with whether there's appropriate environment to support stress corrosion cracking of the Alloy-22 material. We don't expect general or uniform corrosion to be an issue with regard to the waste package Alloy-22 outer barrier. However, a localized corrosion is still a concern, particularly in the areas of the weld seams in fabricating the waste package.

Going on from there, strain rate effects have also not been considered. Typically, high strain rates which could occur when I have a dynamic impact from a rock block that's falling from the ceiling or during a seismic event where things are being shaken quite rapidly, those high strain rates that the materials may experience typically illustrate or causes the material to have a much higher yield stress, but then again it reduces the ductility of the material. In other words, you can't stretch it as far out as you would like to or what it would under very slow applied loads until it fails.

To accommodate the accumulation of damage within the MECHFAIL module we found the most expedient way of doing that was to sum up the plastic strains associated with the event that might occur from one time step to the next. Typically, plastic strains dominate in magnitude the total strains that a material will incur. The elastic recovery or the elastic part of the strain is relatively small, even for very large stress fluctuations. And we found this, like I said, to be the most expedient way to try to accommodate the accumulation of damage or assessing the accumulation of damage from one disruptive event to the next.

Temperature effects. What I've got plotted here is some recent information developed by our TEF folks. The waste package temperature with emplaced backfill, as you can see, can be quite high right after closure, approximately 350 degrees C. That emplaced backfill is going in and taking crushed tuft or some other aggregate and placing it around the drip shield and waste package and filling it up as high as you possibly can to the top of the drift. An added benefit of doing that is that you end up decreasing the void space that the rock can fall into, and you end up building extra support for the drift ceiling and you don't develop these large, relatively large static rockfall loads or you don't have dynamic rockfall any longer. It supports the drift. But they have to deal with the elevated temperatures that go with it for several hundred years. But, ultimately, within the first thousand years you get down to temperatures that you would expect if you had just had an open drift anyway.

Now, with natural drift degradation using the degradation rates used within the MECHFAIL module, the waste package surface temperatures were estimated, and that's identified by the green curve here. The temperatures aren't nearly as high as they would be for the emplaced backfill case but still rather high, much higher than the 150 degree C range that has been typically considered to be a maximum value, if you will. And it turns out to be still quite significant from a mechanical property standpoint, and I'll show you that on the next slide. For all of our analyses this plot was generated after we had done a great deal of our work, and we were using the ultimate drip temperatures for our mechanical properties, and that was assumed to be 150 degrees C.

What I wanted to quickly show here is that a lot of people don't recognize or realize that these temperatures can have a significant effect on the mechanical properties of the EBS components, particularly with regard to titanium grade 7, which is the plating material for the drip shield. These are normalized yield strength values on the left. Yield strength is at the point when the material no longer behaves in a linear fashion. Once you exceed that stress it plastically deform and it won't spring back to its original shape. And these are normalized with respect to their room temperature values, all right? At approximately 150 degrees C, the titanium grade 7 plate its yield strength has been reduced by 30 to 35 percent relative to room temperature. This was not considered in the original deal reassessment of their drip shield design, and this is, in my opinion, one of the major oversights in that initial design process.

After we get up to the natural backfill condition, the maximum temperature being around 250 degrees C, it's reduced by roughly 60 to 65 percent, but once again the rockfall loads haven't necessarily fully manifested themselves at that point either.

Then we have similar behavior for the other materials. Also, I want to point out that the ultimate tensile strength is also significantly reduced. The ultimate tensile strength is the point at which it can no longer carry any more stress and for all intents and purposes it's been breached at that point.

One of the things I want to point out, though, is that this can be overused in the sense that just because you get to that stress level or you make some approximations that you're approaching the ultimate stress, you don't want to necessarily say that you've breached the system. It turns out that Alloy-22 is very, very ductile material, and you have to get roughly 60 percent strained before you get to failure. So when we start approaching stresses of this magnitude, we recognize we're going to undergo a lot of plastic deformation, the contact between maybe the drip shield and the waste package in the contact area may increase significantly.

By the contact area increasing, we're reducing the overall average stress, and therefore you may not ultimately end up breaching material. You want to take advantage of the ductility of that material. That's why we're trying to base the accumulation of damage on plastic strains, the accumulation of plastic strains, because you want to take advantage of what the material gives you, and it would be premature just to do an easy stress analysis and say, "I've breached it," because that's not the case, because you've got all this plastic deformation or ductility available in the material.

Characterization of seismic loads, I'll just go over this very quickly. It's based upon -- the TPA code uses the seismic hazard curve data developed for a rock outcrop on the surface. It's characterized in terms of the mean peak horizontal ground acceleration within the TPA code. That's the only parameter at the present time we have to work with in assessing what kind of damage may be incurred by the EBS system under seismic conditions. There isn't enough data at this point to determine whether that's sufficient to make a fair assessment of the EBS under seismic conditions. That work is still underway, so I'm not sure if this is going to be ultimately sufficient or if we're going to need more information in the long run or not.

And I'm sure you guys have heard about this before and are well familiar with the low frequency or low probability of occurrence earthquakes, what their magnitude should be or won't be, whether they should be capped or not, so there's a lot of variation and potential variation of what could happen here. Whether those are risk-significant loads or not I'll leave to the PA folks to explain in the future. Apparently, if I assume that a ten to the minus six event fails all the drip shields and waste packages and the releases are simply through the ground surface, when you combine that dose with that probability it's not really risk significant. But what we're concerned about here from a seismic standpoint is can I accumulate damage from the much higher frequency earthquakes such that at the end of a couple thousand years have there been enough of these events to ultimately end up causing breaching to occur anyway? I don't want to focus just on one event causes failure and if it doesn't, then I forget about it. I need to know what the highest seismic load can be -- or, actually, let me turn that around, what the lowest seismic load is that would cause potential damage to the waste package. We need to start accumulating that damage. Is it a ten to the minus three earthquake, is it a ten to the minus four, ten to the minus five earthquake before I start seeing appreciable damage on the system?

Right now we feel like the TPA sampling

methodology is a good way or a good approach for dealing with the high frequency -- high probability seismic events, but if we get into the lower probability events, we probably have to look at it as scenarios, unique scenarios.

For the response to the drip shield of seismic loads, we haven't performed any detailed seismic ground motion time history analysis as of yet. We're in the process of doing that. Before we develop the models for this type of analysis, we're performing Eigenvalue analyses to get a sense of where the natural frequencies of the system are. Natural frequencies are a strong part of how systems behave under seismic loads. Will the natural frequencies of the system be excited or not? Is the potential for dynamic amplification of the response there? One of the other questions that has yet to be answered is what effect will these accumulated masses or rockfall loads on the system have? Will the rock mass move in phase with the drip shield? Will it respond as one? Will they counteract each other, and we will ultimately have kind of a mass vamping scenario? There's a lot of uncertainty here.

The analysis that have been done to date indicate that the drip shield has several natural frequencies below this 33 hertz threshold. The 33 hertz threshold is important because that's where the vast majority of the energy associated with the seismic event lies within that frequency spectrum. It depends on whether it's a freestanding drip shield, whether they bolt it to the invert floor or weld it to the invert floor. All these things can have an effect on how the system will behave under seismic conditions.

Moving on to static rockfall loads, here's our process level model. It was recognized very early that when I had drift degradation the rubble accumulating on the sides of the drip shield will provide some structural support, and we felt it was very inappropriate not to take some consideration for that structure support in assessing the capabilities of the drip shield and how it will respond under these static low conditions. We've modeled it as a continuum. Now, how much stiffness is associated with that rock rubble is a very difficult thing to get a handle on. There's a lot of variability potentially there, so what we did was a sensitivity analysis varying the Young's modulus of that rock mass on the side of the drip shield to get a sense of how it could affect the overall response of the static loads.

MR. HORNBERGER: What's the basis for the depth distribution there on the previous slide?

DR. GUTE: You mean as far as --

MR. HORNBERGER: Yes.

DR. GUTE: -- from the depth?

MR. HORNBERGER: Your blue curve.

DR. GUTE: Oh, the blue here?

MR. HORNBERGER: Yes.

DR. GUTE: This is the boundary of the drift, of the drift wall. And it goes up in the --

MR. HORNBERGER: So that's not a pressure distribution on the curve.

DR. GUTE: No, no. Actually, this is displacement constraint. This is an interface where we're allowing this to slide along the drift wall, the original drift wall. And everything above this point is degraded above it. And then we've got the overburden pressure assigned on the top surface here and also the appropriate pressure over the crown of the drip shield as well.

MR. HORNBERGER: Okay.

DR. GUTE: The results indicated that the buckling load of the drip shield is really sensitive to the Young's modulus that was assigned to the rock mass on the side. Based on this information, along with some insight into the deficiencies of our process level model, we've taken advantage of symmetry, boundary conditions, loading conditions, not necessarily the elevated the temperature to the 250 degree C that we saw earlier. There's a number of things that come into play. Putting all the information together, like Goodluck talked earlier, you just can't look at one piece of the analysis and come to a conclusion. Putting all of our knowledge together we developed a distribution for the appropriate buckling load of the drip shields that would be assigned throughout from within the MECHFAIL module.

I neglected to point out earlier and I need to resolve that now is we account for spatial distributions or variations within the MECHFAIL code by breaking each of the TPA code subareas into two spatial grids. One spatial grid represents the lower lithophysal rock, the other spatial grid represents the middle nonlithophysal, because there are unique properties associated with both. The important ones are the bulking factor. For example, the bulking factor for the lower lithophysal could be potentially much smaller than for the middle nonlithophysal, so we have different ranges there. Am I running out of time? Okay.

What else? There's a few other parameters that we do vary spatially, so that is accounted for in the MECHFAIL module. So we're accounting for both the spatial and temporal variations in the number of our key parameters.

Okay. One last note here: During a seismic event, the effective loads of the accumulated rockfall is also increased to account for the seismic conditions. Right now we have no idea if there's any potential dynamic amplification within the rock itself, how does it respond to seismic loads, those types of things? But right now we're just treating it as dead weight, rigid body that is increased by whatever the PGA of that particular seismic event might be.

Drip shield response to dynamic rockfall loads, here's a quick overview of the model. One of the important things to note here is that our rock block has an infinite strength and a response and a purely elastic matter. Now, everybody recognizes that when the rock block impacts the drip shield it's likely to fracture in places. It's hard to say whether it will be highly localized or whether it will be a general fracturing of the rock block, but there was kind of an understanding between us and DOE where we did not want to spend all of our resources and time trying to figure out how much of the energy associated with the rock block is taken up by the rock block fracturing, because really what is the important thing on our mind is how well is the drip shield going to perform under these conditions? So we've taken the approach that the rock block should be modeled as -- well, I shouldn't say should but it's acceptable to model it as a purely elastic body and not get too hung up on its fracturing and how much energy is being dissipated. Because as it ultimately was shown to be that this is not a highly risk-significant mechanical loading scenario.

