UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD

ENGINEERED BARRIER SYSTEM PANEL MEETING

Gold Room, Pleasanton Hilton Hotel
Pleasanton, California

August 28, 1990

BOARD MEMBERS PRESENT

Dr. Don U. Deere, Chairman, NWTRB
Dr. Ellis Verink, Chairman, EBS Panel
Dr. Donald Langmuir
Dr. D. Warner North
Dr. Dennis L. Price

Professional Staff

Russell K. McFarland
Dr. Sidney J.S. Parry

PROCEEDINGS

DR. DON DEERE: Good morning, ladies and gentlemen. Welcome to the meeting of the Panel on the Engineered Barrier System. I am Don Deere, Chairman of the United States Nuclear Waste Technical Review Board and an ex-officio member of the EBS Panel. I will co-chair the Panel meeting today and tomorrow with Dr. Ellis Verink.

Dr. Verink's four-year appointment by President Bush has not as yet been made, but hopefully is only a few days to a week or two away. The Board has retained Ellis as a technical consultant to continue working on the EBS question. I will turn the meeting over to Ellis and will ask him to introduce the other Board members.

DR. ELLIS VERINK: Thank you very much, Don.

The members of the EBS Panel include Don Langmuir and Dennis Price, and as an ad hoc member, Warner North. The other members of the staff with us, Russ McFarland, a senior professional staff, and Jack Parry, who is right here and also a senior staff.

In my opening remarks, I would like to draw attention to the four questions which were propounded at the January meeting in Lawrence Livermore, and so that we'll have those behind us and in front of us.

Basically, can a waste package be developed that can be demonstrated to have a reasonable assurance of lasting

10,000 years, and if the answer to that is yes, how will that be done? If the answer is no, why not? A typical professor's question, I guess you'd say.

The second question: What ambient conditions or factors need to be modified, if any, for a 10,000-year package to be attained, if it's not possible already?

Thirdly, how would the probability of attaining a 10,000-year waste package be influenced if the as-emplaced heat generation rate of individual canisters was minimized? And naturally, the accompanying documentation would be required.

And the fourth question is: How does the siting of the repository in the unsaturated zone as compared--or opposed, perhaps--to a saturated zone impact the ability to consider a 10,000-year package? And we'd need, likewise, backup information.

Well, now, those four questions are before us and I think they bear strongly on the deliberations that we'll have today and the things that the Panel will be working on in the coming months. One item of considerable interest, and I think importance, which has occurred in the interim is that NRC has put out a position paper on long-lived waste packages which provide considerably greater enlightenment and less chance for misinterpretation of the requirement of 300 to a thousand-year requirement as seeming to be restrictive on the amount of credit that could be granted to a longer-lived package in assessing ability to meet requirements. There is no limitation as long as the proposed life can be qualified, and anyone who hasn't seen that particular position paper, I'd be glad to show them a copy.

With that, I would like, without further delay, to turn the program over to the next speaker, Mr. Petrie.

MR. TED PETRIE: My name is Ted Petrie. I'm the Acting Division Director for the Engineering and Development Division at the Yucca Mountain Project in Las Vegas, Nevada. I'll be talking today about the engineered barrier system and the waste package that goes with it.

The major topics I'll be talking about today is the waste package strategy and the implementation plan, the waste acceptance process, the waste characterization associated with high-level waste glass and spent fuel, and the waste database development. I'm going to be covering these sections, as indicated here.

This chart shows you the organization and who reports to whom within our organization. I'd like to point out that the project office, Carl Gertz is the manager. For this project, the Engineering and Development Division has the lead and Mike Cloninger is the Branch Chief responsible for it, and working with him to resolve those issues are the indicated organizations. It should be known there are other divisions within the project office who have other responsibilities, of course, but for this particular activity, this is the way it looks.

Now, within the DOE, there are two major organizations who are associated with this activity, both reporting to the Secretary of Energy. There's the Office of Civilian Radioactive Waste Management that I report to, and the Office of Environmental Restoration and Waste Management, and within our organization there are the activities associated with the geological repository and processing of the waste after it's transported to us, and within the Office of Environmental Restoration is the processing activities which takes the waste into a form which can be utilized and put into the ground.

This is an indication of the contractors and what their responsibilities are. Waste package plan implementation is the responsibility of the Lawrence Livermore National Laboratory. Les Jardine is with us today, who is the TPO for that organization and who will be presenting to you later. Pacific Northwest Laboratories has responsibility for spent fuel characterization and testing; Argonne National Laboratory, the high level waste glass testing, and then within the Office of Storage and Transportation, which is another organization within the Office of Civilian Radioactive Waste Management, there you have Pacific Northwest Laboratory, who is looking at the reactor specific data base development of spent fuel, and the Oak Ridge National Laboratory is looking at high level waste characteristics and data base development. And then, again, within the Waste Management Projects Division there is the Hanford Waste Vitrification Plant, West Valley Demonstration Project and Defense Waste Processing, which are classification-type activities. There are going to be representatives from most of the organizations speaking to you at one time or another during these sessions.

Just as a reminder, this is some of the interactions we've had with you in the past. In August of '89, there was a brief introduction to containers and transportation to the Containers and Transportation Panel on the EBS. In January, there was a meeting on the near-field environment and container materials; March, there was a discussion of thermal considerations in the EBS design.

We're going to attempt today and tomorrow to provide you with an understanding of the EBS or Engineered Barrier System waste package strategy plan for its implementation, present an overview of the waste acceptance process, provide a briefing on glass waste form characterization activities, and give some discussion on the current spent fuel studies and how we gather the data associated with those.

A couple of things we need to bring to your attention--disclaimers, whatever--as you well know, our resources are governed by the Congress on an annual basis, and so although we make plans to do things in years, next year and the year after, we are subject, of course, to those constraints and so any schedules or milestones that we might talk about are constrained by whatever actions that are taken in the budget area. And the activities important to safety are performed in accordance with OCRWM and EM quality assurance programs. That's the two major DOE organizations.

Ellis talked about the four questions, and it turns out I'm going to talk about the four questions, too, for just a little bit anyhow. They were transmitted to us in January. The goal is for the Panel and the Board to eventually be able to respond to the questions--and I say eventually, because much of our resources are going to go into determining the suitability of the site and the work on the waste package and the repository, to the extent necessary to evaluate the site. So at least that's the present direction that our new Director is taking us. But we do plan to do some discussion of this today. They'll be talking about some procedures on how we might go about trying to provide some answers to those questions.

And, in fact, here are the questions and I'm not going to read them. They were already read to you, but here they are in the record twice today.

Now let's talk a little about the agenda, and it's on five pages as you go through it and maybe I just won't go through it all now, but suffice it to say that each one of these is indicated in your information and we can follow those along.

With that, unless there are some questions, we'll goon to the first speaker, who is Mike Cloninger.

Any questions?

(No audible response.)

MR. MICHAEL CLONINGER: Thank you, Ted.

I'll be briefing you twice today. The first briefing is somewhat of a review for the Board, just an overview of the Engineered Barrier System, waste package compliance strategy, and an introduction to the implementation plan for that strategy. I'll be starting with a brief description of some terms, the Engineered Barrier System, waste package and things like that, and then I'll give a brief overview of the compliance strategy and introduce some strategy implementation. At that point, Les Jardine will take over and give the details on that implementation plan.

We're frequently asked what the Engineered Barrier System is, how that differs from the waste package and how that, again, differs from the near-field environment which is a focus of interest for the waste package program.

In the regulations from NRC, 10 CFR 60, part 2, the Engineered Barrier System is defined as a regulatory boundary in which we'll measure releases. It includes all the waste packages, plus the underground facility. The underground facility is the underground structure, including all of the openings and backfill materials, but excluding shafts, boreholes and their seals. Now, the focus of this briefing is not on the underground facility, it's on the waste packages.

Just a pictorial representation of those systems. There will be many waste packages, and the Engineered Barrier System itself is all of the underground openings and placement drifts and access drifts up to the surface of the seals, but not including the seals. Now, the seals themselves are engineered barriers and of interest to us, of course, but they are not part of this boundary called the Engineered Barrier System. It's an artificial boundary from which we will measure our regulatory compliance for releases after the containment period of 300 to a thousand years that Dr. Verink discussed.

The area of interest and responsibility for the waste package program does not stop at the engineered barrier system boundary, however. There is a zone--normally 20 meters--around each waste package where the geochemical and hydrologic characteristics of the geologic media itself will be dramatically modified due to the heat and radiation from the waste itself, and you see here a pictorial representation of the waste package. This is about the floor of the drift and there's a fairly large area where these properties are dramatically modified, and that's what we call the near-field environment or the service environment for that waste package, in which it must perform the functions assigned to it.

Here's a little better drawing than what's in your package, a little easier to see as a view graph. These affected zones overlap considerably, such that the area of interest for waste package and the service environment of the waste package is really quite a large portion of the underground area at the repository horizon itself, and that's quite different from the regulatory term, engineered barrier system boundary.

The goal of the waste package program is fairly straightforward and simple. It's the development and demonstration of a conservative design that will meet the content and the intent of the regulatory requirements with sufficient margin for uncertainty. The program is designed to provide all of the evidence that we'll need to go forward with to the Nuclear Regulatory Commission such that they may make a finding that there is, indeed, reasonable assurance that all of these requirements will be met.

The attainment of that goal is a program using an iterative systems engineering approach that relies on a multi-barrier approach as required by regulation--makes good sense--the unsaturated nature of the Yucca Mountain site, consideration of technical alternatives as well as design alternatives and, most important, sufficient resolution of technical and regulatory uncertainties.

There are three key internal interfaces--tools, I call them--in the program: functional areas of waste package design process where we specify requirements for the design, do conceptual and detailed design, which tell us what kind of testing and model development we need to do and, of course, going forward to do the waste package performance assessments that need to be done to demonstrate compliance. These are all closely interfaced with the repository and site design process, repository and site testing and modeling, particularly the site characterization, and the repository and site performance assessments. It's through the performance assessments that we do most of our regulatory interpretation and interfacing with the regulatory agencies to determine whether or not compliance can be demonstrated.

The strategy itself is indicated in these five main boxes here. Starting with the regulatory requirements and the agreed to interpretation of terms between the Department and the regulatory agencies, we begin a process of design basis development where we develop design requirements, determine what we need to do in terms of waste form characterization, materials testing, environmental characteristics determination, and scenario development, and these are the scenarios that we would develop to analyze the waste package performance against.

When this is established, we then begin a process of designing a waste package allocating performance to the various components of that package, and it defines further testing and modeling that must be done. The step prior to licensing is the performance assessment, and I should note here that there are activities ongoing in all of these areas at all times and not shown on here are feedback loops, decisions to be made regarding what needs to be done in the next step, and most of those come out of the performance assessment step and I'll talk a little more about that shortly.

Well, the key regulatory requirements that drive the waste package program are primarily limited to two. As part of our licensing process, we need to show--through tests and calculations for anticipated processes and events--which is a regulatory term still subject to interpretation--substantially complete containment within the waste packages. Dr. Verink mentioned that earlier, that the NRC has said that the required period for that is 300 to a thousand years, somewhere in that range, but we're not limited to that thousand-year cap for a containment function in order to demonstrate compliance with other requirements. And after the end of the containment period, controlled release of radionuclides from the engineered barrier system. It's that somewhat imaginary boundary that's defined by regulation.

There are also specific design considerations that we have to keep in mind when we're designing and demonstrating compliance. We need to maintain 50 years of retrievability of all that waste for 50 years after we initiate the first emplacement. We must consider alternatives and alternative designs that would provide greater containment or longer isolation. We have an input to the total system performance, the EPA requirement for maximum allowable releases to the accessible environment. The engineered barrier system and waste packages, the performance predicted for them is the source term for the calculations to show compliance with this requirement, and there are various design standards promulgated in the same regulation regarding waste form, interactions, a whole variety of things.

The performance allocation and design development steps go hand in hand. Once we have our regulatory requirements well-defined and just the practical engineering requirements that are needed in order to manufacture and emplace the waste forms and packages, and the available testing data base, we can identify design concepts, and it's an ongoing process as well. And for each of those design concepts, we need to select system elements, identify top level functions for each waste package element. Containment is one of those top level functions primarily assigned, of course, to the container.

We allocate specific performance to each of those components and a numerical value, a quantitative value of measure of performance is determined. Then we have to demonstrate that the product of all of these requirements, specific design requirements, actually will meet the regulatory requirements, post-closure performance requirements, and from this we identify testing and modeling needs, performance assessments that need to be done in the future. It's kind of an iterative process and it's ongoing at all times, but we have divided it in some formal design phases which I'll talk about just a little bit in awhile.

The performance assessments are also ongoing, and by performance assessment here I mean simply calculations to predict or bound the future performance of the waste package or any other system, and compare that prediction to the required performance. The performance assessments have to include consideration of the total system variability throughout the repository and among waste packages, as well as uncertainties regarding that performance.

For the entire program--not just the waste package program--the pre-closure performance assessment is fairly well-established. The techniques have been used for decades now, and primarily use real-time data and methods, just like an automobile where you can predict, basically, how long an engine will last, how long it will be before it needs a rebuild, things like that. The post-closure performance assessment, however, is the focus of the development in the program and what drives that is the reliability paradox. The reliability paradox basically says that the more reliable a component or system, the less can be known about its failure rates.

Well, we have some quite unprecedented time extrapolations to do. They have never been addressed before in engineering, or for engineered systems. We'll be having time extrapolations in our performance assessments of 100 to 1,000 times the test period. What used to be considered a very long-term test, ten years, is a very short-term test to us when we have a system that we have to consider its performance over a 10,000-year period. Therefore, that's led us to seek a so-called "mechanistic" understanding of the fundamental thermodynamic and kinetic processes at work in the system, and apply that statistically to account for system variation and uncertainty.

The efforts in the current waste package program are focused heavily on performance assessment development, as well as providing input to design basis development, but a lot of the work you'll be hearing about this afternoon and tomorrow are to provide the bases for performance assessment submodels, provide data for use in those models and/or provide partial validation for those models.

The application of performance assessment, ultimately, is to assess that performance, compare it against the required performance, and if the predictions are that the design meets the requirements, then we can proceed towards licensing and make our case before the Nuclear Regulatory Commission. If we feel that the design does not meet the requirements, including the uncertainty requirements, then we have to evaluate and select alternative actions. These kind of increase in complexity, cost and time requirements as you go down. I won't go into any great detail, but we could simply assign additional performance to components that exist but we haven't taken credit for. Perhaps our computational model is too conservative. We need a more realistic model. It's predicting disaster when a realistic model might predict quite full compliance. Perform more tests, get a better database, or now you're talking a more costly and time-consuming process, change the design. Once we do this, we have to do all of the above as well, so we want to do the design right first. Or, failing all of that, if we feel that we cannot meet a requirement, we may have to go back to the regulatory agency and propose a change in the regulations. In order to do that, we will have to show we've done all of this, we don't feel we can demonstrate compliance. That's one. We also have to show that the regulation is not necessary and is over-restrictive, and propose a different regulation that still provides sufficient provision for public health and safety.

DR. DEERE: Question.

MR. CLONINGER: Yes.

DR. DEERE: Is this alternative study here a different one than the one under your specific design considerations, where 10 CFR 60.21 requires studies of alternatives? Because this is pretty late for that study, isn't it?

MR. CLONINGER: Oh, yes. We would do this process for each conceptual design, each alternative that we're considering, up to a point. Once we've selected a final design, we don't want to get stuck here again, though, because you're right, that would be very late. I'll talk a little bit about the design process here in a couple of slides.

DR. DEERE: Okay.

MR. CLONINGER: And how that fits in. In fact, the next slide.

There are five primary technical areas that we'll proceed somewhat in parallel through those design phases, beginning with the pre-advanced conceptual design phase, which is the phase we are in now. The engineering and systems studies is more the classic engineering efforts that go on, including the design function. The Board heard some information from that last March in Denver regarding the thermal impacts of the systems analysis that we're doing, both from Sandia and Livermore. Performance assessment, which is the subject of a future meeting--and waste package will be included in that. Materials characterization and selections, these are materials other than waste forms. We discussed that, as well as the near-field environment characteristics in the meeting last January here in this same hotel, and the focus of this meeting, particularly this afternoon and tomorrow, waste form characterization.

These five technical areas in the waste package plan, the implementation plan, are color-coded again here, and Les Jardine, our next speaker, will be developing this in some detail for the pre-ACD phase which we're currently in, and with that, if there are no further questions?

DR. PRICE: I'd like to ask a question.

MR. CLONINGER: Yes.

DR. PRICE: I think, Mr. Petrie, you indicated that funding for this was dependent upon the amount of resources and that there was something that might have higher priority to this that would cut into this funding, and the question is: Is this program as presented here shown somewhere in a diagram that indicates the critical path, that indicates where the slack is and where these kinds of decisions and adjustments can be made? Is there such a document?

MR. PETRIE: The answer is yes, there is such a document. It's a long-range planning document that shows the entire program, so the answer to your question is yes.

DR. PRICE: I have not seen a critical path drawing as such, and with probabilities assigned to various paths, and then I would ask the same question about this program here, where you have some parallel functions, you have a variety of tasks, and in your waste package plan, I think in the appendix there's a whole page of various tasks, and so forth, and has that been assessed in terms of probabilities of completion and time and schedules into a CPM or PERT or something like that?

MR. PETRIE: Well, as far as probabilities is concerned, I'm not sure that's been done.

MR. CLONINGER: No. We haven't done a risk assessment, programmatic risk assessment on the critical path. We do plan to baseline our critical path and project matrix, I believe, sometime in October, in fact?

MR. PETRIE: It'll be in the fall, let's put it that way.

DR. PRICE: Is this program somewhat subject to sacrifice for higher goals? It's hard for me to get a feel for this.

MR. PETRIE: Yeah, and the answer is yes, it is. It's the service-based testing and the underground testing are, at this point, considered to be higher priority items than at least parts of this program. We need to do sufficient of it so we can assure ourselves that the site is suitable, but there are other higher priority activities associated with early determination of site suitability.

DR. NORTH: I thought I heard you use the term "iterative" in describing performance assessment. I'm rather surprised on this flow diagram, which was your preceding slide, to see performance assessment only appearing in the advanced conceptual design stage, as opposed to appearing in all three pre-advanced conceptual design and the license application design.

MR. CLONINGER: Yes, Warner, that's because this is out of the waste package program, and performance assessment is not part of the waste package program in our work breakdown structure. It's a separate functional area covered by a separate plan, and in the performance assessment implementation plan you'll find the detailed descriptions of the performance assessments that are being done and how they feed into the other avenues.

DR. NORTH: So you are assuring me that it is, indeed, an iterative process and performance assessment will be carried out all the way along the line in each of the three phases, not just in the middle phase as shown in this diagram.

MR. CLONINGER: Last August I showed this slide, but the performance assessment has a feedback loop throughout the process and it is ongoing, to the best of our ability. However, you have to have a pretty good idea of what your design is. You have to have developed design-specific performance models and then apply them, and that's a time-consuming process, and we are working this year and next in the program to develop a little better turn-the-crank-type performance assessment models that can be used as design input.

DR. NORTH: Yeah. It would seem to me that as you go through the process in your Box No. 4, develop design concepts, you want to immediately follow that with an evaluation phase where you check out those concepts with your engineering evaluations and performance assessment to determine whether those designs, indeed, do the job.

MR. CLONINGER: Yeah. I would call these bootleg performance assessments right here, done with much cruder, simpler models just to get a view--

DR. NORTH: But there the next box is performance assessment. What concerns me is the lack of those boxes over in the pre-ACD stage.

MR. CLONINGER: They're there, but not, as I say, in the waste package plan. They're only there by reference.

Yes, go ahead.

DR. JARDINE: Can I throw in an extra comment?

MR. CLONINGER: Go ahead; sure.

DR. JARDINE: To support what Mike has just said, the plan emphasizes other than performance assessment, but in the waste package plan which has now been issued, even before Box 4 up there in the pre-ACD, there's a paragraph that makes the commitment that you're looking for and that reads as a preliminary assessment of the performance of the various concepts will be conducted using the existing container materials characterization, near-field environment, waste form characteristics information. The purpose of these assessments is to assist in establishing a screening and prioritization of the concepts. Other aspects of the design concepts will be considered in the prioritization process,including manufacturing and feasibility costs and operational implementations.

So in the construction of that diagram, which focused on the--you get into our work breakdown structure. It did not emphasize performance assessment, but the plan has words in there that are not shown on the diagram. So there certainly is a commitment, as Mike has said, to once a design concept is established, to then let the analysts do their thing with this working performance assessment simulation model of the EBS waste package. That certainly is our intent, and I think it's in the plan.

MR. CLONINGER: In fact, we have done some back of the envelope-type of performance assessments. They are not published. They're not--

DR. NORTH: Good. We're anxious to see those as soon as you can share them with us.

MR. CLONINGER: Very good.

Well, I lost my agenda slot, I think. No, here it is. More questions?

(No audible response.)

MR. CLONINGER: Okay. I'd like to introduce Les Jardine. He's the Technical Project Officer for Lawrence Livermore, and is responsible for implementing the waste package plan.

DR. JARDINE: Good morning. I have the privilege to give a discussion on, in some more detail, of what the waste package plan is and how we're implementing that plan, and I think I do need to, you know, at least give some credit--I certainly want to give some credit to a couple of people who are no longer in our program, and particularly Jack Hale and Leo Little, who were very instrumental in allowing the development of this document starting last November, and I'm sure and confident without those two the plan would not have happened and, of course, to the Livermore staff who developed the draft of that document, which then received further massaging as it went through the system, and so I do want to make credit to both of those people, senior DOE people who are no longer in the program, in addition to Mike, who's here, and of course, is still contributing to this.

The purpose, really, today of the talk, I've got two parts and I've broken it into giving an introduction to some background information on the waste package plan, and then, second, I want to talk about the waste package plan and how we're beginning to implement different parts of it, and it's going to be broken down into four different parts: engineering and system studies, materials characterization and testing activities, near-field environment characterizations, and waste form characterizations, and I might just remind you, as Mike did, that the center two bullets were covered in more detail in our Pleasanton meeting. Later today and tomorrow we will be covering in a lot of detail other technical activities and wrapping around waste form characterizations. The talk after this one will talk in more detail how we are going to implement engineering and system-type studies in more detail.

So skipping the one view graph, going to page three here in the handout, and basically this is a way of background information. It was at the Denver meeting in March where the commitment, or at least an offer was made to present the waste package plan, so this presentation closes out that action for the DOE to present that waste package plan to the Board, and after that meeting the plan now stands as approved and has been put on controlled distribution, and it's my understanding that the Board has an on controlled copy of that document, and I see several on the table that are available for the Panel. And where we stand is we are now implementing that approved plan and developing lower tier in more detail as to how we're going to implement that.

The waste package plan objectives can be stated, in a sense, and captured in these four bullets. The purpose is to describe the waste package program of the Yucca Mountain project and from a management perspective, in a sense. Second is to describe the essential elements of the program, which would include the objectives, the technical plan, and the management approach. And again, this is at a higher level, being a project plan. And third, to establish the technical approach against which overall progress, as the plan is implemented, can be measured, and then lastly, but not least, is to provide guidance for waste package program activities and, in particular, gives guidance for the development of more detailed, lower tier planning documents that are being developed by us and other subcontractors in order to implement the plan on those four topics that I showed you.

Moving into the organization of the plan, there basically are ten chapters to that document. The heart of the document is Chapter 3, which is the technical plan, and I'm going to cover that in more detail, but I'd like to make the point that the organization and contents of the plan are derived from the DOE Order 4700.1, which requires that, or it's based on a major systems acquisition of the repository system, MGDS, or mine geologic disposal system, and that's the format that was used to determine these chapter numbers and the content that went into these. So there's additional guidance in this DOE Order as to what goes into a waste package plan.

And, of course, it does touch on the project schedule, some major schedule things and some schedule decision points which are outlined in that plan, and I'm not going to go into those today. What I really want to spend my time on is focusing on the technical plan.

DR. DEERE: What's the date of that Order, 4700.1? More or less.

MR. PETRIE: It's about three years old.

DR. DEERE: Okay.

MR. PETRIE: There was a predecessor to that, but the present version is about three years old.