And Goodluck mentioned this earlier, a couple of the assumptions in the MECHFAIL module is that once a half meter of rubble is built above of the drip shield crown, the effect of that dynamic rock block coming down and hitting the drip shield is pretty much mitigated, and so we don't worry about its effect on the drip shield per se, hitting it directly. We do, though, consider the accumulation of that rockfall into the static rockfall loads. That is accounted for. Also, dynamic rock block loads have been assumed to only occur during seismic events. The accumulated rockfall loads are characterized in terms of the time degradation rate that's been assigned to that particular spatial grid element, and it's controlled by its bulking factor and some other parameters. But dynamic rockfall only occurs during a seismic event.

Here's an example of the analyses that were conducted at the Center illustrating the response of the drip shield to a two-ton per meter rock block. The stresses turn out to be exceptionally high here in the transition area between the side and the crown, in this area here, and also up in the reinforcing bulkhead and the transition between the plate and the supporting bulkhead here. Another item to point is because it has been assumed that the dynamic rock blocks only occur during seismic events, that the invert is also moving upward at a constant one meter per second over the duration of the analysis.

From this information, we ran a number of these, we were able to abstract or characterize drip shield displacement, velocity, equivalent plastic strains, Von Mises Stress and a number of things in terms of rock block mass and its fall height.

Waste package response to seismic and rockfall loads, not a whole lot of work has been completed in this area. We've been working on this quite vigorously for the last year or so. Once again, the response to seismic ground motion time histories has not been assessed. We're currently in the middle of an Eigenvalue analysis to determine what the natural frequencies of the individual components in the overall system are. We have not conducted any analyses to assess the response of the waste package to direct rockfall loads. DOE is committed to protecting the waste package from those rockfall loads by way of the drip shield.

One of the things that could potentially be an issue here, and let me see if I've got this on the next slide, has to do with drip shield and waste package interactions. What happens when the drip shield buckles is that it transfers that load to the waste package, and the design that we're evaluating has these roughly four centimeter thick bulkheads underneath the crown of the drip shield and based upon our estimates of the rockfall loads, which is anywhere from 40 to 160 tons per meter length of drift, that load is all being focused on a per meter length because these bulkheads are separated by approximately one meter. All that load is being transmitted to the waste package through that bulkhead that's only four centimeters wide. There's no guarantee also that that bulkhead will be resting flat on the waste package. Chances are it's going to be skewed a little bit and the edge of that particular beam could be eating or digging into the waste package.

And we're conducting analysis now to find out how much plastic deformation must be incurred by the waste package before it can reach equilibrium to support those loads above it that are being transferred to it. Ultimately, the drip shield may be shown to not buckle at all once they come in with their revised design, but that design is not available to us now for reevaluation and consideration in the current abstractions we have in the MECHFAIL module.

That's under static conditions. The issue also becomes exacerbated under seismic conditions. Let's say I've got this large static rockfall load, the bulkhead's digging into the waste package surface, I've reached some equilibrium point, I'm okay, but now a seismic event comes along. What's it going to take now to cause more plastic straining of the waste package to get me to failure? And those are all questions that have yet to be answered, and hopefully we'll be getting those answers here in the next six months or so.

Let's see, MECHFAIL module outputs are the modules. We provide the percentage of drip shield failures. And by failure there's two aspects of failure when we're talking about the drip shield here. One is continuing to protect the waste package from rockfall loads, and the other is has it been breached? Now, right now if it does buckle, there are localized plastic strains that occur as a result of the large displacements associated with the buckling that also causes local breaching to occur. The size and extent of those breaches is very difficult to quantify, but we do have a pretty good idea of where the general area of those are, but quantifying the sizes is a difficult thing to do.

Percentage of waste package failure on subarea time step basis, and here's another area I need to emphasize. Right now the MECHFAIL module does not predict any performance parameters of the waste package at all. We don't have the abstractions in place. Although we have the place holders in the MECHFAIL module code to insert the abstractions and the logic and everything is there, the specific abstractions necessary to assess what potential waste package failure has yet to be implemented within the MECHFAIL module. All we can predict right now is we have a pretty good handle on -- and I shouldn't say predict -- but estimate the potential drip shield response to these mechanical loads. Okay?

Preliminary results indicate that on average 75 percent of the drip shields buckle under static rockfall loads within 500 years after closure. Degradation of the invert may increase drip shield interactions with the waste package. Up to now many of these models have simply assumed that the invert remains intact. However, the invert is made of carbon steel structural framework. That carbon steel is going to corrode very quickly after closure, if not -- actually, this is kind of an issue during the pre-closure timeframe as well because carbon steel apparently corrodes very quickly in the presence of nitrate, and from what I understand, the nitrates are being taken credit for as being a corrosion inhibitor for the Alloy-22. So it's either one or the other. But, anyway, the carbon steel is expected to corrode rather quickly. The aggregate, which may be highly compacted or whatever, that exists between the structural framework of the invert could have a very high compressive strength but then again it probably doesn't have much of a tensile or sheer strength unless they provide some type of cement material to enhance its mechanical properties or behavior. But that invert could degrade quite quickly, and how good is that -- of a support does it provide the engineered barrier system, and do we end up with -- the drip shield legs or feet is a very small surface area, and with the rockfall accumulating above it, it could settle into the drift in very odd orientations. And the same with the waste package.

Let's see, it's not clear to us that when DOE does come out with the update design that we were going to have to go back and redo all this analysis again. Conceptually, once we're all done with this stuff, we may find that based on the information we have that the current performance characteristics are enough to say that, "Hey, this really isn't risk significant." That information doesn't exist yet, but ultimately we prove to ourselves, and DOE may provide the information to support this, that it's not a major problem. But on the other hand, if it's ultimately shown that this drip shield-waste package interactions does lead to a significant number of or percentage of waste package failures or concerns, it's going to have to be taken into consideration and evaluated, taken the time to evaluate the new drip shield design in more detail when it is ultimately released.

And that's the end of my talk. Any questions?

MR. HORNBERGER: Yes. Thanks, Doug. Am I -- let's see if I have a main message here from what I've heard in the past two talks. Is one of the main points that from a risk insights perspective it is the static loading and hence the calculation or assumptions of rock fall and the extent of rock fall and the loads produced by rock fall is probably the most important thing?

DR. GUTE: It's what's driving the system really from a mechanical failure point of view, from my perspective. Those are the design basis loads or the expected loads that need to be considered in assessing how the EBS will behave or respond under seismic conditions as well as just the static loads themselves.

MR. HORNBERGER: Okay. Thanks. Mike? John?

CHAIRMAN GARRICK: I just wanted to comment and make it a question, and that is that in your risk insight statement you said that the removal of the drip shield will increase the dose some 75 percent. That strikes me as maybe this is a "no never mind" issue given the fact that the dose calculation itself, I suspect, has an uncertainty associated with it by a factor of at least ten and probably more between the fifth and 95 percentile. So why are we fussing around with this?

DR. GUTE: Well, if you take the drip shield out of the system, you no longer have a rock shield for the waste package.

CHAIRMAN GARRICK: I know.

DR. GUTE: Okay.

CHAIRMAN GARRICK: But I'm thinking about the end result here. So what?

DR. GUTE: Well, as I said, we're --

CHAIRMAN GARRICK: If you remove the drip shield and you only get an increase of 75 percent in the dose, why do I care?

DR. GUTE: Well, the TPA code does not consider the potential failure of the waste package from those direct rockfall loads.

CHAIRMAN GARRICK: I'm not communicating. I'm saying that I don't care if the rocks come in if it doesn't affect the performance substantially, and your risk insights information is telling me it doesn't affect the performance.

DR. GUTE: No, it affects -- well, if you just take out the drip shields and assume nothing happens to the waste package, your interpretation is correct. However, the TPA code does not take into consideration the potential failure modes of the waste package that occur because the drip shield is not there. We're taking credit for the drip shield being --

CHAIRMAN GARRICK: Has that calculation been done?

DR. GUTE: Well, that's why the second part of the calculation was done to take out both the drip shields and the waste packages to see as --

CHAIRMAN GARRICK: Yes, but how much of the waste package was taken out?

DR. GUTE: One hundred percent.

CHAIRMAN GARRICK: Well, see, that's an irrelevant -- that's a nonsensical assumption.

DR. GUTE: Yes, it is -- well, it's a back-of-the-envelope calculation is what it is.

CHAIRMAN GARRICK: Yes, right.

(Laughter.)

DR. GUTE: Because it's convenient, because we don't have enough information to make any more detailed assessment at this point.

CHAIRMAN GARRICK: Yes. Well, I always like to look at the so what question.

DR. GUTE: Well, I appreciate that. That's fine.

CHAIRMAN GARRICK: What is the consequence here of rocks falling in on the waste package? Does it really make that much matter given the uncertainties that are involved? Given that you're two orders of magnitude below the standard, given that there's probably a factor of ten to 100 uncertainty associated with the dose calculation, what kind of impact does this really have?

DR. GUTE: Well, as I mentioned earlier, when you take away both the drip shield and the waste package, you end up increasing the dose by two orders of magnitude and not --

CHAIRMAN GARRICK: Yes, but that isn't -- I'm talking about physical reality --

DR. GUTE: Yes.

CHAIRMAN GARRICK: -- and in terms of our knowledge of the analysis. And our knowledge of the analysis -- we should be able to calculate within a certain uncertainty what the dose is as a result of what we expect to actually happen, and if we're now saying that what we expect to happen is that we're going to fill these tunnels up with rocks in a few hundred years rather than a few tens of thousands of years, that ought to be something that's very calculable. That's all I'm saying.

DR. GUTE: Well, I appreciate what you're saying, but -- yes?

PARTICIPANT: Tim wants to say something.

DR. GUTE: Oh, okay. Go ahead, Tim. Thanks.

MR. McCARTIN: I think we agree with you, Dr. Garrick. I guess one thing I would like to supplement some of the things that Doug's saying. Although label the risk insight, there is a part of that calculation we will take out the drip shield. But as he was saying, the only thing accounted for there is the fact that now we have more water coming in. And so that increase in dose was really due to fill-up time for our bathtub model primarily, and so the dose occurred a little earlier and becomes a little larger. Part of the risk insight, though, is also that what isn't accounted for, and that's the explanation of we didn't account -- that calculation doesn't account for the ability of the -- the capability of the drip shield --

CHAIRMAN GARRICK: I guess --

MR. McCARTIN: -- to limit the deleterious chemistries getting on the waste package. And that needs to be looked at, and so that part that, gee, without the drip shield, maybe corrosion of the waste package could occur sooner and there could be other effects that the TPA code isn't accounting for.

CHAIRMAN GARRICK: Right.

MR. McCARTIN: So there are some other aspects that go beyond just that number.

CHAIRMAN GARRICK: Yes. I understand. Okay.

MR. HORNBERGER: Of course, when we talk about taking out the drip shield, the understanding in terms of the risk insight doesn't mean that we necessarily have to consider that the drip shield has been physically removed.

CHAIRMAN GARRICK: No.

MR. HORNBERGER: We just mean that some of it, a portion of its capability has been compromised, and I think that's the thrust of the question.

CHAIRMAN GARRICK: Yes. Right, right. It is.

MR. HORNBERGER: Ruth?

MS. WEINER: I have two kind of unrelated questions. When you talk about performance of the drip shield, something interfering with performance, are you talking about something in addition to just protecting the waste package from drips?

DR. GUTE: From the water from --

MS. WEINER: Yes, from water.

DR. GUTE: We look at it from a mechanical standpoint. I view it as more of a rock shield than a drip shield, because it is taking credit by the DOE to protect the waste package from all rockfall loads.

MS. WEINER: Okay. That was one question. The other thing is you have a code that calculates all this stuff, you know, deformities and so on. Have you ever looked at how your MECHFAIL code would calculate falls and stresses in the waste isolation pilot plant, for example? I mean here is a place where you've really had rockfalls and you really do have impacts on stuff, barrels that are sitting there. Would that make a good calibration benchmark, whatever?

DR. GUTE: Well, what you're saying is have we validated our finite element and computational models.

MS. WEINER: Yes.

DR. GUTE: We have significant experience, several decades of experience doing this type of modeling effort. NRC has accepted over I don't know how many years now these computational models for assessing transportation casks, accident scenarios, the behavior of the materials are fairly well understood under these types of conditions, the appropriate assumptions are pretty well understood. So validating these models against actual empirical situations has really been done quite a bit way back in the '60s and '70s at Sandia Labs, NASA and any other applications, and we have a lot of confidence that these are pretty good approximations of the behavior of the system.

MS. WEINER: So you used a finite element model like the kinds we used at Sandia to --

DR. GUTE: Or any other --

MS. WEINER: -- look at the deformation casks.

DR. GUTE: Absolutely. Absolutely.

MS. WEINER: Thank you.

MR. HORNBERGER: Questions from staff? Any other questions? Neil?

MR. COLEMAN: Neil Coleman, ACNW staff. Doug, how important is seismicity in your drip shield calculations?

DR. GUTE: Actually, little to none. What happens is that the -- based on the current design and the abstractions as they were developed, it turns out that, as I pointed out, 75 percent of the drip shields, on average, fail or buckle within the first 500 years, so there's very little seismic activity in that first 500 years. At the end of 1,000 years, and I just talked to somebody the other day about this to get a handle on where the code stands and what type of behavior they're getting out of the MECHFAIL module, because all we really did was develop the individual abstractions and then we put it all together, and what the ultimate result was we had no idea. So we wanted to get -- see what the results were as to what's dominating failures, what can happen.

From what I understand, the current output from the MECHFAIL module indicates that buckling in roughly 80, 85 percent of the drip shields within the first 1,000 years, and the remaining 15 to 20 percent experience creep failures in the titanium plate. But, once again, that's under mean conditions. That's a single realization under mean input value, so there's not a lot of different variations as far as playing around with the distributions and everything as you would get from maybe doing 500 realizations. But that's the information I have now, but it's not dependent on seismic loads to cause that buckling to occur.

What I saw early on when we were first

developing this was after that first 1,000 years because the code assumes that the -- I shouldn't say assumes, but our abstractions indicate that the static rockfall loads will have fully manifested themselves within the first 1,000 years, at that point we've got all these drip shields that buckled and within the next 9,000 years you see maybe a small percentage of additional buckling occurring because of the seismic activity beyond that point, but it's not significant.

MR. HORNBERGER: Good. Thanks very much, Doug. We have at least one --

CHAIRMAN GARRICK: We have two.

MR. HORNBERGER: Two.

CHAIRMAN GARRICK: Raj wants to make a comment, and then we'll hear from Mark.

MR. NATARAJA: This is Raj Nataraja, NRC staff. I'd like to make a couple of closing remarks, basically. First, I would like to thank you for this opportunity to brief you on these two topics which we think are risk significant based on the information we know. And it may so happen that you will be hearing a lot about these things within a short time when you go to Nevada. Hearing presentations might cover some of these similar topics. So we thought it was appropriate for you to listen to the staff views before you went for this meeting with DOE there.

And I don't want to say too much about the PCSA. I think we are on the right track. We all agree that it is son of PRA, if you want to call it. But we'll have a lot more work that we'll do in the coming --

CHAIRMAN GARRICK: SPRA, a pseudo-PRA.

MR. NATARAJA: Okay. And we will work with more examples and more kinds of designs as the information becomes available.

As far as the drift degradation issue is concerned, as you know, it's a very complex topic and we don't have any simple techniques to use to come up with predictions. And DOE and NRC staff have been discussing this issue for a long time, and whatever we have said here is not -- no surprises here. DOE has heard these before, and I'm sure Mark Board is going to make some final remarks, and his observations may not agree with our observations, but we also know that. We have had these discussions. We will have more discussions on this topic.

And the reason why we have done what we have done is because of the fact that there were assumptions made which we thought were not technically supportable. Why we expect the -- there is a lot of lateral radiability within the repository horizon. There might be some sections which will remain stable for a long time relatively. There might be other sections which might collapse relatively shortly after the post-closure starts. So there's going to be a whole range of conditions, and in reality things are somewhere in between. They may not be totally elliptic with 160 feet of rock sitting on top of -- it may not be a clean opening, but all these have to be factored into the performance assessment, and already it is just a fear of KTI. We don't do the consequences. So we are sort of forcing this issue on the PA so that they look at the impacts and it's the goal of DOE to show it's a "no, never mind." It may be "no, never mind," but I don't think that we have the information to make that conclusion and decide. So that's what I wanted to just say, and hopefully with this background when you go and visit the DOE you will have the entire picture before you. Thank you once again, and I would like to thank all the staff from the Center who spent a lot of time preparing for this, and we had a number of rehearsals. It's look like it paid off. We are well within our time.

CHAIRMAN GARRICK: Well, we would like to thank them too. The presentations were very interesting, and we realize the preliminary nature of them.

MR. NATARAJA: Thank you.

CHAIRMAN GARRICK: All right. Mark?

MR. BOARD: My name is Mark Board, and I am the Subsurface Project Engineer for BSC at the Yucca Mountain site, and I just wanted -- well, first of all, I just wanted to state a couple of things that I thought were probably necessary to be stated in regard to the calculations that you saw, because we do see things a little bit differently. And I know you're coming out in another month and we'll show you our calculations and take you underground and look at the rock, and perhaps we could have more discussion at that point in time. So I'm not going to go into any of that but I just wanted to overview perhaps where we have a little bit of differences.

First of all, I want to thank Raj. I just wanted to point out that I think we have a very good working relationship and information exchange with the people from the Center and from NRC. I think we've had some very frank technical exchanges and discussions with them, and I feel that they've been very open in sharing information, so I want to thank them for that.

And I also want to agree with Wes Patrick. He said in his opening statement that we need to be very careful with using empirical mining studies to make extrapolations for this particular problem. And I want to second that point. Most of what you saw today is based on empirical calculations that are extrapolations from mining studies, and you need to be very careful with those studies, because they're typically based on situations where the rock has been subjected to very high stress levels, high extraction ratios because people want to make money. It's an economic situation. So they mine as much as possible right to the level where the rock is going to give them problems and collapse.

For example, the coal mining example that you showed, the extraction ratios are typically very high with high pillar stresses in a laterally or horizontally bedded deposit which is what promotes vertical piping and collapse. And in our case we've got tunnels that are very widely spaced apart. They're five and a half meters spaced on 85-meter centers, and I don't recall that's an extraction ratio certainly of less than ten percent, which means that the excavations act as isolated headings that don't interact with one another from a stress standpoint.

And we feel that you can't simply take empirical studies and extrapolate those things with our situation because it just doesn't necessarily apply.

If you look at the current ESF and ECRB excavations there that we have right now, which have been open for about seven years, five to seven years time, we have excavations as large as 25 feet in diameter that have been mined in probably our poorest quality lower lithophysal unit that don't have any recorded ground falls or rockfalls at all in that five- to seven-year span of time, and they're monitored very closely. Plus we measure deformations and those excavations have been stable from a deformation standpoint since they were excavated. So just keep in mind that although it's not 1,000-year timeframe, we do have some examples there.

Just to point out that NRC's approach has been on an empirical approach where they calculate depth of failure and time to failure based on empirical methods, and they ultimately have to lead to very conservative results or on the very high end of the scale. The reason being that all these things like stand-up time are things that were developed for the mining or tunneling industry to keep people safe, almost like OSHA requirements that state that you can't send people into work under an unsupported roof after it's been open for so many hours.

Very clearly, if you look at things like stand-up time curves, you see times in hours or days there that even good quality rock stands up for. Well, we know that that's from a collapse standpoint is ludicrous. We have many, many excavations around the world that are unsupported that have very large spans that have been open for hundreds of years. I could take you to Sweden down in the Stora coppermine where every kind of Sweden dating back to Gustavus Adolphus has signed the wall of a main entry chamber that's unsupported since the 1500s, and tour groups are taken down there. So it's very clear that this doesn't necessarily apply to all rocks. It's really a tunneling contracting type of a situation.

We feel, from our standpoint, it's much more important to try and understand the mechanics of how the rock behaves and use extrapolations based on an understanding of mechanics as opposed to the empirical route, although we try to use that -- we've been trying to use it to calibrate our models. And what we've been trying to do is use parametric studies to see just how sensitive the response is to variations in rock properties, stress conditions and things like that. So we are using different approaches.

I think the bottom line is I certainly think we agree with the comments that Goodluck and Doug made, and that's that the static weight of the broken rock is the important issue. It's probably not so much the seismic issue, but it's that static weight of the rock that's important. We differ with them on the depth that the rock fails and the load that's applied to the static -- to the drip shield and the timing over which that happens. We think it's going to occur over a much longer period of time than what they do. Now, maybe in the end result that's going to be splitting hairs depending on what the TSPA model says. I really don't know right now. We're just trying to take it from the calculations standpoint that we're at to try and show what those loads and things are. I really can't tell you, I don't really know what the ultimate impact is going to be. What I can tell you is is that we are taking into account these different effects in the TSPA model. I know originally that, and they are correct, that the statement was that tunnels will be soon be circular for all time. We are now taking into account drift degradation in our calculations, so it's part of the calculation.