DR. JARDINE: And that's the document that makes a commitment to the systems engineering-type approach, and it also comes up with this thing of a work breakdown structure.

Well, let me comment a minute here that Chapter 3 in the technical plan, this is a more detailed breakdown of what is in the contents of Chapter 3 or Section 3 of the waste package plan. This WBS I'm not going to talk about, but the DOE Order requires this. This is the way the DOE organizes its work scope and work packages for the budgeting and schedule and the monitor of the technical baseline.

There are two other parts that I want to talk about;

the boundaries that are established under the technical plan, and the logic and technical approach which is required to implement the plan. It can be broken into 25 different steps or boxes, and this maps back to the diagram that Mike Cloninger showed you, and I'll go into more detail. So the heart of this plan is really Chapter 3 and the logic that's been established, and the development of this logic and technical approach.

I want to put this up one more time to make again the point that this was presented at Denver, but the point I like is that the near-field environment is a very large fraction of the underground repository. Now, it's very difficult to put a definition on what this boundary is in terms of its length, width or height or volume, and if this cartoon can be used to show the waste packages are emplaced in drifts, and then when they go into the repository configuration, there are different drifts and panels that go along with the emplaced waste. The blue zones are intended to represent perturbed environment due to the fact that the emplaced waste has been put into the site, and I remind you that depending on a process--let me give you an example of a stress may only go out a few meters. Things such as thermal fields, if you want to pick a certain temperature value, may go out ten meters or more, and the same with the water content. The sites vary with distance. These processes vary with time because of the radioactive decay process and the change of the heat source that's associated with that, and that's really the points I wanted to make, and then Helen is going to turn down the lights. I wanted to give another perspective to this that has not been shown, and Michael Cloninger is going to pass out Xerox for the Board, but this is an artist--

DR. PRICE: Excuse me, Les. Could I just quickly just ask a simple little question? I think your cartoon showed it elliptical, and there's no significance to that?

DR. JARDINE: No. Let me clarify. Which one, elliptical here?

DR. PRICE: Yeah, right in there. Those are elliptical shapes, and there's no significance to that?

DR. JARDINE: No, strictly an artist's rendition to try to make the point that--which I was going to do on the next one, too--is that these are spaced so close, if you're talking about a stress, it may be a meter into the rock. A thermal field may go all to layers up above and maybe even down to the Calico Hills, and this is why it's very difficult to put a definition on a boundary of, how do you define near-field environment? How do you define disturbed zone? How do you define these things? They depend on the process. It varies with time after emplacement, and so they're very difficult to define, but once you define the term, a definition and a boundary could be established.

DR. VERINK: Perhaps a miscellaneous question. Does that mean that the near field is considered part of the engineered barrier system?

DR. JARDINE: I think I have to answer that from a regulatory standpoint, or the 10 CFR 60, the engineered barrier system stops at the mine surface of the borehole wall, or the drift, emplacement drift. But in my viewpoint, in the sense of an engineered barrier system from coming up with the concepts that will capture the waste, a very important part will be that rock in the vicinity of the packages which will, indeed, retard the radionuclides in some cases, and then that slows down the source term and the material may never go very far from the source.

So I wanted to use this cartoon, and I think we've given you copies of this. It's not in the handout in the audience, but this is intended to put another scale or perspective on this. This is drawn to scale and this shows emplaced containers of alternating--this is a defense high-level waste glass, spent fuel, the co-mingled concept, and the point that I'd like to make is that, indeed, when you put some scale on these with the seven and a half foot spacings, they're very close together.

In addition, when you look down this alley or this mid-panel drift, you can see the next tunnel and the next one at 121 feet spacings in this direction. Depending on your process, there is an overlapping influence of these packages on the ones in the next emplacement drift, or among each other, and it also adds another perspective to the--at least in my mind, of should there be a failure of some package at some point in time, you know, this is a very important environment or region to have some characterization of because that will provide the source term, which is then fed into the total system modeling releases.

Let me have one last example. This is in the handout. I will not talk about it. That's just a reference configuration. You've seen it many times. I would like to put one example up and remind you--of which we gave you a lot of detail in the Pleasanton meeting in January. For the cartoon that Dale Wilder presented, which shows emplaced waste looking down two drifts, and what is the boundary at which the liquid water condenses, if you like, and forms this what were labeled boiling point isotherm?

And the point is--and it would be at two years it's closer in. As it moves out in time, at ten years it may be this, and it moves out and then it moves back and, because of gravity and other effects that we told you about in Pleasanton, this cartoon is not strictly correct, but it makes the point that if this is one of the phenomena you're interested in, this boundary of this boiling point isotherm varies with time and depends a lot on what's in the packages and the interactions that take place.

DR. LANGMUIR: Did you assume a waste temperature for this modeling?

DR. JARDINE: I believe I would have to recall--which I can't right now--what the details were for the Pleasanton meeting, but that would have involved some of the talks of John Nitao in detail, and I think the record would have that kind of information.

DR. PARRY: How about the KW content for the package?

DR. JARDINE: Well, I think, again, you know, that detail I would want to look at in the record and find out exactly what John Nitao established or assumed in terms of the kilowatts and the age after emplacement.

MR. CLONINGER: I think for this particular calculation, it was 3.3 kilowatts.

DR. JARDINE: And I might remind you that if you look back at this, you need to also recall the information we gave you at the Denver meeting where besides the near-field stuff, we showed you techniques that are super-position and included more than a single package, which was presented by Lynn Ballou and Gary Johnson, and Sandia also had some models. So, again, you know, you've got to be careful when you ask the question or try to answer one as to what was assumed, but generally these answers are available and the calculations have been done, and it's a matter of getting the question established, then we can provide the answer.

DR. DEERE: Does this include the heat pipe effect?

DR. JARDINE: Well, again, this is a--I'm sorry, let me clarify. This was a cartoon I was intending to represent, but let me answer your question, which is?

DR. DEERE: Whether this includes the heat pipe effect.

DR. JARDINE: When some of our heat transfer people and hydrologists do calculations, they are taking into account the condensation, if you like, and then the re-boil of the water, and also the effect of fractures and matrices and the tug and the pull that goes on, and the competition around a package for--does it go into the matrix or does it go into the fracture? But this, again, is a detailed question which would be more appropriately addressed by our hydrologists, like we had at the Pleasanton meeting or in a future interaction, but they do take into account those phenomena.

I think I might like to add the comment that in Denver we pointed out that for engineering calculations, a lot of the time thermal conduction models showed that they're within about a 10 degree delta centigrade of what you predict with these more detailed two-phase, multi-phase flow heat transfer models of the single package. So for a lot of engineering scoping calculations, a thermal conduction model is sufficient to deal with large arrays. You have to understand something about the single package, multiple heat sources in order to be sure that you are, indeed, conservative for your more simplifying, conservative engineering calculation.

Now what I want to do is really move from the boundaries into the technical approach that is going to be used and is stated in the waste package plan, and what it says is that a classic systems engineering approach will be used. The way I like to think of it, in one way, is that over a period of time, the very first thing you have to establish and do is define the waste package and EBS design requirements, and you go through a process, and what your goal is, is to end up at the end of the design process and development process, that you can verify that those requirements have been satisfied against the requirements. That gives you confidence that you can go forward and acquire that license, and we've shown on here some different points in time to give you a feeling of what is in the plan in terms of the phasing that goes on, and we have found that it's a very difficult and a very challenging job to establish what are the waste package design requirements, and my second talk after this will show you in more detail how we're going to specifically spend quite a bit of effort defining the design requirements and developing the design concepts in this pre-ACD period.

This is the diagram that Mike showed you, and the intent is to just, really, before moving on to this more complicated one, is to make the point that the waste package plan is structured with parallel activities in technical areas that focuses on the four lines, the top one and the bottom three, over a period of time. It uses phases in the design, or time phases as a way to separate different points and different parts of the project, or the development of a waste package engineered barrier system.

Now, let me put up the more detailed waste package--basically, it's called the flow diagram of the waste package program, and I want to spend just a few minutes talking about some of the important parts of it. It's color-coded such that this orange color corresponds to what we're calling engineered and system study activities. The yellow are basically the materials testing and characterization activities that we talked about at Pleasanton. The preliminary near-field environment characteristics are this blue line, and the green line is the preliminary waste form characterizations that go on.

DR. PRICE: What are the brown ones?

DR. JARDINE: There's a couple boxes that touches on Warner's earlier question that deal--this one particularly deals with performance assessment, and it was somewhat an ability to put it in the diagram and not get too far out of bounds to show that, indeed, there is some performance assessment when concepts are done or what some people perceive as engineering evaluations may also be performance assessments. If there was room on a diagram, as I read into the record awhile back, Box 4 would have a box down that would be do a performance assessment as you're doing this, and some of the difficulty we have is defining what is a performance assessment, what is a design evaluation, an engineering evaluation. So that would be a performance assessment. That's why it's a slightly different character, and it's also the logic for why Mike's diagram or mine had five lines on it.

Now, the point of the engineering and systems studies is as we begin to implement this thing, or, say, the logic that we're going to use, we are going to make the recognition that the very first thing you need to do is define the requirements before you go off and develop design concepts, and get those documented. It also recognizes that we have to have written down current information about what we know about the near-field environment and the waste form characteristics. Those are very important feeds to the systematic process of developing design concepts for a different host of requirements.

This process of developing design concepts means to me to get things down on paper, to get a sketch or a drawing in order to have the ability for materials people to say, yes or no, for that concept there are materials available or we have some closure problems, and so once a concept is developed, it's that point where material selection criteria and the selection of candidate materials is done and feeds back to, yes, that is a concept, a design concept that you have a chance of implementing.

The design concepts also identifies explicitly the need to tag all of the interfaces that exist between other parts of the mine geologic disposal system. A large fraction of those deal with the repository, and I'll show you later that that's an important part of this process.

DR. VERINK: What latitude, if any, do you have in shaping the surroundings or the environment in which this process is going to take place? You're just going to take the rock as it is, or could you conceivably alter the environment?

DR. JARDINE: If I could defer to the talk after this one, which I'm enthusiastic about--not that I'm not with this one--but (laughter) I will show you a concept or two which are quite different than the reference concept, and it's an illustration of how we anticipate the alternative approach to the EBS and waste package is going to be perceived, and you'll find something with a backfill over it, and packing materials. So if I can defer to that, I would appreciate picking it up at that point.

But as you go on in the design process, you know, the first step here, pre-ACD, is intended to get an early definition of the concept and the feasibility and the requirements. As you move to another phase in the design--and we're using the period 10/92 because it's in the 60-day report to Congress from Watkins, then you move into what were labeled ACD, and I think the important thing is you move from one phase of design to another phase, and then there are more constraints placed on the designers, and you go into more detailed evaluations and develop the design further. You may or may not want to produce prototypes in order to verify and get a better feeling that, indeed, you can fabricate some of these concepts, and at the end of the ACD, which we're labeling 6/96, basically, is the point where you move into the license application design.

Again, you've done a lot of work and you're narrowing down your options and getting more constrained. I need to point out that in parallel with this, the underground site characterization program is going on. The plan says that we will make continuous updates of the near-field environment as we understand it, incorporating new information about the site and have this available to continuously feed back up into either the materials people or the design process, and the same is true with the waste form, and we do this continuously. And these boxes, which I'm not going to go into detail with, but the schedule is tied to having available surface based drill core from the surface based testing program. Also, it's tied with having access to the underground in order to have either larger pieces of rock available for near-field environment characterizations, and some in situ field test or ESF-type testing. The time is compressed, but the plan makes a recognition of that and it's an important point I wanted to point out, that these activities are tied to the availability and access to the site to give us more confidence that we understand the near-field environment, and then removes, hopefully, some of the uncertainty in the selection of materials and how we will do our analyses to show that those things will perform well.

So let me move on to the second part of the talk on the waste package plan, which deals with a little more detail. Again, it's going to be limited to an overview of what the waste package plan makes a commitment to do, and it's summarized by those four bullets.

The very first activity is engineering and system studies, and in summary form, this is intended to represent the box numbers that were on the more detailed logic diagram, so that the engineering and system studies encompass Boxes 1, as shown here, through 25 and the appropriate ones that are called out.