CHAIRMAN GARRICK: Okay. Thank you.

MR. BOARD: Thanks.

CHAIRMAN GARRICK: There's no comments from anybody? Okay. Any other questions? Comments? Hearing none, we will adjourn for lunch. Get back at 1:15 -- 1:30.

(Whereupon, the foregoing matter went off the record at 12:13 p.m. and went back on the record at 1:32 p.m.)

CHAIRMAN GARRICK: Our meeting will come to order.

This afternoon we're going to have a presentation on the response to the external peer review of the total system performance assessment, and we're going to have a presentation on the total system performance assessment Version 5.0 code. And I guess we're going to do the peer review first. Is that correct? And to do that we have John Peckenpaugh, and why don't you proceed.

MR. CAMPBELL: John, I'm going to do a brief introduction. I'm Andy Campbell. I'm Chief of the Performance Assessment Section. And I just wanted to make sure that people are going to understand that we have two presentations today.

One, John is going to be talking about the peer review and some of the outcomes of the peer review that was done on TPA 3.2, and he'll talk briefly about some of the changes that were made in TPA 4.0 and 4.1.

And then, he'll be followed by Chris Grossman, who will talk in some level of detail about TPA 5.0, which is the code -- TPA code we're going to run -- roll into licensing for review of issues while we're doing a review of the license application.

And I just wanted to make sure that everybody is aware that the purpose of our code is to be a flexible and independent tool for reviewing both prelicensing issues with DOE as well as licensing issues that may come up in the course of a review of the license application.

We believe that the enhancements to that code, which are based on a variety of sources, increase our capability and flexibility to evaluate what the key issues are, and we also have increased confidence in the code that it's an appropriate tool for LA review.

So with those brief remarks, I'll turn it over to John.

CHAIRMAN GARRICK: Okay. Thank you.

Thank you.

Go ahead, John.

MR. PECKENPAUGH: Okay. My presentation today will cover the response to the external peer review of the total system performance assessment Version 3.2 code. This presentation is based upon the response to the external peer review which was published in February of 2003.

Several staff members contributed to this presentation. The main contributors were Lane Howard from the Center for Nuclear Waste and Regulatory Analyses, and James Firth from the NRC.

An overview of this presentation includes the purpose and goals of the external peer review, external peer review comments, staff responses to the comments, TPA code changes, and a summary.

The rationale for performing the external peer review of TPA 3.2 includes the following. In October 1997, the ACNW recommended an external peer review of the TPA code be conducted. The review was conducted during the summer of 1999 to document both the capabilities and the limitations of the TPA 3.2 code, and to evaluate the suitability for use in reviewing the DOE license application.

NRC staff and others believed that an

external peer review should help the NRC staff plan enhancements to the TPA code in preparation for the potential licensing review.

The external peer review complemented other steps used to provide confidence in the TPA code. Several years ago, the NRC staff decided that it would benefit from independently developing its own total systems performance assessment code, TPA.

This TPA tool has two primary purposes. First, it is one of several tools used in prelicensing reviews, and it's anticipated that it will be used in the DOE license application. Second, it plays an important role in helping the staff develop risk insights to guide NRC reviews and other independent investigations.

Because of the importance of the code in review and risk insight activities, several measures are used to provide confidence in the code results, in addition to the external peer review. The code is developed under a former quality assurance program. Specific software controls are used to ensure that the proper version is being used. Software validation testing has been conducted. Appropriate use is made of comparison with DOE results, benchmarking, checks against analytic solutions, and the use of analog information.

The external peer review group, ERG, consisted of eight members with expertise in rock mechanics and mining engineering, volcanology, hydrology, material science, and corrosion engineering, geochemistry, performance assessment, future events and processes analysis, and health physics.

The last slide in your handout lists the actual members of the ERG. Members of the ERG were selected either by peer acclamation or by staff recommendations. Selections were limited by conflict of interest and availability of the potential group members.

Purpose and goals of the external peer review group were the following. The ERG was asked to perform the following items pertaining to the TPA code -- examine the methods and assumptions, recommend improvements for future versions of the TPA code, evaluate interpretations of conceptual models, including parameter selections, determine whether the NRC approach to TPA is sufficient to review the DOE license application for the proposed Yucca Mountain repository.

Each member of the ERG submitted an

independent review. A consensus report was not developed. However, the NRC did encourage the ERG to communicate with each other. The NRC also held a group kickoff meeting for the ERG with several days of briefing and discussions.

The major external peer review comments were the following. The code was well developed and captured the important physical processes associated with the repository. The code would be sufficient in technical quality and flexibility to be used in the review of the license application. However, improvements would enhance the code.

Reviewers provided several suggestions for implementation in the code, including comments on modeling coupled processes, improving the modeling of chemical composition of the water, data used in modeling the saturated zone, basis for selecting the radionuclides tracked, and code documentation.

ERG felt that the TPA documentation did not explain the technical bases for the model extractions, input data, parameter values, and probabilistic approaches adequately. They also believe that the overall transparency of the code would be enhanced by preparing documents that explain how features, events, and processes were included or excluded from the code.

Response to the external peer review comments. Processing and tracking. A spreadsheet is being used to track the resolution of the 233 unique comments by the ERG. Comments were grouped according to issue areas, assigned to appropriate NRC CNWRA staff. Responses were developed and documented in the final report. All comments were addressed. The spreadsheet is periodically updated.

Staff responses to the comments. Most responses to the comments did not require enhancement to the TPA code. For example, some of the comments pertained to project design changes by the DOE while other comments pertain to other DOE issues.

Responses to comments that did result in enhancement to the TPA code, responses -- or response was addressed as TPA code changes in Version 4.0 or 4.1, or response would be considered in a future version of the TPA code. And the current version is TPA 5.0.

Currently, approximately 17 percent of the comments have resulted in modification to the TPA code. Responses to comments that were addressed through improvements in the TPA code documentation -- justification was provided in User's Guide 4.0, or justification will be provided in User's Guide 5.0 when it is completed. Currently, approximately 12 percent of the comments require additional documentation to the user's guide.

All comments were addressed in response -- in the response to the external peer review report. The major responses to comments that have not been previously mentioned are the following -- a citation in the report of the documented sensitivity analysis or other report that indicated that the issue or comment does not affect the calculation.

And, finally, in response -- and the report indicated that assumptions made in the modeling or selection of parameters are reasonable. In some cases, this required additional documentation.

TPA code enhancements, both external peer review and staff generated. Based upon the recommendations by the ERG and the staff, changes were made in Versions 4.0 and 4.1 of the TPA code. I will briefly discuss some of these changes. However, changes in Version 5.0 of the TPA code will be covered in a following presentation by Chris Grossman.

Changes in TPA 4.0 or 4.1 code. A number of the recommendations for the TPA code modification by the ERG were already being considered by the staff.

Some changes in the TPA code were based upon ERG comments. One example is a modification in the code to provide the ability to specify different waste package failure models -- bathtub or flow-through models -- or different failure types.

Some changes in the code were based upon staff recommendations. An example is when the code was changed to modify the amount of water that can enter the waste package by adding time-dependent flow rate factors.

In summary, the external peer review identified some areas of the TPA code that could be improved. Several of the comments were addressed within versions 4.0, 4.1, and 5.0 of the TPA code. The external peer review of TPA 3.2 code provided additional confidence that the code reasonably models the repository system and is appropriate for use in review of the DOE license application.

If you would like additional information on the response to the external peer review of TPA 3.2, I'd recommend that you examine the second reference on this slide.

And this concludes my presentation. Are there any questions?

CHAIRMAN GARRICK: Any questions?

MEMBER WEINER: You had a slide early on -- I'm desperately trying to find it here -- that said that the peer review panel decided that -- let me find it. It said that the code was well developed and captured the important physical processes associated with the repository and would be sufficient in technical quality and flexibility, and so on.

How did they -- can you say briefly how they reached that conclusion? Or maybe the reverse. What would they have needed to have found in order not to reach that conclusion? That might be easier.

MR. PECKENPAUGH: Well, as I mentioned, there were eight members on the panel, and each developed their own responses. It wasn't -- they didn't do it jointly.

And the staff then went through each comment, and all of the comments of the different panel members are presented as appendices in the report that I referenced. And staff determined that overall, based on the comments of the different eight panel members, that they really -- they didn't have severe objections to the way the code has been developed to represent the physical system.

But they did have a number of comments, which the staff has attempted to address either through changes in the code or additional documentation in the user's guide or additional explanation through siting of peer review journals and additional documentation that were included in the report.

I'm not sure if I really answered your question.

MEMBER WEINER: You did answer it. The other question is, during the course of the peer review, were the results that you obtained, the output of this code, compared with any other performance assessment codes using the same or very similar inputs?

MR. PECKENPAUGH: Well, I'll just briefly discuss the process in which the peer review is conducted, and maybe other people -- staff members can then come in at the end to maybe add some additional clarification.

But the peer review itself was conducted over a fairly short period of time during the summer of 1999 over less than three months. And the way it was initially set up, the staff was given -- not the staff, but the panel members were given TPA 3.2 code, and the user's guide for TPA 3.2, and then a NUREG that has some information on sensitivity analysis and uncertainty that was run on the previous version of the code. I think it was 3.1.

And they looked these documents over over a period of about six weeks or so, and then they met in San Antonio for a number of days to have this -- what they call a kickoff meeting, and then they were briefed by the staff and they had a chance to have questions back and forth.

And then, they went back and I think it was over -- I think it was a two- to three-week period after -- excuse me, a three- to four-week period they had to finalize the review and submit their written reports.

MEMBER WEINER: So the answer to the question, did they compare the outputs to any other performance assessment code, the answer is essentially no.

MR. PECKENPAUGH: Well, they did ask, and they had the opportunity to ask for additional information from the NRC, and we did provide that. But I don't know if we actually provided any other codes to them to look at or not.

MEMBER WEINER: Okay.

MR. PECKENPAUGH: I don't believe so, but --

MR. WITTMEYER: John and members of the ACNW, this is Gordon Wittmeyer, staff at the Center in San Antonio. We didn't do the explicit comparison of the results of our TPA code, then Version 3.2, to the DOE results. I think, though, that a number of the individual reviewers consulted DOE reports.

I don't think they looked at the performance assessment results, but they certainly looked at the DOE model extractions or saturated zone flow for geochemistry. I think also for waste package models.

MEMBER WEINER: Thank you.

CHAIRMAN GARRICK: George?

MEMBER HORNBERGER: Yes. It's been a little while since I read the external peer review, and I will admit that although I've gotten the second volume that you have on the screen up there I haven't had a chance to look at it yet. So forgive me if I'm not totally up to date on everything.