Now, to put words to what is the scope and the nature of the engineering and system studies, what those activities consist of is to define both the design requirements and the design concept selection factors; second, to develop alternative design concepts, more than a single concept; thirdly, to evaluate the concepts against the requirements and the selection factors that you'll use to judge how you're going to select among different alternative design concepts in order to come up with acceptable design solutions; and fourth, for the selected concepts that are narrowed down in this process--and I'm going to cover that in the talk after this one, that what we have in mind as to how we are going to do that--we will then develop increased design details and conduct additional engineering analyses, performance assessments, and also, this gets us into the prototyping where necessary and appropriate, and I guess I've labeled that here. And then we will continue, you know, the design system studies and design analyses in order to get to the license application design. That's the objective of that.

DR. PRICE: Les, when you look at those boxes and see what feeds into some of those boxes and kind of look at this thing and the statement you just made about it being dependent upon accessibility to the site, certain of these functions, and if there isn't accessibility to the site, your schedule is pretty well going to collapse; is it not?

DR. JARDINE: Well, what happens, I don't know if it collapses, but one of the things that happens is that the people--and I'll tell you later--we're going to make the commitment to write down what we know about the near-field environment. It makes the assumption in January of '92, not '91, surface based core is available for our scientists to do, let's say, the near-field fracture test through the hydrology. We're assuming that there's enough time to do those tests in order to have a reasonable update to this point, so I think if there is a significant delay, one of the things that will happen is that this activities of the near-field environment will become, you know, we will have to ask ourselves, are we able to work around it? Is there things that we can do, not having site-specific rock or media? And that'll be difficult. It's another question for the waste form characteristics. Those materials are around and you still have the question, do you understand the service environment which those are going to be in? So, yes, you do get into a scheduling problem as we go out.

DR. PRICE: So the blue line there is basically a pacer; is that correct? And if you can't realize going from Box 2 to 10, completely, then certainly above that you're pretty impacted in ability to go forward from that point, in fact.

DR. JARDINE: Yeah. I think it sometimes depends if you're talking to an engineer or an earth scientist.

(Laughter.)

DR. JARDINE: But, I mean, this is the heart of the question and I can't really answer it, but it's, you know, what's driving this thing and it's a debate in the program and, fortunately, I feel right now we're behind this line and, I mean, in the pre-ACD period, and there's a lot of things that we can do to establish and put some order to this and hopefully be in a better position downstream to--I would like to come back at some time later and have an opportunity to answer that question.

DR. VERINK: What's the date of that line?

DR. JARDINE: This one is October of 1992, and that is in the 60-day report of Watkins to Congress.

Let me get back to--I think, Jack, quickly back?

DR. PARRY: Before the light goes out again.

(Laughter.)

DR. JARDINE: This is an example I wanted to put up. This is a diagram that is in the waste package plan, and I wanted to use it to discuss once you have developed design concepts, what's the kind of information structure that has to be associated with the design concept? And there are four things that we have to pay attention to or be aware of. There are different time periods involved for our mission here of designing a waste package EBS system. Those include the pre-closure, the containment period, and the post-closure or controlled release periods.

There are different waste types that we have to deal with, and these only show to and, of course, there are other waste types and we're aware of that, and the plan makes that acknowledgement, that those will be studied, also. There are different components that are associated with the design concept, from containers, shield plugs and other things, but last--and it's not intended that way, these really are the requirements, and the way this diagram really is done, it starts with a definition of the requirements and the functions that have to be performed with some kind of a functional analysis, and sets up the criteria, and I'm going to go in more detail in my next talk.

But the point you can make is that once--the way you would read this is that for each time period, say, if you want to deal particularly with the pre-closure period, and for a waste type, for each high-level waste type, you have to specify in the waste package design requirements to the next step of design these pieces of the concept that are applicable to the specific waste package EBS concept, and for each--and so for pre-closure period, for the high-level waste and for that container that contains that, then you have to, for the container, specify all of these different requirements. And so it's a very hierarchy-type situation and it's very complex, and there is an order to that and we're proposing some concepts, or we're actually implementing them as to how we think we're going to handle this, but it really starts with a functional analysis and works our way through to where we derive a design concept. And then when we get all done with the process, we're going to document it in something that we're calling a specific waste package design requirements document, and that will be the document that is, for the selected concepts, handed to the next step of design, after ACD, and would allow a facility designer, someone more traditional, to go forward with the design process.

So in terms of the engineering and system studies, the near-term activities can be summarized as what we're going to be doing in this pre-ACD period, is developing the methodology and the criteria for evaluating and screening the acceptable design concepts; develop the acceptable design concepts and reduce to two or more those that will be further evaluated during the next phase of design; develop and baseline--that means control--the specific waste package design requirements for those selected acceptable design concepts. We will define the physical and functional interfaces with other waste management system components. This is Box 5 on the logic diagram. These basically are a lot of the Box 4 on the logic diagram, and we will continue the EBS waste package repository scale thermal analyses, including analyses that cover the low-temperature alternatives that are also feasible, or at least will be looked at as feasible concepts, in addition with all the other parts of the waste management system, and we will continue some nuclear criticality calculations because of this--

DR. LANGMUIR: Les, before you go on, when you make the point that you're going to reduce design concepts to two or more, will you be going over how you decide to make that selection at some point here? Will this be covered in the next couple days?

DR. JARDINE: I think my next talk will begin to show you how we're going along that path, and the traceability that will be there and the basis for a decision to be made, and that's really the next talk. If I can defer that one, that would be a better place for you to ask that question.

DR. VERINK: Any field testing of this would be in the next time frame?

DR. JARDINE: This certainly says that and I think it's our current understanding of the program, that the field testing is not something that's ongoing in this time period. At least when we prepared this view graph, that was my understanding. And that's also what the waste package plan says.

DR. PARRY: How about small scale testing, heater testing?

DR. JARDINE: I think that's one that falls in Ted's comment, that depending on sites and funding levels and other priorities, that's a decision that has to be made. It's not precluded from the plan.

DR. PARRY: But it's not planned?

DR. JARDINE: Not at this time. It's preparing study plans for--in the event that we do have an opportunity to go to a vertical heater test or something like that.

DR. PRICE: But on that slide, you don't show anything on environmental characteristics, preparation of Box 2?

DR. JARDINE: What I was going to do, let me put this up, Dr. Price, and I will cover that down here. What I wanted to do was, I was limiting that to strictly the engineering and system studies, and then what I wanted to do was go to this box and say something about the materials characterization selections in the waste package plan, then I'll cover your Box 2 in this line. That's the way we structured this talk.

So let me switch from the engineering system studies down to the activities that the waste package plan outlines and gives guidance to on the materials characterizations and selections corresponding to the Boxes 6, 7, 9, 12, 16, 17 and 22 on the logic diagram.

Again, in the same format, the objectives of the materials and characterization activities are to develop the methodologies and the criteria in order to be able to select materials that satisfy the design concepts that are proposed, and then to select materials--and the fabrication processes as applicable--for those components and concepts that are to become part of the EBS waste package system; identify the most likely modes of component degradations after emplacement--and also during the pre-closure period, if that's applicable--to develop models for the prediction of component lifetimes--and again, I'm speaking about the combination waste package/EBS-type system; to perform the necessary materials testing that's required to support either the selection of materials or the development of those, what I call failure-mode models, and then also has the general charter, is all of these activities are to develop more detailed process models and the data that's required to support performance assessments, site suitability determinations and other applications that are associated with this large mine geologic disposal system activity.

DR. PRICE: And can some of those activities take place regardless of the status of Box 2, of preliminary environmental characteristics preparation? On your overall scheme, it shows it downstream of that and your feedback loop goes up to design and concepts and then back down to material selection, but can you do some of that regardless of the status of Box 2?

DR. JARDINE: Well, as we showed you in our Pleasanton meeting, we are operating under that assumption, and we have, since our January meeting, actually have laboratory testing under the highest quality assurance levels ongoing. So what we have is some materials testing activities that we feel confident would match up as to when this report is to be written, which is this fiscal year or this calendar year, that we will show that we are within the bounds of what we would expect the site conditions to be and, if not, then we will have to make some adjustments to the ongoing materials testing activities.

DR. PRICE: So once again, it does appear that the Route 2 and 10 there is very critical to the satisfactory and complete completion of so many other things; is that not true?

DR. JARDINE: The way I view it, it keeps you within the service environment, you know. You have a mission to accomplish, and that is to construct an EBS waste package system, and you have to know that service environment, is what I refer--in the system engineering language, in order to be sure that you're within that design envelope, and the question is, without having underground access to the site, how confident are you of those conditions that, indeed, will be underground when you get there?

DR. PRICE: Is it possible to proceed on the engineering in some of these other aspects on developing a concept that would be somewhat immune to that pacing, that would be not bound by environmental characteristics?

MR. CLONINGER: Is it possible?

DR. PRICE: Everything's possible, yeah, I know, but I'm just trying to get at the question.

MR. CLONINGER: Without knowing what kind of bounding conditions we have to design to, though, no, it is not possible. Say we were completely wrong about the site, we got down there and found that it was completely saturated and reducing, all of our design concepts presently would be thrown out.

DR. PRICE: Present design concepts.

MR. CLONINGER: Yes. But there's no reason apparent right now for us to be designing to saturated, reducing conditions because, not in my wildest imaginations, anyway, do we expect that down there.

DR. PARRY: What if the site fails?

MR. PETRIE: You mean it's unsuitable?

DR. PARRY: Yes.

MR. PETRIE: We'll go to some other site.

DR. JARDINE: But I think in my next talk you'll see that there is--

MR. PETRIE: That's beyond the ken of this group.

DR. JARDINE: Yeah. I hope you will see in the next talks--not this one--we have set out a strategy--and we're beginning to implement--as to how we can deal even with the conditions of being wet, and I need to get to that talk to maybe let you bring up your questions, and I think we will be showing you some concepts that we expect to come out of the process that if the site was suddenly unexpected--if tremendously unexpected conditions in some fraction--not the whole thing, some fraction--then there are some concepts that could be available to put into those regions or areas of the repository.

MR. CLONINGER: Excuse me, Les, but I'd like to expand on that just a little bit. Two points. A lot of the work we're doing in moving the science of materials evaluation and predictive technology forward would not be wasted if we abandoned the Yucca Mountain site. Furthermore, if we do encounter zones there with significant water, there are design concepts--at least in our minds--that would handle that quite well, but we are not presently considering designs that would account for a fully saturated site under reducing conditions. But I think that--well, I'll put it this way. My own opinion is, even if we had a dramatic climate change in the surface above Yucca Mountain, it would be several thousand to tens of thousands of years before we would ever reach those kinds of conditions at the repository level.

DR. DEERE: According to your existing models, without site characterization?

MR. CLONINGER: Yes.

DR. DEERE: That's the problem.

MR. CLONINGER: We cannot complete the design process without site access, if that is the question.

DR. LANGMUIR: I guess we'd like to see the engineered part of the system more robust, so that it was less dependent on anything that might be found down there. That's one thought.

MR. CLONINGER: I hear you.

DR. JARDINE: Okay. Is it okay to move on, then? I'll go back to the talk, but remember, I'm talking about these lines here in the yellow, and particularly, Boxes 6 and 7, and let me put this up to use as the kinds of activities that, indeed, are ongoing in this pre-ACD phase, and it makes the recognition that the materials characterization and testing has to have a design concept in order to do its thing, and the thing that it is going to do is develop the necessary criteria to select among the materials and then go ahead with a process to select candidate materials that, indeed, are for that concept.

We've introduced some lined boxes here in order to explain, try to illustrate what is required here. We have our current reference waste package concept, which you've heard a lot about in previous meetings, being the single metal, thin-wall container. We will be developing alternative waste package EBS-type concepts for which there will be materials of different kinds than currently we've been talking to you about over here, and there are also some peripheral materials, boreholes, shield plugs and packing materials I could have equally as well listed here.

Those things that come out of different design concepts--in my next talk--will go through a process in the materials and characterization in order to be sure that we have criteria to select among them, including appropriate factors, technologies available and those kinds of things as we told you in our Pleasanton meeting in January, and selected, so that's the kinds of things that we were doing and, in addition, we are continuing with a large fraction of those materials tests that we told you about in Denver.

I might point out that I think your handout in the audience is different than this one, so you can make the correction. The Board has the correct copy.

Let me move on to the next one, which I put in here under materials characterization because I know there's an interest and I was asked to address it in this talk, and basically, I wanted to make some comments about, you know, what is the basis of our current reference concept. And as we told you in Pleasanton, the thickness of 1 to 3 centimeters was based on a lot of past events, analyses and constraints which are being reexamined with the implementation of the waste package plan.

These reexaminations will include looking at the current and different design concepts and the associated different materials that go with those, and the underground near-field environment as we establish it from our site characterization program, or the lack thereof if we get into that mode, but as I've tried to say, we have a lot to do between now and the '92 time frame to get our ducks lined up; and then to carry out the appropriate experimental test and failure mode models.

Now, I think I need to make the point that part of the assumption that was built in here was, indeed, that in some of these past events, is that if Yucca Mountain was an unsaturated site which was quite different than any domestic or foreign site that exists in the early 1980 time frame, that did have an impact or an influence, a constraint on the setting of the wall thickness, among a lot of other things. But I think that that point needs to be continuously borne in mind, that the objective which led to the SCP reference design was targeted at an unsaturated site, contrast to other sites in the U.S. or foreign sites.

So to try to summarize, the current basis of 1 to 3 centimeters is consistent with that it is thick enough that it can be handled and emplaced. It doesn't have hydrostatic or lithostatic loads to contend with. It's thick enough with that. It's thick enough for the corrosion allowance--again, assuming that it is warm and dry for a large fraction of the time period that you need to worry about; that it was based on reasonably available standard material, such as Schedule 40 plate or pipe; and that you could close this thing. And I think as we told you at Denver in response to a question, there was a constraint that the DWPF glass pore canister being round and about two feet, had an influence on the dimensions of the containers that we've been showing you, nominally two feet to 28 inches, but not on the material, so that's really the basis as we are, and we've told you that as we go through the process, we're going to reexamine these things and be sure that the reference case falls out as the number one preferred, as selected by the process and DOE, or some other thing.

DR. LANGMUIR: But, Les, the analysis will be principally a science engineering approach to the materials you're looking at, rather than bringing in the public's perception of performance of these materials and the risks associated with them. That's what it sounds like.

DR. JARDINE: Yeah, I need to get to my second talk and I can take that question. In the hierarchy of requirements, we show some non-technical factors--that is what we've labeled them in the next talk--that can be used by the Department to deal with those questions that you're asking, be it programmatic, policy or public acceptance. But beyond--at a certain level down in the requirements, they become technical, and so I think the next talk recognizes this and has a mechanism in place to sort those out, not how you're going to make the decisions of what the balance is of how much effort you want to spend in the wet conditions as opposed to the dry conditions, but the process I'll show you in the next talk makes that acknowledgement, and those are labeled--as you will see--non-technical factors. There are three of them. Basically, it deals with the wet/dry, the hot/cold, and the 300 to a thousand years versus an extended lifetime. Those three things are labeled, in the next presentation, non-technical factors, although technical thing comes in, but the reasons for going one path or another is--may not be technical.

So let me go on to the last two here, but mainly, the near-field environment characterizations, which consists of Boxes 2, 10 and 20, as we've been receiving a lot of inquiry about, and the objective of the near-field environment characterizations is to characterize this near-field geochemistry, water chemistry, the mineral alterations and the radionuclide interactions that go on in the vicinity of the waste packages, and this is where my comment was coming from, that I perceive the EBS to necessarily include the rock adjacent to, because a lot of that material may not go very far, and we have to understand something about those processes, and that's the charter of the near-field environment characterizations.

Secondly, this will be developing the necessary fluid flow and transport models that are based on a mechanistic understanding of the phenomena of the near-field environment and the geochemistry, including the radionuclides that will be associated with any fluid movement, or should there be a breach of a package downstream in time.

Thirdly, to characterize the response of the near-field rock to different mechanical, geochemical and thermal loads by the appropriate modeling and experimental or R&D tests. Continuing on in the objectives of this series of activities is to conduct field prototype tests in order to prove instrumentation and data analyses and to train people and develop procedures so that when we do go to the exploratory shaft or to the field, we, indeed, have high confidence that our models are correct and that our tests will be successful. And this basically would encompass our G-Tunnel activities that were reported to you in the Pleasanton meeting, you know, this scope of work.

Then lastly, again, is to develop the necessary models and data that are required to support performance assessment, site suitability determinations and other applications throughout the program, and makes the tie to the total system modeling that goes on, be it hydrology or geochemistry.

I wanted to take a minute on Box 2 on the logic diagram, and the waste package plan makes this important commitment that an initial report will be generated, and it will be based on what is currently known about the site as all of our scientists understand that site, and the kinds of information that will be put into that will be the existing knowledge about the different hydrology parameters, the thermal parameters, or the geomechanic properties around the package, and it also will take into account what we expect or the effects the emplaced waste will have on the near-field phenomena and properties of interest. We'll also identify where there is gaps or where information is needed in order to--as we go in and fill in this process. This would be what is available to assume that the development of design concepts has its surface environment documented and available, and also that the materials testing people that are doing tests are within the bounds of what we think is there today.

It makes the commitment that this report will be baselined and updated continuously as new site characterization information becomes available, and by the process of incorporating and revising this, there will always be in DOE's technical database a current status of the existing knowledge about the near-field environment and, again, you know, I've been soft on the definition, but I hope I've shown you why it's, you know, when I say near-field environment, you may have your own term for that, but it's the area that's really effected most by the emplaced waste and it may have tens or hundreds of meters distance, depending on the way you prefer to define that near-field environment.

So this is a very important commitment, and we expect to have our draft document internally reviewed in the calendar year '92--or this calendar year, '90, excuse me; by December of this year and submitted to the project office. And the staff are all working on this rather eagerly in Dale Wilder's technical area, who--most of those people presented to you in the January meeting.

DR. LANGMUIR: Before you go on with that, will this document be available for--I presume it will be--for outside review? The Board would love to see this document as soon as it's available. I assume that your activities to follow it will be based in large part on what holes you identify and others might identify in the data and its interpretation and modeling that come out of this report. I'm sure you'll find some.

MR. CLONINGER: Don, we plan to make the report available to you when we receive the Livermore draft, of course, not for public release at that point until it's been reviewed and issued.

DR. JARDINE: And, of course, our document that we transmit to Mike will have been through our quality assurance program and been internally reviewed within our QA program and will be something that Livermore will stand behind.

MR. NIEDZIELSKI: Did you say when it will be available to the Board?

MR. CLONINGER: We will make it available to the Board when we receive it from Livermore; however, that will not be for public release at that point until it's been through Department of Energy review and approval for publication.

DR. PARRY: Would the person who spoke identify themselves, please?

MR. NIEDZIELSKI: Phil Niedzielski-Eichner.

DR. JARDINE: Okay, moving on, then, to the last of these four activities in the waste package plan, and I'm talking of the waste form characterizations involve Boxes 3, 11 and 21, and again, I remind you, you're going to hear a lot about that this afternoon on the glass work and tomorrow on the spent fuel work, and in detail, so, really, the objectives as laid out in the plan are to summarize again the existing information as we know that about the waste form that is needed for the necessary engineering, systems studies and performance assessments to have available in one document which, again, is baselined and controlled, information that all people are using and we're pulling from the same technical database.

Secondly, to develop the predictive models for the release of radionuclides from the waste package and EBS that incorporate the appropriate effects of waste form degradations in the service environment, the waste package component interactions, you know, as you make waste package EBS systems more complex, you get more components and you have to deal with that, and also, the near-field environment interactions, including radiation effects will be taken into account, or that's really the charter of these set of activities, and to assure that the appropriate data required by the models are available in the programs that are carried out in the laboratory. As appropriate, we'll validate the models and the data using natural analogs, laboratory experiments and peer reviews as, again, appropriate.

And then, lastly, again, has the same theme, and this is our tie into the performance assessment. We recognize it very clearly in the waste package plan, that we will be developing the more-detailed models and processes in order to support performance assessment, site suitability determinations and other applications throughout our program.

Now, again, Box 3 is this very first thing that's important before you're developing design concepts, has the same commitment as the near-field environment report, that an initial report will be produced based on what we currently know about the waste forms, be it glass or spent fuel. The kinds of information and the structure that we're choosing for this document involves information on waste form structural information--in other words, the sizes, the weights, maybe the composition of the unradiated material, the kinds of things that the engineering and systems people need, or perhaps some people even doing more follow-on origin calculations of radionuclide inventories.

And then the third part deals with the waste form radionuclide contents in either the spent fuel and gas, particularly things such as burnup and ages are very important. Continuing on with the contents of what is going to be in this report, again, the existing information will cover the existing information as you're going to hear about on spent fuel oxidation, dissolution and cladding releases will be compiled and put into this document in this particular section, and the dissolution work down here of glass work that you'll hear about this afternoon.

And then it also will encompass bringing what we know about, you know, recognizing that there is other kinds of material out there besides commercial spent fuel from the LWR's.

I want to make one point with this particular slide, that the waste package plan does discuss in several paragraphs, and it deals with the question and makes a recognition that we have a challenge before us if we're going to design a system, and the point of this is that we have, by this lower bounds here, an inventory--and as a function, thousands of tons versus burnup.

This represents the distribution of the quantity of tons of fuel that exist today in the inventory; in other words, it's about 20,000 tons if you integrate under this whole area. But because the reactors are all built and they're generating spent fuel, and the fuel vendors and others are working towards extending the burnup and pushing things out so that the lifetime is different, we have to deal with the question of, what is the projected inventory which has, among other things, higher burnup, perhaps, and certainly different radionuclide content and compositions, and this upper curve is the projections that come out of the databases in terms of what it is, and there's a big shift that you have to deal with. This is what we have available today for studies or for designing, and the projections are, hey, things are really moving out in time--I mean, not in time, in quantities. So how does an engineer, a designer of performance assessment deal with the question, what about these burnups that maybe push the 50,000 megawatt day per ton? What does that do to your reference concept or your bound that you're trying to work to in a traditional sense?

So there's a unique challenge here of dealing with, this is what we've got today. We think, if everything goes well, this is the projected inventory. Now, what kind of a sampling plan, if you like, needs to be available to have in place an approach so we know what our test matrix is and how we're going to do tests? And I'd put this point on here today, that a lot of the fuel you're going to be hearing about today is done on either Robinson or Turkey Point fuel, which falls in this bin of 30-35 megawatt days per ton.

You can ask yourself the question, you know, what is the relevancy of that testing that's done on those particular burnup specimens, given--looking at this diagram the way I do, there is a lot of stuff in different burnups, and this--and the associated things that go along with it, the decay, the radionuclides, grain sizes change. This may have or may not have effects on the release of radionuclides from the waste package EBS system, and the waste package plan makes this recognition and says that we will make the commitment to establish a test plan, a plan of how we're going to deal with the representative in this question of future projected inventories, and how we're going to deal with that both in our testing program, as well as in our approach to designing a waste package. It's a difficult challenge, but it's something that's very important to be aware of, and it has impacts, of course, way beyond the waste package. I mean, it's of tremendous importance, also, to the repository designers if you're doing a simple shielding calculation and setting hot cell wall thicknesses, you know. How do you deal with administrative things versus pouring more concrete, or hard engineering decisions that have to be made. So the plan is going to deal with this and--not the plan, but the Box 3 is also going to make an attempt--not an attempt--it's going to address what we know about this and put in the existing information and we have Oak Ridge, under our technical direction, is contributing to giving us information that we think will be in the right format that the waste package or the engineering designers would need to know, out of their database.

So let me try to summarize or end this thing by putting up again the flow diagram of the waste package plan, and what I've tried to show you is the way it's structured is that there are four parallel activities that deal with the engineering and system-type studies that go through different points in time. A very important part of that is the necessary feeds, continuous feeds of what we understand about the underground site that we're going to perform, and also, the surface environment during the pre-closure period. We cannot forget about that, and what we know about the waste form characteristics. That allows us to develop design concepts using a process that I'll talk about in the next talk, in order to have concepts available and materials people being sure that the materials, indeed, can make them and they can perform in the service environment. So there are feeds that aren't shown on here, in the interest of clarity, but we will move at the 10/92 point, having this stuff documented and available for turnover, and a decision, shall we proceed or shall something else happen, and we'll have our opportunity to make a readjustment based on our access to the underground, and move into the next more-detailed design, which as I'll show you a few designs, maybe two to four concepts will be at this point.