You gave just a couple of quick examples, John. And in particular, you said, "Well, okay. Based upon ERG comments, the ability to specify different waste package failure modes, etcetera, bathtub," that that was a change. Did you pick that example because that was the most -- thought to be the most important comment that you got from the peer review? Or if it isn't, could you tell me what you think are the three top comments you got that led to changes in the code?

MR. PECKENPAUGH: I'll answer your second question first. I'm not sure I can answer which were the top three. But there is a little bit of uncertainty within the -- based on the comments, which ones were entirely from the -- we know what comments came from the ERG. But in many cases, the staff felt a -- and in some cases they were already working on making some of these changes in the code anyway.

MEMBER HORNBERGER: Right.

MR. PECKENPAUGH: So I tried to pick one example that we felt was definitely a comment that the staff wasn't anticipating doing any work on, and that's why I selected that one.

Now, other staff members might have a better feel for your second question.

MEMBER HORNBERGER: Yes. Gordon, aren't you going to weigh in on that one?

MR. WITTMEYER: The other comment that comes to mind that -- where the one member had extreme concerns was about saturated zone flow and transport. And that was based on, at least at that time, the relative absence of data in the alluvium.

I think that since that time we've certainly - the DOE and Nye County have gathered more data, and the Center staff in hydrology have developed much more refined process-level models, and we still use the same basic extraction. You know, development of a manifold -- from the repository location to the receptor location.

But we have addressed that, and that has really been, you know, largely due to time and more data being gathered. I'm trying to think if there are others that come to mind. I think the usual concerns about coupled processes and how they are linked in something that -- like the TPA code, which really functions in a serial fashion. We've only been able to address that by doing a better job of establishing end states for various coupled thermal hydrologic chemical processes.

I'd ask other people here and at the NRC if they recollect anything else that was, you know, a big ticket item from the ERG.

MR. McCARTIN: Yes. Tim McCartin, NRC staff. One comment, not so much towards the code itself but towards the documentation that I remember, the way the peer review -- as John described, they had the documentation, and then we had the meeting. And they came to the meeting with a lot of questions, and actually at least two or three of the members, maybe more, felt we had done a very superficial job based on the documentation.

Having heard us explain everything that we had thought through in getting to the extracted models, etcetera, they said, "You really sold yourself short with your documentation. You actually have considered a lot more than what you've put down there." And, of course, they wanted us -- you need to do a lot more documentation of this now.

Part of that is, well, the Department of Energy will, in their application as a review tool -- we felt we didn't have to do quite as much. But it was an interesting perspective that in developing the user's manual we certainly weren't as comprehensive as when we explained things. And that was an interesting part of the -- some of their perspective on what they read. And I think Dave has some --

MR. ESH: This is Dave Esh with the NRC staff. I can add to your first question about where the changes come from basically. TPA 4.0 and 4.1 were at least under discussion, and I would even say under development whenever the TPA 3.2 peer review was ongoing.

So it's really hard to put your finger on -- it's a chicken/egg type of thing, who came up with it first. Well, that really isn't important to us as long as the important changes got made.

One change that I can think of when you asked about top three, I think we had a number of comments from our geochemistry representative. And some of our models were pretty crude, and a geochemist might say they are still crude, but that's an area that I think we improved a lot. And maybe Chris Grossman might say something about that during his presentation.

VICE CHAIRMAN RYAN: Dave just answered my question.

CHAIRMAN GARRICK: Oh, good.

I wanted to comment on one thing. You indicated that you didn't have an integrated report from the peer reviews, but you had individual reports. But as I recall, there was a lot of interaction among the peer reviewers, were there not?

MR. PECKENPAUGH: Yes. And it was encouraged to, as I mentioned -- that the external peer review group were encouraged to talk back and forth or call back and forth to discuss things with each other. I mean, that was not prohibited. We actually actively encouraged them to do that, and they were encouraged also to ask for additional documents if they felt it would be useful to them, too.

CHAIRMAN GARRICK: Yes. One other thought here. I notice in the issues that you've identified that none of them were -- had to do with the probabilistic issues, and I would have expected some of those. Is that because everybody was satisfied with the way you handled probabilistic issues? Or is it because it was a lack of expertise on the peer review in that area?

MR. PECKENPAUGH: I'm going to have to defer that to some of the other staff members that are more familiar with that area.

MR. WITTMEYER: This is Gordon Wittmeyer at the Center in San Antonio. Brian Thompson was probably our foremost expert in probabilistic methods who was on the external review group. He did make some comments not about the -- it's not about the code in general, but he had some comments about the use of unbounded distributions, which would be something we need to check with in building our input data.

He also had some comments about our sampling procedures, about whether we needed to consider switching from Latin hypercube to perhaps something that -- you know, an important sampling method to do a better job of giving the extremes of the output distribution well defined.

Those are things I don't think we -- the latter we haven't done anything in detail recently. We certainly are going back as we do versions of the code and trying to develop more technical basis for the input distribution, the input parameter distributions, make sure that the tails don't stretch off into a region that's not physically possible or plausible, comments in that general area.

CHAIRMAN GARRICK: Were there any comments regarding having built-in algorithms for updating data using, for example, inferential methods such as Bayesian updates?

MR. WITTMEYER: I do not recall.

CHAIRMAN GARRICK: Okay.

MR. WITTMEYER: There may have been, but I certainly don't recall that.

CHAIRMAN GARRICK: Okay. Any other questions?

MEMBER WEINER: I have --

CHAIRMAN GARRICK: Thank you. Okay, Ruth.

MEMBER WEINER: -- one more to whoever

wants to answer it. Did the reviewers -- were the reviewers able to structure their own distributions from the input data, or is this something that the code did? And did you get any comments on that question?

MR. WITTMEYER: This is Gordon Wittmeyer at the Center again. We did not ask them to conduct any sort of a -- you know, well, we didn't conduct an expert elicitation to try and get new data from them. And I don't recall -- I frankly don't recall if any of them reanalyzed any of the information that was provided in the documents on process-level models to see whether or not they would have a different take on, you know, the distributions we abstracted for input parameters.

MEMBER WEINER: My question was not, did they provide new data, but for the waste isolation pilot plant, we put out a little volume that said essentially, "If your data looks like this, this is the kind of distribution we recommend." And I wondered if they could -- taking whatever data they had, if they structured their own distribution or if you gave them guidance.

MR. WITTMEYER: We didn't really address that topic. We didn't discuss things like whether or not we should always use maximum entropy type distributions or anything like that in this external review.

MEMBER WEINER: Thank you.

CHAIRMAN GARRICK: Just as a kind of a follow-on to that. There are a number of PRA codes around the country that have excellent data packages in them that have full updating capability and processing capability that, you know, you may want to look at in terms of possible modifications for your own code.

And I don't know what data packages you have in your code, but I do know that in a number of PRA code packages the distinguishing feature between the really good ones and the not so good ones has been the capability in the code to process data. And as I say, I don't know how far you've pushed the TPA in that arena, but it is something you may want to consider. It's certainly something you don't need to start from scratch on.

Anything -- any other questions? Yes, Mike.

MR. LEE: Just one question. On slides 3 and 12, you make reference to confidence-building measures that kind of developed as a result of peer review. In some parlances, confidence-building has also been referred to model validation, which gets everyone's Irish up if you will, because it means many things to many people.

But are there plans to do additional confidence-building in relation to the -- how the code models the system, the repository system at Yucca Mountain, especially in light of the fact that both NRC and DOE take different views on the behavior of the vadose zone, unsaturated zone hydrology?

MR. PECKENPAUGH: Well, I mentioned that we did do -- we have done software validation testing.

MR. LEE: But that's --

MR. PECKENPAUGH: That's --

MR. LEE: That's kind of getting into evaluating the numerical capability of the code --

MR. PECKENPAUGH: Right.

MR. LEE: -- which is -- some people call verification, but, I mean --

MR. PECKENPAUGH: Right.

MR. LEE: -- aside from that, is there --

MR. PECKENPAUGH: You'd have to address that to other staff members.

MR. LEE: You alluded to work on algorithms. Are you comparing C-well test results with how the -- what comes out of the stream tube analysis that Gordon referred to a little bit?

MR. McCARTIN: Tim McCartin, NRC staff. Well, certainly, from the NRC staff standpoint, there is the key technical issue people, the discipline people, that are looking at the DOE information. We certainly look at it in PA, but as both Center and NRC scientists are looking at the DOE information.

In terms of our particular code, I mean, it's more of a review tool. And we have an ability to look at a variety of different ways. It depends on what the Department comes in with.

MR. LEE: Okay. Thank you.

MR. ESH: Yes, this is Dave Esh. I would add to that, Mike, you know, that we -- take, for example, the spent fuel dissolution. We have basically four different data sets, or you could call it conceptual models that we can implement to look at effects of that change.

But to answer your question very directly, we haven't done a validation exercise per se to say which one of those applies. We just have the flexibility to use any one of those as we may, so --

MR. LEE: Okay. I wasn't implying that the same level of validation was necessary in the NRC code as in DOE's code, because the burden falls on DOE. I was just curious as to what level of --

MR. ESH: John mentioned the software validation testing, and you're correct that that's different than conceptual model validation.

MR. LEE: Right.

MR. ESH: But even that software validation testing has elements of model validation in it. There were some elements in that test plan of comparing code models to experimental results, seeing how they compare that sort of thing.

MR. LEE: Sure. Okay. Thank you.

CHAIRMAN GARRICK: Any other questions or comments? Thanks, John.

Chris?

MR. GROSSMAN: Just one second, please, while I get the slides set up.

(Pause.)

Okay. I want to thank you for inviting us to talk about the external peer review and the modifications that we've made to the TPA code. And before I go too much further, can you hear me through the microphone system? Okay. Sorry.

My name is Chris Grossman, and I am a member of the performance assessment staff here in the

Division of Waste Management. And I've been kind of the point person for the TPA code, but I wanted to make it clear that the TPA code is a big effort of the performance assessment group and the staff in general, and it encompasses a lot of people, both here and at the Center. A lot of people put a lot of time and effort into this code to make it what it is.

So as the point person, I get the honor of coming before you to present the information. If you recall, last March this committee held a workshop or a working group on performance assessment in which members of the staff came and presented on the TPA code. And at that meeting we had the opportunity to present -- to give staff's envision of what the role of the code is in the process for Yucca Mountain.

We provided an overview of the conceptual models within the code, as well as some specific details regarding the source term modeling, and then also a brief understanding of the results that have come out of the code.

And so I would refer some of the newer members of the committee back to that presentation or those sets of presentations in March for a fuller overview of the entire code. The presentation I'll talk about here today deals more with just the modifications that have been made between 4.1 and 5.0.