As you move out into the LAD, I think the plan is drafted--and it can be changed--makes the statement that a decision will be made at this point that a single design will be selected for more detailed development into the license application design. So several concepts will be carried along which will primarily be defined in the flow down of the requirements mapped out in the pre-ACD period. The ACD will take it a little step further, and then the narrowing down will be done before you move on into more constraining and detailed design. These activities are ongoing and continuously updated. There are boxes, and the plan has scheduled dates where there's information transferred from, say, the near-field environment up, which again is tied to the current site characterization activities.

That's all I really want to formally say on the waste package plan.

DR. VERINK: I suggest that, so that everyone will be properly prepared for receiving the next information that you're about to give us, that we take a break at this time and reconvene at ten-twenty, say?

(Whereupon, a brief break was taken.)

DR. VERINK: Let's reconvene, please.

DR. JARDINE: Okay, so let's get back to the agenda, and where I propose--if it's all right with Dr. Verink--is to pick up with the talk on the waste package/EBS alternatives design approach. Is that acceptable?

DR. VERINK: Fine.

DR. JARDINE: So in this talk--which, it's broken into three different parts, and basically, what I will do is give you an overview of the approach that has been established for identifying alternative waste package and EBS designs. The three parts of the talk are to make the point that it is a systems engineering based methodology that will be used to look at the different kinds of alternatives that are available.

I will give an illustrative example only of how that methodology will probably work in order to show you the thought process we've gone through to feel reasonably confident that this approach and the methodology will work, and then end with a summary.

So let me move into the very first part and make the point that to establish the number and the kind of design concepts for the EBS and waste package that will be carried forward, we will use a systems engineering process. This diagram I talked about earlier, and really, all I want to say here is that the process I'm going to be describing will focus on what's required to define the design requirements and the design options, how those will be developed. So these are the two parts of this thing that I'm going to be talking about, and we can put this up for just a minute and say that the process that I will be describing really involves the pre-ACD and the activities that are considered in this portion of the diagram; namely, starting with the definition of some requirements, recognizing there's inputs on the environment at which you have to do your job and the kinds of materials you handle. That allows you to develop concepts, identify requirements and verify or be sure that materials are, indeed, available and in this--implicit, although not shown here but will be done--are the nature of the design evaluations, trade studies as appropriate, and performance assessments that are required to be sure that the concept will work, which is the objective.

Now, to begin the point that we will be using a systems engineering process, this is a diagram that is taken out of these two references here, and it's intended to say that systems engineering has a lot of different definitions. This is a textbook definition, and our mission now is to convert this and apply it to the repository waste package/EBS subsystem elements, and the point I'd like to make here with this textbook example is that the very initial things you have to do are come up with a set of input requirements that are not overly constraining. This consists of some general statements of what the objectives, mission objectives are, the environment at which you have to perform that mission, and what are the constraints and how are you going to make your measurements of how well you have to do.

You then move into the steps that I'll be calling requirements analysis, which moves you into a functional analysis, a synthesis of design concepts against those general requirements, and asks the question, you know, a couple questions: What is the available technology that you've got as you construct these concepts? I didn't modify this for the waste package or the repository program, but this is an aerospace-type application. But you work your way to saying: Will these design concepts work based on available technology and the requirements? And you perform and evaluate as appropriate, trade studies in order to support a decision: Is the solution and design concept acceptable against your general requirements and those that are invoked in this system engineering requirements analysis process?

At the very end, you end up with an ability to write a more prescriptive description of the subsystem element you're after, and this is where you detail more constraining and more specifics, and go to the next phase of the design.

Now, let me begin to say how we're taking this textbook example and beginning to tailor it, if you like, to the repository or the mine geologic disposal system, and what I've done is these letters here correspond to the same points on the previous diagram.

Step A involves coming up and writing down input mission requirements, and the same effort in a parallel way is to define the design selection criteria that you're going to use to select among possible solutions, because you'll have multiple solutions that come out of this and you, at some point, will have to rank them and decide what are the best options, and maybe an analogy is a statement to provide me, in the aerospace business, with an aircraft, but you don't specify up in here, for example, one engine or two engines. This process will produce a solution. One solution by one vendor may have two engines; another may have one engine, but they may satisfy the general objective of go 5,000 miles and carry a 5,000 bomb. That may be all we should put here.

And so, this is the process that is important and I want to spend some time on, and we're calling it here a requirements analysis, and it's a way to bring in the flow down and the traceability and the constraints and the requirements of how we're also going to interpret the regulatory requirements, not up front, put them here and constrain ourselves, and so I want to show you some of our thinking of how we're beginning to go.

This is the Box C here, these three activities in order to end up with an ability to say: Are the designs feasible or are they workable? And then for those that are, we would document those designs and then have a process where we use our original criteria and revise as appropriate in order to select and rank the preferred design solutions so that we can write the specific design requirements, as we've labeled WPDR--and I showed you a little bit what the information structure is--and for the number of concepts that are selected--and I'll be showing you that there will be a few, from two to four--you would write a specific design requirements for each of those concepts and go into the next phase in the design. And our reference point we're using for time is roughly October, '92 for today's discussion.

Now, this diagram--I'm going to use one that's on page 16 just to say it again, because rather than go through it and then pull this one up, I'm going to come back to this one. But it's the same steps and it's another way to envision what I'm trying to communicate. Step A is define some mission requirements. Write those things down, at the same time recognizing that you're going to have to go through a ranking and a prioritization process. Come up with those selection factors that you want, you know, like what are the criteria that you're going to judge that you have a workable solution?

You then move into this functional analysis, trade studies and synthesis, and the term I'm going to introduce today is a requirements hierarchy, which is an ability to trace through the process requirements that are invoked, and you can pick different pathways or combinations of requirements through this in order to constrain and design downstream. When you do this, what you end up producing is drawings and specifications and performance as appropriate, and, of course, you carry out the kinds of analyses you need and have information that you need to support how you're going to go through and rank and select among the alternatives. And F is really--for the preferred option, there's a reference pathway through this requirements hierarchy that leads you to an ability to write a more specific set of requirements which you pass to the next phase of design. And I hope I can show you--and I'll be rather specific of what we're planning on doing there, but this is another way to say the same thing; the flow of the process that you go through, and the key part is this ability of tracing the requirements when you invoke them and showing that there are multiple choices, but we have to capture those and document them.

So moving into the mission requirements thing, I want to make a point that when you develop the waste package mission requirements, Step A, there is a definite flow-down and a hierarchy that starts with the Waste Policy Act itself, which says geological disposal, among other things--and perhaps it says concern yourself with Yucca Mountain right now, if you get into the Amendments Act--and there's a mission plan in these waste management systems requirement documents which are hierarchy-type system documents in Volume 1 and 4. Four is specific to the mine geologic disposal system, and the systems requirement document, which is a project document in Las Vegas. We have to extract out of that the necessary constraints and requirements, and write Step 1 or Step A, the waste package mission statement or requirements.

That allows us to go through the process, and what we will come out with after we select and rank things are more than one concept. Each one of those concepts that will come out, we will write a document, the specific design requirements. So, really, the point is there is a necessary flow-down. This is where we invoke more constraints and requirements for the different concepts, and those will be different, and we have to maintain this traceability on where we invoke them.

So let me make a couple more remarks on this requirements analysis, and really, what I'm--to remind you, what I'm talking about is this process here. I'm calling it Step C in order to get you up to the language we're using.

The requirements analysis can be viewed as a hierarchy of things that you invoke and starts, of course, with the Waste Policy Act and flows down. The requirements can be classified as of two types. This first type are the non-technical factors like we heard this morning from Dr. Langmuir, which could be programmatic, policy, public acceptance or other kinds of things. There are things that I think I can show you are purely more technical, where the engineers and the scientists can get involved and get down into more of the nuts and bolts, but it's important to recognize that there is a hierarchy, so that some things are subject to detailed technical trade studies, and some have to come from other sources, those kinds of decisions and constraints, and those are what we are labeling non-technical things for this talk.

Then we have to recognize that selections have to be made on the alternatives requirements that are possible if you're going to go forward and develop different design concepts. You have to pick a set, maintain the traceability and the choices, and move forward so you're in a position to answer how did you get to what you got, and what are all the things that you assumed, if that's what you want to use, or what are the constraints that are invoked on it, and where did it come from? Was it a constraint invoked from the repository subsystem element, or was it something that came from a CFR or an interpretation of it? But we have to do those things, and also, a key part is that the documentation and the flow-down traceability is a very, very key part of this, and it's what we're committing to do in order to have a defensible answer as to, how did you get to what you've got?

And let me introduce this thing I've labeled a requirements hierarchy and tell you that I'm going to go through three tiers of this, and the idea is that the upper tier are things that we're going to call probably non-technical selection, non-technical requirements, and what I've tried to lay out is, somewhat of an analogy is there's a set of input requirements if you go back to the textbook of system engineering, and there's a need to have this service environment. And this is intended to represent that a choice has to be made. Is the environment that you're going to do your design under dry, as we expect? Is it wet? And it's not intended to represent that it's a binary-type choice here. I mean, there's a whole range of these, but it's intended to lay out that what we're hearing is for the Yucca Mountain site, what if we have a dry environment? What if we run into unexpected conditions if it was wetter than normal, or at least in some small areas? How would we deal with it? This is invoking that thought process.

As you drop down to the thermal conditions, which is another kind of thing, this is intended to represent for the selection of a wet environment, is that constraint? I think of them as constraints or additional requirements imposed on the design process. Give me a design concept that is cold, cold meaning--and we have to define that, and not intending, again, the illustration only to define that, but it could be taken to be below the boiling point of water as opposed to warm, hot being above the boiling point of water. And then as you work your way down this hierarchy, another thing is kind of a general constraint, the containment period. How long is it you're going to invoke as a requirement or a design requirement on your designers? Is it going to be the 10,000-year type lifetime--or containment period, I guess--excuse me --is what we're using--as opposed to the 300 to a thousand-year, and let me take you down this path because it represents what is viewed as in the current site characterization program.

That is, the mission requirements would lead you along this path that we're assuming that the site is dry, that the packages, indeed, are hot or warm. The objective and the goal there is to keep them above the boiling point, and let's use the 300 to a thousand-year lifetime or containment period as the design constraint.

This continues down in more detail--and I'll show you in the next slide. Now, there are other pathways through here, and again, we've intended this to show you three potential combinations of requirements that could be invoked from this process, and I prefer to think of these as more non-technical factors. They may be things that are invoked, you know, somebody going down this path--or let's take this path, which maybe I didn't talk about, but if you went down the dry path and you decided to, for different reasons, go to a concept that would be colder than the normal current referenced concept--and there a lot of reasons why that could be, from MRS's to less kilowatts per can, to increased spacing where the real estate of the repository is not that important, and again, these are not all technical things, and then maybe this process would invoke these as constraints in the upper hierarchy and give it to the people down below as, do it that way. And the choices can be made by others, by the Department in a programmatic or policy sense as to how much effort to go down these different pathways, and to build and have other options and contingencies besides just the current SCP approach. And that's really the thinking of the way that we want to approach the waste package/EBS system.

Now, if I move down one more notch in the hierarchy of trees, this is intended to represent at least for this--there's a boundary here which we talked about up above, and I'm just showing part of this, and I cannot leave off the fact that there was a flow-down from the top and it's very, very important to recognize that there is severe constraints and interactions--and the arrows should really go both ways between the repository--that have major influences or impacts on the requirements that are invoked there. There are broader studies and engineering analyses besides the waste package/EBS system that come from the repository, or perhaps elsewhere, that also can invoke constraints.

I've chosen to label this that there are some decisions yet to be made as to how much of the fuel should be assumed to be not consolidated versus consolidated; decisions such as: Are we going to continue with the reference concept of co-mingling the defense and the spent fuel, or are we going to separate them into different tunnels and drifts? So the idea is--to try to illustrate--this is not all of them by any means. There's a very major influence and an interaction that has to take place with the repository subsystem elements that invoke constraints and flow down.