I'd like to start off providing just a brief overview, and first I want to reiterate what our vision is for the code -- the review of a potential license application for Yucca Mountain.

Next, I'd like to step through briefly just the development process. I don't want to bog you down in the details of the process, but to give you an idea of how this occurs here and at the Center, follow that up with the role that the external peer review -- tying this in with John's presentation of how the external peer review played a role in TPA 5.0 modifications, and then get to the meat of this talk, which are the -- some of the significant modifications or what I'll call major modifications that were made for 5.0, and then conclude with the path forward and a vision for how we intend to use the code going forward.

So starting off with our vision of what TPA -- of how TPA fits into the program, it is a review tool. And unlike the Department of Energy's TSPA model, which will be a compliance demonstration, the TPA code was developed specifically with this task in mind of being a review tool and not a compliance demonstration.

It does allow us to have an independent capability to test and probe DOE's model. And where possible, as we develop that independent capability, we base it off of fundamental principles and available data.

We also -- two other considerations that we take into account when developing the code are flexibility, so that we can evaluate a lot of different scenarios so to speak, or different cases in DOE's case, whatever that might be, because that's an evolving -- I'll refrain from using the term I was thinking, but it's an evolving document.

And, finally, we also consider computational efficiency. The code is really no good to the staff if we can't use it quickly to get the results we need. We can't be burdened with -- it would be troublesome to be burdened by lengthy algorithms and calculations.

A brief overview of the development process. Basically, the planning for TPA 5.0 began back in 2001, which is actually shortly before I started. But at that time, staff identified modifications that we felt would enhance the capability. And we based these modifications or these proposed modifications off of criteria, which I'll explain a little bit later, that we used to decide what got in and what didn't at this point.

The modifications are described in the software requirements description, which I believe was provided to the committee in advance of the meeting. And the specific implementation of these modifications are documented in a series of software change requests at the Center, which is kind of a QA tool as we develop the code.

The development activities then continued through this past summer. In July 2003 is when they wrapped up. And then, the end of the development I should note coincided with some confirmatory testing activities which was another confidence-building activity.

In the planning process we used several sources to arrive at proposed modifications. Notably, the external peer review was considered, and the responses we had from the peer reviewers. We also relied on our review of DOE documents, the TSPA SR and the supplemental science and performance analyses, as well as using the TPA code, past versions of the code, and the experience we've gained from that.

And then, finally, a discussion among the KTIs and what processes would be desired to be considered within the code. And, finally, the modifications that were identified were meant to enhance our capability to review a potential DOE license application.

Some of the specific criteria that we used when determining potential modifications are listed here on the slide. Most notably, we had to be ready -- we had to prepare our capability to review potential license application from DOE for Yucca Mountain. So that's kind of the chief criteria.

Secondly, would the modification improve staff understanding of the repository system? And this relates to other areas in terms of developing our independent understanding and determining -- not determining but having an idea of what's important within the system.

The final two criteria, as I mentioned earlier -- I'll reiterate those -- is we'd like to enhance the flexibility in our models, and the input and output, so that we can handle a lot of different cases, if possible, and then also maintain computational efficiency.

I'd like to note at the end that many of the modifications that met these criteria were also recommendations from the external peer review.

Okay. So kind of the heart of the matter here, what modifications were made, and the conceptual model modifications -- and I'm going to break these into two categories, which are kind of my own doing. I'll call them major and minor. And this terminology doesn't really relate to significance or risk significance or anything. It's just some were more complex or bigger tasks than others, so I'm going to dwell on those -- on the major modifications as opposed to the minor enhancements to the existing conceptual models.

The minor enhancements are included in supplementary material at the back of the presentation, so that you can get a sense of some of those. And then there are also modifications to the executive driver of the code, which were really mostly to accommodate flexibility and new data that characterize the system.

And, again, I just want to reiterate that -- and the following slides are not going to talk to the entire code, but just some of the major modifications.

So the first one, and what I consider kind of a big one, is near-field chemistry. We added a new conceptual model to describe the chemistry that is considered important for corrosion modeling. And just to note that this was also one of the external peer review recommendations dealing with near-field chemistry.

But essentially here, if you consider their three periods for the repository system -- you have before a thermal dryout period, you have during a thermal dryout period, and then following a thermal dryout period -- and this conceptual model deals largely with during the dryout period.

And what we have is -- it's considered the critical period for corrosion, because what you have is evaporation processes going on, and you are concentrating brines on the surfaces of the engineered barriers. And if we were to attain a high relative humidity during this time, it could lead to delicate questions of the salts in which a thin film of water forms on the salts -- on the surfaces.

This combination of the high relative humidity with the increased concentration of species such as chloride, which are important to the corrosion chemistry, could lead to an increased chance of localized corrosion.

So the Center did some extensive process-level modeling using equilibrium software to develop a range of chemistry that is sampled in the code. That range of chemistry covers the concentrated brines. And what we find, then, from this model is that it leads to an increased chance of localized corrosion. And when we do see -- whereas in the past we saw little to none, we're now seeing some in a few more realizations.

The other two areas I talked about were before dryout and after dryout. The model -- the way the model abstracts those two periods is that before and after they're done similarly, and right now they are based on ambient poor water, the J-13 water.

The code also has the flexibility to specify chemistry as a function of temperature, although that data is not currently in the code.

The second area, as we kind of move through serially, of the code -- the drip shield, and I'll talk a little bit about the model here for the drip shield lifetime. There are actually two improvements to the drip shield which was in a previous version in a different form.

The first one which I'm going to deal with deals with corrosion of the drip shield, and more specifically general corrosion. The second one, which is the drift degradation effects on the drip shield, were talked about this morning. So I'm not going to go into those in too much detail. You may have had more than your fill for the day for that topic.

CHAIRMAN GARRICK: You may be right.

(Laughter.)

MR. GROSSMAN: This upgrade to the drip shield model was done to improve some of the realism in the code, and we use -- what we do is we use data for titanium-7 to develop a range of corrosion rates. And this data is similar to what was used before to develop the distribution failure times.

And that range of corrosion rates are then sampled, and we calculate a drip shield thickness versus time, based on degradation to general corrosion.

Here the failure time affects -- the drip shield, again, affects the water contacting the waste package, and the code offers the flexibility to specify different chloride concentrations on the waste package. Some of the output from this change doesn't really result in any major change from previous versions, largely because it's built on the same data that was -- or similar data to what was used before.

And then, as I mentioned, there was also the MECHFAIL edition, but I'll leave that.

Moving on to the waste package, then, we added a new model to describe weld corrosion, and this was done largely to enhance our review capability. Based on a review of the site recommendation, it was found that DOE was attributing most of the doses during the compliance period to diffusion through stress corrosion cracks. So this model was kind of developed to help our capability to review that.

Essentially what happens here is that you have small failures in the weld areas, and what this graph shows -- I'll use this. Okay. Keep in mind for their corrosion abstraction -- is that if the corrosion potential goes above the repassivation potential, then we see an increased chance for localized corrosion.

So on this graph we have some data that the Center developed for thermally-aged specimens, and these were aged five minutes at 870 degrees Celsius. And this is alloy-22, and the solid line represents the mill-annealed, which would be essentially the alloy-22 on the waste package itself. And the dashed line represents the aged alloy-22.

And what we see is that the repassivation potential is lower for the thermally-aged than it is for the mill-annealed, which suggests that it could possibly experience an increased potential for localized corrosion. So we use this data, then, to bound areas for parts of the waste package such as the weld, which would be in some sense thermally-aged due to the welding process.

The abstraction, then, is similar to our waste package corrosion modeling, with the exception that we use parameters tailored to the weld areas. What this does is when weld failure occurs, then it affects the amount of water entering the waste package, which is a function of the geometry of the weld area.

It turns out to be kind of a minor effect, and that's largely due to the fact that in practice the parameters used for the weld area didn't result in much change from the actual waste package. And what you see is that though you have some weld failures earlier, that the waste package actually coincides fairly closely to the weld area. So it doesn't result in a large difference in the new code.

Moving on to the source term, then, we added a new model to evaluate high-level waste glass, which was not previously in the code. And this was added largely to evaluate DOE, which does take -- or does account for high-level waste glass.

The model is analogous to the spent nuclear fuel model, and the data -- there were many experiments completed to determine the dissolution rates, and so there's lots of estimated rates. However, those rates are dependent on many variables, which I've listed some here -- the glass formulation methods, testing methods, test conditions themselves.

For our model we chose a path similar to DOE's, and what we have are a forward dissolution rate, which slows as the silica builds up in the system. And then, we also -- the intrinsic dissolution rate, which -- excuse me -- which is -- this K goes here, and that's a function, then, of temperature and pH.

And it's important to remember that temperature dependence -- because what we've seen is that in some cases, particularly during the temperature spike, the glass can in fact exceed releases of the spent nuclear fuel. But over longer terms, the spent nuclear fuel comes back because of the larger inventory and --

CHAIRMAN GARRICK: Chris, does the code allow you to consider a mix of different water compositions? In other words, if the evidence indicates there is -- X is going to be this composition, and Y percent chance that it's going to be some other composition, and Z some other, can you accommodate that?

MR. GROSSMAN: For this particular model or --

CHAIRMAN GARRICK: Well, for this one, and for the spent fuel model.

MR. ESH: This is Dave Esh with the NRC staff. Yes, I think you could. It would be a little tricky, but we have user-defined distributions, that you could basically make a user-defined distribution to define the intrinsic dissolution rate, for instance, that would be representative of, say, and acidic condition or a basic condition.

You could do the same thing with the spent nuclear fuel model. You could define a user distribution that would represent the likelihood of --

(Approximately 45 seconds of proceedings lost due to house audio system failure.)

MR. MOHANTY: This is Sitakanta Mohanty, staff. For any conservative approach without taking into account any trend for reverse reaction. So we only implemented the forward reaction in the model.

MR. GROSSMAN: Thank you.

MEMBER WEINER: Thank you.

MR. GROSSMAN: Okay. The other areas, as I mentioned earlier, based on review of the DOE's new documents, we have had diffusive release in previous versions of the code. It was removed largely because it was found not to be too risk aversive for our code.

But based on what we've seen, and some of the results that we reviewed in our SR documents, we decided that adding back into the code to enhance our review capabilities DOE might be a good a idea. And so the modification was made.

Essentially, the abstraction for the diffusive release involves transport through films both inside and outside of the waste package. And here the user defines the length of the transport path as well as the thickness of the cross-sectional areas.

What we find is that the thickness tends to be a limiting parameter, but it's so small -- it's on the order of -- the assumed thickness we use is on the order of 10^{-8} square meters. That it's shattered by vector release, still, so it hasn't changed much between different versions, but it's in there for our review capability.

And the last piece for the source term would be colloidal release, and this was added to -- as well to enhance our review capability of the DOE model. DOE has a rather complex colloidal model, and our model is based off theirs, but I would characterize it as somewhat more simplified.

This, by the way, was also an external peer review recommendation. The colloidal release and transport was similar to DOE's, and the way we abstracted it is a fraction of the release is specified as irreversibly absorbed to colloids. These colloids then become distinct species with their own transport properties, which can transport out of the engineered barrier, through the unsaturated zone, saturated zone, to the biosphere.

In the UZ, the radionuclides irreversibly absorbed to colloids -- can be filtered out in the matrix. However, we don't account for any retardation within fractures. And that filtration -- I should mention the UZ is a permanent filtration. They are completely removed, then.

In the saturated zone, we model it with retardation in the fracture top in the alluvium, and that's -- some of the distributions that we use in the code are here on the left. For the fracture tuft, this was abstracted from data on the C-wells microsphere test. And for the alluvium it was developed from theoretical calculations for the retardation.

In terms of radionuclides reversibly absorb to colloids, we don't explicitly treat that, but one way we deal with that is if we can modify the transport parameters for the dissolved species to account for that reverse absorption.

In terms of the impact of this change on the code, we're still evaluating that at this point.

Okay. The unsaturated and saturated zone flow and transport. The big change for these parts of the code was time -- radionuclide transport parameters to the geochemistry that's encountered on the transport paths. And we thought this would be a good improvement to the realism in the code, and it was also a recommendation of the external peer review.

Essentially, what was abstracted here is that we used process-level modeling to calibrate our response surface to experimental data, and some of that data was developed at the Center and some was taken from literature sources.

This occurs for the actinide elements only. The other elements are still modeled as they were in the past. And essentially, what we have is you can see a typical response curve. I think this is for neptunium. This was, in fact, developed at the

Center. We sampled the partial pressure carbon dioxide and pH, which are sampled over ranges that are representative of Yucca Mountain waters. And then, a retardation factor is calculated based on those two sample parameters for that element.

We found that this improved some of the efficiency over the old method, which they had to be sampled with the Latin hypercube sampler, which tended to be slower than the current method. And it also results in a narrower range of retardation factors than we had previously.

CHAIRMAN GARRICK: Did you say a narrower range?

MR. GROSSMAN: Narrower range, yes.

Okay. And then, the -- I believe this is the final -- yes, this is -- the final modification I'd like to talk about deals with the disruptive scenarios, and particularly igneous activity. And we added an ash redistribution model to allow some flexibility to look at remobilization parameters and the importance of those parameters.

In the past, we had modeled long-term remobilization. This new model, which is kind of represented here by this box diagram, improves on that by adding some quickly remobilized contaminated ash.

Essentially what we have in this model is you have three inputs. You have waterborne erosion of contaminated ash, airborne erosion of contaminated ash, and then kind of a dilution factor, the uncontaminated airborne erosion.

And then, as I mentioned, under this waterborne erosion you have three classes. You have the quickly mobilized, moderately mobilized, and then long-term mobilized.

The parameters were based on process-level modeling in some cases, and then existing data -- I believe some of the data came from USGS for the uncontaminated airborne erosion.

What we see with this model -- and we're still evaluating this, but what we've seen so far is that in the old version of the code with the long-term immobilization you had this rapid spike followed by decay off. In this version, what we've seen so far is kind of a rapid spike followed by a slight increase to that immobilized fraction, and then a tailing off due to the decay and removal from the RMEI.

So to conclude, I hope I have provided an indication here of how some of the modifications that we included in the TPA code enhance our review capability. We feel they improve the realism of the code and also the flexibility that we have with the code. I think staff is confident that the code will be an effective review tool based on the past versions and the current modifications that we've included this go-round.

We plan to continue to evaluate parameters and complete confirmatory testing to increase our confidence in the code and its output. And we also plan to continue to use the TPA code to assist our reviews and improve our understanding as we go forward.

And with that, I'll end the talk and open the floor to questions.

CHAIRMAN GARRICK: Okay. Questions? Ruth.

MEMBER WEINER: You mentioned that you include an equilibrium code. Which one?

MR. GROSSMAN: The equilibrium model -- it was done offline, and then the data was -- it was brought in.

MEMBER WEINER: Yes. What --

MR. GROSSMAN: It was EQ36 I believe is what it was.

MEMBER WEINER: That's what I -- that was what I imagined you had used.

On your colloid slide, you mentioned that the actinides are bound to colloids. What's the colloid? And did you consider that plutonium-4 is itself -- forms colloids? It almost doesn't dissolve; it forms colloidal --

MR. GROSSMAN: Yes. I'm going to actually turn that question -- is David Pickett available at the Center? He is kind of the expert there.

MEMBER WEINER: Oh, here's your colloid expert.

MR. PICKETT: Yes. This is David Pickett at the Center. There is nothing explicit about how the colloids are assumed to be irreversibly bound. It will be taken into account that DOE data suggesting permanent attachment to waste form colloids, but also data that suggests that attachment of plutonium and perhaps americium to, for instance, iron oxyhydroxide colloids is very slowly reversible, so that it could be considered irreversible for transport considerations.

MEMBER WEINER: Did you consider the --

MR. PICKETT: What was the other part of the question?

MEMBER WEINER: Did you consider the formation of colloids from the actinides themselves?

Plutonium-4, oxidation state 4, forms a colloid. It's not -- it's not a true solution.

MR. PICKETT: Right. Not explicitly. And I guess the consideration being that you're unlikely to maintain the -- presumably, you mean because you're reaching the saturation state of the plutonium, so you're forming colloids.

MEMBER WEINER: No. It forms a colloid. It exists as a colloid, and we have a lot of data to back that up. The reason I'm asking the question is that the mobility of colloids is something about which there is a great deal of uncertainty, and it depends very critically on what assumptions you are making about what the colloidal substance itself is, what size it is, what the surface of it is.

MR. PICKETT: Yes. And our model can accommodate those types of considerations. You can adjust how much you think is being transported colloidally and also the size characteristics of that, and so forth. But that is done offline, and then you alter your input data to try to simulate those types of considerations.

MEMBER WEINER: Yes, that is what's important. What pH range did you use for your colloidal mobility? What pH range do you put into your model?

MR. PICKETT: Part of the simplification that we've used here is we're not explicitly considering the pH range. But offline, as we consider the concentrations that are possible, we will consider the pH -- the solution. But that's not in the model explicitly.

MEMBER WEINER: Okay. Thanks.

I have another question for you, Chris. Can you give me some -- an example of where your TPA is -- where a TPA designed for review differs from a TPA designed to assess performance? Just an example of what the difference is.

MR. GROSSMAN: Yes, I can give you a generalized version. I mean, one thing that we look at is you've heard the word "flexibility" mentioned a lot, and maybe the colloidal model might be the one to go with, since we're talking about that.

You can't explicitly -- or we don't explicitly model true plutonium colloid with this extraction, but it can be done through the flexibility. And I think that that may be one area as with -- with our tool we are able to analyze different situations by kind of finagling code, so to speak. Whereas I think for DOE and a licensing type of code there would be a much larger burden of proof to provide a technical basis and validation of the conceptual models, and so forth, than might be needed for the review tool.

CHAIRMAN GARRICK: George.

MEMBER HORNBERGER: Yes. Just -- I had somewhat the same -- one of the same comments as Ruth, and I'd just like to emphasize or suggest to you that in part it should be semantics. I understand that when you treat colloids you are doing this offline, and I understand how you're doing it in a TPA code.

But when you -- our former member Ray Wymer always went crazy because to him there were colloids and pseudo-colloids, with plutonium-4 being a colloid and the iron oxyhydroxides being pseudo-colloids. And you only talk about them being irreversibly bound, and that's what raises the question in the minds of people who think about colloids.

So I think you should just be a little more circumspect in how you do your description. It doesn't make any difference to how you do your TPA.

I have a general question, Chris. So, let's see, when was the first version of TPA?

MR. GROSSMAN: Probably about the time I

was born.

(Laughter.)

MR. LEE: '88 or '89. It was published as IPA Phase 1.

Tim, do you have a better --

MEMBER HORNBERGER: The exact date doesn't --

MR. LEE: In that general range, yes.

MEMBER HORNBERGER: Okay. And so my question -- you talk about -- throughout your talk it's that you want to make this computationally efficient. Okay. Now, over 15 years computational efficiency changes sort of, right, because of computer capabilities.

MR. GROSSMAN: Yes.

MEMBER HORNBERGER: Okay. So how does that get factored in? I mean, I assume that it gets factored in, that you are now able to do more complicated things and still be efficient. Is that roughly what we're talking about?

MR. ESH: We work for the government, so we still have 15-year-old computers.

(Laughter.)

I think your question is a good one, and I'll answer it.

MEMBER HORNBERGER: Okay.

MR. ESH: We basically expand to match our computing needs is the answer. We do as much as we can with the new resources, the computational resources that we have.

MEMBER HORNBERGER: Yes. I guess, really, there are probably two ways that one could look at it, Dave, and I just don't know how you balance it. I mean, on one hand you might say, well, we would like to use at least part of our increased computational capability to be able to do more realizations, in which case you really are maintaining computational efficiency in the old sense, just so you can do more calculations.

On the other hand, you could expand your calculation to do the same number of realizations, but have a more complex code. And I was just curious about what your balance is there.

MR. McCARTIN: Well, I mean, I can go back to when we first developed it, and basically what we wanted to do is have a code that we felt we would be running somewhere on the order of 400 realizations. And we wanted that -- to be able to run that overnight on a Cray and have the results the next day. And so we backed out sort of --

MEMBER HORNBERGER: Now you can run them on a Mac and have them the next hour.

(Laughter.)

MR. McCARTIN: Well, as it has turned out, we're not too different than that now, in that we still have a code that we can run in approximately a day, except we're running it on a PC rather than a Cray. And I think we always would want to keep in that ballpark frame that -- we don't want to add a module that now, gee, it's going to take us two weeks to get results out. But I think the desire was to have something that got you -- you could run overnight and have results with 400 realizations. But it's on our -- even our laptops now.

CHAIRMAN GARRICK: Mike?

VICE CHAIRMAN RYAN: Yes, a couple of questions. First of all, I think the improvements are real interesting to track through. I'm curious -- for your major and your minor improvements, have you done any sensitivity studies on how a particular change -- are you calculating higher doses, lower doses, better dose numbers? I mean, how does it impact your answers or your ability to interpret the answers?

MR. GROSSMAN: In terms of I think digging down to find out specific causes of changes, some of that went on as development testing occurred. But a lot of that will be coming up in the next year with our performance analyses as we use the code and start to exercise it.