But at some point we get down to where what I'm going to show you, I hope, are what I'm calling more technical choices to be made, and for example, for the waste package, is it in a borehole or is it not in a borehole? That is a choice that has to be made either technically--presumably technically. It has major ramifications and interfaces with the repository people, because you get into things, you know, a lot of factors that come in before you can really know which is the preferred way to go.

As you drop down in this tree--and I'll try to aim down this one, which takes us down the SCP path--there's another choice that if it is in a borehole, is that borehole horizontal or vertical, and what is your technical basis for making that selection? As you continue down in the hierarchy --and in the SCP, a vertical borehole was assumed as the reference case--is there or is there not packing material around the waste package? And the way packing is defined in this program, Dr. Verink, as you know, I guess the buffer you're using when we talk sometimes, but packing means the material outside of the container between the borehole wall. But for the SCP and for the reference concept, no packing is what was selected for the design concept.

And finally, as another level here, is there or is there not filler material inside of the container? And let me give you an example where you may put a material in that could help you with the radiation effects in the outside environment, such as, you know, I don't want to get into materials, but you could put different materials in with high density that could be viewed as a filler, among other things, to reduce the shielding on either the near-field environment effects or perhaps for operational safety aspects, and maybe you can reduce wall thicknesses, and if you're into the self-chilling concepts, which leads me over--I wanted to go down this other path that is if you took a choice of a concept and a constraint, give me a design concept with no borehole. Don't constrain me to get into the borehole. What would that package and EBS system look like? If it isn't in a borehole, let's assume it's in a drift. I mean, it's not in a borehole is what I'm trying to communicate. How do we lay out those packages? Are they side-to-side, you know, kind of like a bunch of pencils in a row; or are they end-to-end? Because, nominally 15-feet length of packages means you could put them kind of one after the other in the center of the drift for spent fuel, and the reason is the nominal spacing is 15 feet among spent fuel packages. But that's a choice that you have to look at from operational considerations, retrievability considerations, things that are much more broad than strictly the waste package EBS.

And similarly, are you going to put packing or backfill in the drift or not on these side-to-side concepts? And similarly, the filler material, is that something you want to use in this concept? So again, I've drawn here to illustrate two potential combinations of requirements that could be invoked to lead you to outcoming downstream design considerations or design concepts.

This part of it deals with the kinds of things that you have to fold in in the engineering and design sense, or the kinds of considerations that you have to pay attention to in order to make trade decisions about viable or workable solutions; namely, thermal limits come into account, the criticality considerations as you put more fissile material in a package, and there's very serious and important handling and emplacement considerations which you have to take into account. You need to be able to get that in the ground, and then depending on your mission requirements--and I think retrievability is a very fundamental constraint--you need to have that in mind as there's a trade-off between retrievability and some of the concepts that you may want to pick through this tree.

Now, let me take you down one more step in order to introduce the idea that as we go down this requirements hierarchy tree, we're getting to the point where there are multiple decisions that can be made by a designer--and I think should be delegated to the designer--that can lead to equally acceptable solutions, and I know I first learned this in my previous incarnation, or not that, but in my life where I had a brilliant idea, I thought, to go to a project engineer in an engineering company, and he quickly--not quickly, but he taught me that, hey, there's a schedule out there. There's all the other disciplines that have done their job based on this reference concept. You've got maybe a better idea, but the one we've got is workable, so we can't just accept this point design, point single solution and go forward, but once you pick a workable solution the process goes forward, and that's part of an engineering design process and schedule and that kind of thing.

So there's a point to be made. As you work down what I again have chosen to be the SCP thing, the designer has an ability to pick--and should--how many assemblies really go in the container, you know, what is really the shape of that container, for instance, and then the question about the length of the container. Is it really best to have a single length for handling, or is two lengths an equal solution, recognizing there's a significant but--to some people, might be a significant difference in the length of PWR and BWR elements. But for handling operations or other things, maybe you want a single length, and so this is intended to represent that there are multiple choices, and you may come out with solutions that the designer may pick for a host of other reasons--particularly these interface considerations--back over to the surface facility designers and the subsurface designers, and those portions of the whole system that have to be brought in and constrain, in some cases, the choices that are made, or support the choices that are made by the designer.

Now, I want to show you a couple examples of what we would expect to cull out of this process, and basically, this says that there are three concepts I want to show you. The reference, a self-shielded concept, which is one of those pathways, potential combinations of requirements, and some concepts for packing. I don't think this one really merits any discussion. It's been beat to death in several of our meetings, but that's the reference SCP design, and instead, let me take you to a concept that is a possible outcome for one of the pathways of a self-shielded package.

And this concept basically--it has a notion we're in a drift. You pre-place some backfill or packing material, you know. This is a notch. The packages would be placed end-to-end and they're self-shielded enough that you have either the equipment or the ability to emplace them and retrieve them. Another decision is: What is the material that you might want to put over it in a backfill? And to go to Dr. Langmuir's question, this provides you with an opportunity in this kind of a concept to select this material, to control the local chemistry should there be water or some other fluid come along in here and contact this, and the decision as to when you'd add this stuff is another option that's available. You need to be able to retrieve, I believe, because that is what we have in our mission requirements, waste package mission requirements, and there are a lot of trade-offs that have to be considered and one of them I'll just point out. It's that the height of the drift here is only 3 meters and it allows you to have a shorter drift, meaning there is some advantage and you don't drill boreholes, but, of course, you're paying for material, but is there or is there not a filler that's appropriate to put in here to help you with some of the wall thickness that you may need for operational safety considerations?

So we would expect this to be a potential concept that would come out of the process, and gives you some ability--and this is an area where we would tie in and bring in the, you know, our scientific people to contribute to what --for some kind of an upper tiered requirements that's invoked on us, what would be the kinds of materials that would be best put in here? And we have to pay attention to the actual repository people and the mechanical handling of things, but it certainly allows you to have an environment that you may be able to control local chemistries, or even do some modeling and predicting capabilities.

This is actually the third concept, the reference that I wanted to point out, that, again, we would expect to be a possible outcome of applying this process and this shows a horizontal emplaced waste package. It's different than the reference. Now, the concept could have basically the container--I'm not sure what the material would be, but this is intended to say there could be a concept where the packing material that was selected was put in there and the package inserted, if you like. This is a concept that is horizontal, but it has a pre-placed packing material that is beginning to make what we hear a more robust container, these different words, and a shielding.

Also, if you take a cross-section through here, this is intended to represent if it was intact fuel--again, there will be some of both. The ratio has to be determined and planned for in the design. You have an option of putting some filler materials within the package, and then the packing material. So, again, these are illustrations of what we would expect to come out of applying this process, and the reference would also come out and we would have our traceability available to us of how we got to the reference concept and what, indeed, were the constraints and interfaces.

Now, this is intended to summarize, in a sense, what we're doing. One path leads to the SCP reference design, and let me take you through it; that based on the waste package mission requirements which would be a general statement, not too constraining and assuming point designs or solutions. Instead, it would say things like: Make sure that the waste is retrievable, it's in a geologic disposal, and it's an unsaturated site; namely, Yucca Mountain.

If you apply additional requirements or alternatives for that--and this might be some that are viewed, as I'm calling them, programmatic or policy or non-technical--these also correlate with the four questions that Dr. Verink read into the record, and also Ted Petrie later, that these capture the essence of, I think, those four questions. But, for instance, is the environment that you want to do wet or dry? Is it cold or hot? And is the lifetime containment period beyond a thousand years, or is it the normal 300 to a thousand?

You pick a pathway through that, and then you are in a position to continually apply more and more constraining things, leading to the SCP. We know that we assumed the borehole. The choice has been made to put it in a borehole, don't use packing and don't use filler, and it's hot/dry, 300 to 1,000-year containment period life. Then, more specifically, the designer gets involved and says that for the current concept there is no borehole alignment and it would probably be that kind of a material, a high nickel alloy container. There will be a shielding plug and there happens to be three intact assemblies, PWR, for that case.

But an equal solution that could come out of this is another pathway through where you pick the no borehole concept and give me a packing material inside to help assist with the shielding either for near-field environment perturbations or for operational safety considerations--or not the--that's the filler, excuse me, and the packing, you know, is the thing: What kind of a material could we put in there? Maybe you're doing it for reasons up here, that you might run into an unexpected region of the repository where the conditions weren't what 90 per cent of the other places were. So it gives the management an opportunity to have a design concept developed to some detail and on the shelf, with a packing material, and they'd control the local chemistry as you get underground, which may assist in the modeling of the EBS system.

But what you do is you work your way down, and the designer would apply the side-to-side choice and crush material and maybe sets a dose limit on what the surface limit would be on those packages for retrievability and operational considerations when, you know, you do have to have a worker and you don't necessarily want to have him in a shield to--I mean, he may be in a shielded transfer--transporter machine, but you have to recover that machine if something should happen in a failure mode, but that leads you to this process.

So that's really what we envision as how this is going to happen and what the outcome will be of applying this, and so to summarize it, I guess I'll go to my colored one instead of the black and white one, but what I've tried to show you is that, you know, we say we're going to use a system engineering approach.

We've looked at some textbook examples, and we're focusing in on the type that's been used in the aerospace business, and we are applying it or bending it to our portion of the mine geologic disposal system, and that requires that we have the mission requirements stated up front, come up with the methods or the criteria that we're going to use to select and rank among these different possibilities, go into the systematic functional analysis trade studies and synthesis, paying attention, knowing that we have to maintain the documentation and not drown in the documentation, but maintain the ability to have the traceability for what are the constraints and the choices we make so that we can--and we're proposing to use these decision--not so much decision trees as hierarchy trees, or I've seen them referred to as trade study trees. These become note points that you can identify if a trade study is suggested, in order to support your choice downstream.

But this leads to the generation of those concepts or drawings, so it's on paper for both design evaluations and for performance assessment people so that they're operating from the same basis and, presumably, they're drawing from the near-field environment report and the waste form characteristics report so the data that's going on in design analysis or performance assessments or out of the same technical database; also, that the drawings are, indeed--they're all looking at the same thing--will allow you to go through a process to select and rank preferred solutions, and then for each of those preferred solutions that is selected for the next step in design, we will write and track what are the constraints invoked on the next guy, the next step in the design process.

So in summary, this is a status of where we're at in implementing this process, that we have implemented it; that the mission requirements and selection factors are now being formulated; and that the requirements analysis really has been initiated since this slide was made, but we're just beginning that process to go through the functional analysis and the synthesis, and also having to deal with the fact that there's a lot of other parts of the system, mine geologic disposal system, that we have to bring into our process and that's a challenge, and I've said we were going to give special attention to the documentation and the traceability so that we will be able to have an ability to answer where the requirement came from, where the constraint came from, how did you get to where you were, and finally, that--well, not finally. There's another one here, that in terms of the methodology that will be used to make the selection and the ranking, we really have to develop that. We're not in a position to say how we're going to do that. We're certainly going to draw upon information that has been part of the other three major studies that DOE's told you about in Atlanta. That may be appropriate, but there are also the design trade studies that are candidates to make some of these choices in the hierarchy trees, and so we're really not in a position today to talk about how we're going to do that.

We recognize that's a significant area of how are we going to pick among a self-shielded concept and a tunnel drift versus a concept with a packing, or perhaps the current reference concept. That methodology is something that is going to be developed over the next year, and I'm sure we'll have an opportunity to elicit your inputs on that, as well as others.

And then lastly here, that the specific design requirements are going to be developed for a few--and we're saying two to four at this time seems like our number we're putting on the view graph--and those, you know, those will be --that are selected, then, will be developed further in the next phase of the design, and we will have this traceability if it's a technical factor or it's a non-technical factor, as to what led us through these different acceptable or workable design solutions.

I think that's all I really had put together on this approach.

DR. DEERE: Will the existing baseline case also have this traceability with the decision trees where decisions are made along the way so that this has the same degree of scrutiny as your alternative designs?

DR. JARDINE: Our intent is to re-do the process and take it down the path which would include the reference, and if everything was, you know, when we repeat the process, if it still comes out to be an acceptable solution, then out would come the current reference design. So the intent is to run it through, I think, rather quickly and not belabor it, but we would intend to run the current--run a set of constraints up that would lead you to the current reference concept, but we may find in this process there's some choices that were made that were introduced as outside constraints that are hard to put in a hierarchy or a traceability.