VICE CHAIRMAN RYAN: So that's yet to come. And I guess on your other modification slide, 19, which I know you thought were minor, I'm curious that the cladding correction factor -- how that works and why that's minor.

MR. GROSSMAN: For the cladding correction --

VICE CHAIRMAN RYAN: Because, I mean, I would assume that has a big impact on potential release fraction -- release from inventory or something of that sort.

MR. ESH: This is Dave Esh. It can have the potential. But as in TPA 4.1, our CLST staff -- container life and source term staff -- basically advocated the position of no credit for the cladding. So, but we realize that DOE may take credit for it. In addition, their cladding credit is not one where it's static temporally. So it's not one where you have a certain fraction failed at time zero, and then it stays that way for the whole simulation.

VICE CHAIRMAN RYAN: Oh. So you can

handle a temporal difference. Oh, okay. Great.

MR. ESH: We have the ability to receive a temporally-changing rate of the cladding failure in case we needed to.

VICE CHAIRMAN RYAN: Okay, great. Thanks.

CHAIRMAN GARRICK: What is your position on that? Does it continue to be something you're not going to consider, or you are going to consider cladding?

MR. ESH: I think you have to talk to our container life and source term people about it.

CHAIRMAN GARRICK: I see.

MEMBER HORNBERGER: Do you mean you just do what you're told, Dave?

(Laughter.)

CHAIRMAN GARRICK: This is a performance assessment. It's supposed to be realistically representing what can happen.

MR. McCARTIN: Well, I mean, we will review what the DOE provides in their license application. They'll have to defend any cladding credit, and that's --

CHAIRMAN GARRICK: Right. Right.

MR. ESH: From a performance assessment standpoint, the cladding gets a lot of discussion.

But some things that are lost in the discussion is that regardless of the cladding that you have in the commercial spent nuclear fuel you still have stainless steel clad fuel, which the stainless steel cladding is not expected to last like the zircalloy cladding. That represents a certain fraction.

You have a certain fraction in the commercial spent nuclear fuel that has failed cladding. That's an additional failure that goes in. And then, you do have the glass source term, which represents a waste form that's in the repository.

So the ultimate effect of the cladding is not as large as may be expected whenever you do like an on/off type of analysis where you add the cladding in and then you take it back out, because it's not complete protection for all of the fuel.

CHAIRMAN GARRICK: Yes, but it's -- the zircalloy cladded fuel certainly dominates the inventory.

Any other questions? Go ahead, Ruth.

MEMBER WEINER: On your slide 16, the one with the RMEI, you indicate that radioactive decay is the only elimination method from the RMEI. Is that a surrogate for physiological -- I mean, there are other ways to eliminate radionuclides from the body other than just by allowing them to decay.

MR. GROSSMAN: The RMEI is eroding --

MEMBER WEINER: Oh, he's eroding.

(Laughter.)

See, I figured that wasn't it. That came out the side.

(Laughter.)

MR. GROSSMAN: There are other removal mechanisms.

MEMBER WEINER: I would encourage you to be a little clearer about that.

MR. GROSSMAN: Okay. Point taken. Thank you.

CHAIRMAN GARRICK: Questions from staff? Yes, Neil.

MR. COLEMAN: Neil Coleman, ACNW staff. In the aftermath of the March working group on TSPA TPA, the committee wrote a letter, and one of the comments was the committee questions the extent to which diffusive transport is the basis for radionuclides to exit a waste package.

And if I heard you right, earlier in your talk you mentioned that advective transport still overwhelms the diffusive transport. So that being the case, why spend the resources to put a diffusion model back in the TPA code?

MR. GROSSMAN: Well, at this point, as I discussed, it was thought that since DOE does draw doses in a 10,000-year time period, at least based on the IRSR model from diffusive releases that this would be a way that we could probe that.

MR. COLEMAN: But do you think this approach is reasonable? Realistic?

MR. GROSSMAN: For that -- I'd have to defer to someone on that.

MEMBER HORNBERGER: Chris, wouldn't this be a good example of an answer to Ruth's question --

MEMBER WEINER: Yes.

MEMBER HORNBERGER: -- the difference between a code for analyzing what DOE does versus compliance.

MR. GROSSMAN: Yes, that's true. That's true. It would be.

MR. CAMPBELL: This is Andy Campbell. If the Department comes in with a model for LA in which diffusive release dominates the source term within the 10,000-year period, we need to have the ability to evaluate that and say, "Do we feel that's a conservative model? Do we feel that's a realistic model? You know, how conservative, how realistic is it?"

So even if at this point in time advective flow would dominate the releases in the TPA code, it really depends on what DOE comes in with, you know. And you're exactly right, this is an example of a regulatory choice of including something that from a purely risk perspective might not have been included normally.

CHAIRMAN GARRICK: So this suggested constraint on your code that is a little different than if you were just building a code to do performance assessment. And it is a good example of Ruth's question about what is in your code that is explicitly there for the purpose of being a review tool as opposed to an assessment tool, because if you were going to do a risk assessment based on what you know you probably wouldn't do it that way.

MR. CAMPBELL: You probably would have eliminated that somewhere earlier in the process. But given that --

CHAIRMAN GARRICK: Yes.

MR. CAMPBELL: -- we've seen at least in the past this being part of their, you know, presentations of TSPA SR, it was felt it was important to include that.

CHAIRMAN GARRICK: Right.

MR. GROSSMAN: And I'd walk back to the planning criteria. The first bullet there is really --

CHAIRMAN GARRICK: Yes.

MR. GROSSMAN: -- to steal one of your terms, Dr. Garrick, is the 800-pound gorilla.

CHAIRMAN GARRICK: Right.

MR. GROSSMAN: That will be our job is to review that license application.

CHAIRMAN GARRICK: Right. Good. Yes.

All right. Any other questions? Comments from staff or anybody?

MR. MOHANTY: Just a couple of comments.

CHAIRMAN GARRICK: Yes. San Antonio, go ahead.

MR. MOHANTY: This is Sitakanta Mohanty from the Center. Dr. Garrick, I would like to address one comment you had made earlier on data updating -- updating of the distributions.

Either we can use the Bayesian approach or we can use alternative approaches. What we have done so far -- and that work has not been made publicly available yet -- is what we call distributional sensitivity analysis. What Bayesian updating is going to tell us is whether the distribution function we are using is appropriate or not. It can give us an uncertainty in the distribution function itself.

And because the TPA code is used in the Monte Carlo framework, if we bring a PDF uncertainty it is going to significantly increase the number of -- perhaps you can render it almost impractical to do it that way. So that is the reason why so far we have taken the approach of conducting distributional sensitivity analysis to find out if that has significant influence on the proponents.

CHAIRMAN GARRICK: Thank you. Thank you very much.

MEMBER HORNBERGER: See, now I didn't think from my colleague here to my right that there was an alternative to --

CHAIRMAN GARRICK: No, there isn't.

MEMBER HORNBERGER: -- the Bayesian approach.

(Laughter.)

CHAIRMAN GARRICK: But we won't get into that.

(Laughter.)

Any other questions? Andy, go ahead.

MR. CAMPBELL: I was just going to add to something Chris had said earlier is that we're in the process right now working with the Center to develop a -- essentially what we're calling quantitative analysis to address risk issues.

And they will consist of sensitivity studies and a variety of other analyses that help us better understand some of the questions that have been raised with respect to risk insights and to evaluate some aspects of the agreements that we're working through that are being submitted by the Department, and that we feel that will lead us into a capability of using the code in an efficient way in the license review.

And even though Dave says we have 15-year-old computers, we actually have a slug of brand-new ones in, so --

CHAIRMAN GARRICK: No. What he meant is those are 15 years old.

(Laughter.)

I was going to ask you, Andy, that very question of whether or not this very interesting work that you all are doing to implement the risk initiative -- risk insights initiative, is that having any influence on the basic TPA code? Or are you doing a lot of that offline?

MR. CAMPBELL: Well, a lot of the risk insights come from running the TPA code.

CHAIRMAN GARRICK: Right.

MR. CAMPBELL: Primarily running the 4.1 and earlier versions of the code. There is an extensive report that's either out or about to come out on the sensitivity analyses using 4.1. So what we plan to do is address some specific issues that have come up in the context of developing the final risk insights report.

A lot of interaction we've had with the individual KTI staff. People have raised issues about, well, what's the basis for this? What's the basis for that? And through that process, we're going to try and identify some specific analyses that can help nail down some of the issues and questions.

And we're also using risk insights in a variety of other areas, trying to evaluate different analysis model reports that DOE has, which of those are the more important ones to look at.

CHAIRMAN GARRICK: Yes.

MR. CAMPBELL: Which of the agreements are more important to focus our resources on, and so on. So, and even in terms of developing evaluations of DOE, what are the important areas to look at? So it's

-- if you will, it's working its way into the system in a variety of areas. The TPA code provides at least one tool to help us in that process.

MEMBER WEINER: Are you using the results from the TPA code to give you some idea of when you're going to stop? When, you know, TPA -- N equals what is the last TPA that you need. Is that driven by risk insights, or what is going to drive that?

MR. CAMPBELL: I think realistically that 5.0, with some modifications, is going to be the tool we're going to use in the license review, just because of the amount of time for any major changes to be made. And I think -- and correct me if I mischaracterize it -- I think we've incorporated most of the input that we needed to have in the code for that.

MR. McCARTIN: Sure. I mean, that's the hope. I mean, obviously we're always subject to, if something new is learned that is dramatically different, we certainly would revise the code if necessary.

The only other thing I'd supplement, though, it's a two-way street. I mean, having looked at the risk insights, as people sometimes -- often note that depending on what you don't have in the code, you can't see sensitivity to it. And so there is modifications being done to the code as a result of, well, yes, you saw that. But if you added this feature, maybe you'd have a different insight. And so it truly is a pretty dynamic process in terms of the iterative cycle. So --

CHAIRMAN GARRICK: Okay. Very good. Thank you.

We're a little ahead of schedule, and we're going to go into -- unless there was some more on that topic -- there were no more presentations, were there, Andy?

MR. CAMPBELL: No.

CHAIRMAN GARRICK: No. I think what we'll do is take a 15-minute recess and reconvene and go to the next topic.

(Whereupon, at 2:55 p.m., the proceedings in the foregoing matter went off the record.)

CERTIFICATE

This is to certify that the attached proceedings before the United States Nuclear Regulatory Commission in the matter of:

Name of Proceeding: Advisory Committee on Nuclear Waste 146th Meeting

Docket Number: n/a

Location: Rockville, MD

were held as herein appears, and that this is the original transcript thereof for the file of the United States Nuclear Regulatory Commission taken by me and, thereafter reduced to typewriting by me or under the direction of the court reporting company, and that the transcript is a true and accurate record of the foregoing proceedings.

Jennifer Rosario
Official Reporter
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