DR. DEERE: Of course, these are some of the questions that we have raised in all aspects of the program. When were the decisions made and what was the basis for them--not necessarily on the waste package, but on the different things --to try to understand why are we here where we are.

DR. JARDINE: Right.

DR. DEERE: And what decision was made four years ago when some other things were taken into consideration that today might not be, or vice versa.

DR. JARDINE: And I think the intent of this presentation was to show you, the Board, that we intend, the Department intends to look at multiple paths--combinations of requirements is a term I use--to look at some--and they are the ones that are going to make those decisions of which paths and how much waiting in terms of resources down those different paths for non-technical reasons and, perhaps, some technical reasons. Technical people like myself are allowed to feed into that input, and many other people and parts of the system have to play a role in that.

DR. DEERE: And when you come to decisions, wet or dry, maybe you should have one alternative that says wet or dry. You certainly would increase some confidence.

DR. JARDINE: Yes. Do you mean one, only one choice; or both?

DR. VERINK: Both.

DR. DEERE: Wet, dry, or wet and dry.

DR. JARDINE: I think we chose to show you that that--indeed, we're expecting to go down both paths, and there are multiple reasons for that. I alluded to several. There may be small regions--

DR. DEERE: I'm saying not always dry, not always wet.

DR. PRICE: Robust, regardless.

DR. JARDINE: Okay.

DR. PRICE: That philosophy would give some relief from the dependency that you show at this point on site characterization. If you had that philosophy and perhaps you developed a waste package system rather than just simply looking at a container as the waste package, but an entire system that might be robust regardless of the host; that is, the system could have alternatives within the system, where you're looking at the host as part of the system, the interface between the container as part of the system, and the container itself as part of the system, to be robust.

MR. PETRIE: This is Ted Petrie. I'm not sure we can answer your question today, is that will we come up with some kind of a, with a concept which would be able to fit all of those or not. I don't think we can answer that today. I think you're suggesting should that be considered, and I would say yes, they need to be considered. Is that fair, Les?

DR. JARDINE: Yes. And I tried to say those are not binary choices, and we really, you know, I mean, that's the Department's--we've outlined the process we want to try to implement and we've begun that implementation, and then presumably we have to deal with the choices and identify--we think this is a means to organize our thoughts and the different suggestions and get them available for Ted and others to give us guidance, or whoever is doing the work.

DR. DEERE: It also seems that a couple of places, or a number of places you have shown 300 to 1,000 years versus greater than 10,000 years. I think the NRC's statement that came out a couple weeks ago, that we really didn't mean 300 to 1,000, within that range, if you want to take credit for more than a thousand and not go to 10,000. You have the choice of 5,000 to 8,000, or 3,000 to 6,000. Do you think you can cut it any closer than having to go to 10,000?

DR. JARDINE: Yeah, and just so we don't get this on the record, but I think you did say at one point greater than 10,000, and you didn't mean that; greater than a thousand years, correct?

DR. DEERE: Well, I forget if you said thousand or greater than 10,000.

DR. JARDINE: I never said greater than 10,000 years. If I had to say, it would be greater than a thousand years, but I think I used 10,000 years to kind of convey in a cartoon form that that's the total system requirement which we'll show for regulatory compliance.

DR. DEERE: But for me, greater than 10,000 and 10,000 is the same.

DR. JARDINE: Okay.

(Laughter.)

MR. McFARLAND: I'm fascinated with this, as you put it, the classical systems engineering approach, but I think there's a basic fundamental question that you're a piece of the program. In order to be able to work in this check and balance mode, the other parts of the program have to be set up pretty much in the same way so that you're interfacing with the site characterization group, with the surface facility group, with the surface testing group, with the ESF group.

How do you see this interfacing coming about? How will you function if you don't have this approach used across the entire program?

MR. CLONINGER: Dr. John Bartlett, our Director of the Office of Civilian Radioactive Waste Management has directed all elements of the program to initiate the systems engineering approach that is very much like this, and we'll be integrating with all elements of the program in that effort.

MR. McFARLAND: When would you plan the meeting with Sandia, for example, on the design of the repository and looking at their requirements for far-field geology versus your needs on near-field geology?

MR. CLONINGER: Those meetings are already ongoing.

DR. JARDINE: As an example, I can't tell you on the repository design, but I can tell you Thursday and Friday, on performance assessment, my staff's meeting with Sandia, on September 13th, a meeting on geochemistry at Los Alamos.

MR. McFARLAND: Could we request a schedule of those meetings?

MR. CLONINGER: I believe so. Max Blanchard is here. He may have the schedule with him; I'm not sure.

MR. McFARLAND: I'll talk to Max.

One other question: Ted, Dr. Price addressed a question to you this morning on the allocation of resources on the critical pathing on the front end of a systems engineering approach that says: What are my critical needs? What are my critical paths? What happens if...? You indicated that this was being done. Can you tell us who is doing it and how we could access the group of people that's doing the system planning and the allocations?

MR. PETRIE: There is a project control organization within the Department in Nevada, whose--one of their functions is to provide a integrated logic. Does that--

MR. McFARLAND: They work for you?

MR. PETRIE: They work for Carl Gertz.

MR. McFARLAND: They work for Carl Gertz.

MR. PETRIE: Yes.

MR. McFARLAND: Thank you.

DR. JARDINE: Any other questions?

(No audible response.)

DR. JARDINE: Okay. Thank you.

MR. CLONINGER: Okay. We're at the point in the agenda where we're switching gears a little bit. I'll be presenting an overview of the waste acceptance process, the upfront work that needs to be done. I'm suffering the after-effects of a bad cold here, but I'll try to come through a little better.

I'll be talking about the waste acceptance process in an overview fashion, and then after lunch, Bob Brown of DOE Richland operations, representing EEM, will present an overview of the high-level waste glass producer's response to the waste acceptance process, and John Plodinec and Mr. Palmer from two of the waste producers will present some information on how they're going about producing the waste according to agreed-to specifications.

An outline of my presentation. First, I'll just briefly describe the obligations that the Office of Civilian Radioactive Waste Management has in the waste acceptance process, and a brief description of the process itself; discuss the waste acceptance requirements that are being developed from our waste disposal information needs perspective for both spent fuel and high-level waste glass, and then I'll give a brief discussion of the waste acceptance preliminary specifications that are currently under development for high-level waste glass.

Well, the Nuclear Waste Policy Act, as amended, has directed the Department of Energy to accept, transport, store and dispose of high-level waste glass, which--or high-level waste, excuse me, which includes spent fuel. There also exists in the form of Code of Formal Regulations, Chapter 10, Part 961, a standard contract between the Department and the nuclear electric utilities for acceptance and disposal of spent fuel and that specifies that beginning in 1998, the Department will begin taking custody of that spent fuel, and the rights for having their fuel picked up first belongs to the utilities that have the oldest fuel, that fuel which has been discharged the earliest from the reactor. Those rights are tradeable among the utilities for consideration of agreements between and among themselves. Details for the actual spent fuel deliveries and receipts are still being negotiated between the Department and the utilities.

For the high-level waste glass, there are other agreements and they are within the Department of Energy and include the State of New York and West Valley facility up there in New York. These are for vitrified high-level wastes. Acceptance dates are currently uncertain and the primary focus of the program right now is in developing these waste acceptance preliminary specifications--I'll refer to them as the WAPS from here on--and the waste producers' response to those specifications.

Another class of waste that is going to be fairly large, we believe, is the so-called "greater than Class C" wastes, which the Department will be responsible for disposing of. Right now, this waste group is not very well defined and, therefore, we have no current detailed plans to accept and dispose of this waste. However, EM, the Environmental Restoration and Waste Management Office, our sister organization, is going to issue a scope of "greater than Class C" report in early fiscal year 1991, I believe before the calendar year has ended.

The overall waste acceptance process as outlined in the Nuclear Waste Policy Act looks something like this. The regulatory requirements for acceptance, transportation, storage and disposal of these wastes have been promulgated by NRC and the EPA, and they're delineated in 10 CFR, Part 60 and, by reference, 40 CFR 191. The disposing agent, DOE/Office of Civilian Radioactive Waste Management, must obtain a license under 10 CFR, Part 60 to receive, transport and dispose of these wastes.

For the high-level waste glass, or the vitrified high-level waste, the waste producers are represented by DOE's EM organization, and they operate through the waste acceptance preliminary specifications which, as I've said, are currently under development. The utilities, again, operate with us through the standard contract for waste receipt and disposal.

The Department is presently in the process of developing high-level waste acceptance requirements based on our information needs, and those information needs, in general, at first look are quite simple. We need to know what kind of waste will be received, how much of each type, and several specific characteristics regarding that waste for design concepts. We need to know this, of course, because we need to do our planning and requirements development for transporting, storing and disposing of these wastes.

From the waste package program perspective, our information needs are primarily focused to demonstrating compliance with the two post-closure performance requirements that we've already talked about; namely, substantially complete containment and controlled release of the radionuclides thereafter from the engineered barrier system. Furthermore, we have specific design criteria delineated in 10 CFR 60, Part 135, regarding the waste forms themselves and considerations regarding them that create other information needs.

Starting with spent fuel, our information needs lie in two general areas: One I'll call characteristics, and that's just basically everything you ever wanted to know about spent nuclear fuel. It's inventory, distribution, microstructure of the fuel, existing rod gas pressure, et cetera, et cetera, et cetera for the entire population of fuel that needs to be disposed of. Furthermore, there are what we call in-repository performance data and models that need to be developed, and those are primarily the oxidation, dissolution and gaseous release behaviors of the fuel as emplaced over a 10,000-year period. The characteristics data we obtain from others, and the performance data we develop ourselves within the waste package program.

A very important part of that process is done by an organization called the Materials Characterization Center, part of our program, and their job is to acquire and characterize the spent fuels that we use as the source of our general characteristics data and, in fact, they develop a lot of that general characteristics data themselves, and provide to us spent fuel testing materials for us to do the in-repository performance data and model development. These fuels are called approved testing materials.

There are two basic requirements for a spent nuclear fuel sample to be called an ATM, and that in order for our test results, characterization data and models to be valid, these ATM's that we receive and test must, one, be representative of the entire spent fuel inventory that we'll have to dispose of; and two, they have to have characteristics that are representative of nominal or average spent fuel, as well as bounding fuels. Les showed you a chart earlier that showed the very large distribution in just burnup, one category. In fact, that is one of the criteria for selecting ATM's, which is the exposure in reactor and the distribution thereof, where we'll need to select samples that are representative of that entire distribution.

The other criterion is the per cent fission gas release that occurred in the fuel itself during reactor operation, which leads to migration of the lighter elements and more volatile elements within the fuel itself and relocation of it in the matrix. So far, it appears that these two criteria meet some very important requirements. They do apparently correlate with most of the performance characteristics of interest. This is still unconfirmed, and we're working on confirming that, and even more important, they are available. They can be obtained for the population.

DR. PARRY: Mike, excuse me. What do you mean by performance characteristics?

MR. CLONINGER: Oxidation, dissolution and gaseous release behavior in the repository itself. It looks like these at burnup and per cent fission gas release can be used as criteria for selecting fuels that would be representative of those characteristics across the entire spectrum of the commercial spent fuels that we'll be disposing of.

DR. PARRY: When you talk per cent fission gas release, you're talking about leakers?

MR. CLONINGER: No, no. This is the migration of elements in the fuel matrix itself, mostly fission products, that are somewhat volatile at reactor operation temperatures. They actually escape from being uniformly distributed throughout the ceramic matrix of the fuel and tend to collect in areas such as fuel grain boundaries, cracks in the fuel, and the built-in gaps between the fuel and the cladding and between the fuel pellets themselves. A lot of these are also highly soluble in water, and if contacted by water, would tend to give a somewhat pulse release for a short period of time from the fuel. We need to know the distribution within the fuel itself of those in order to do our predictive modeling.

DR. PARRY: So your testing will involve puncturing of spent fuel rods and making appropriate measurements?

MR. CLONINGER: No. There are models, actual models--in fact, my next slide addresses that a bit--to predict, given the fuel design and the reactor operating history, what fission gas release during operation would have been. At our temperatures that we'll receive the fuel at, store it at and dispose it at, these are no longer volatile materials, but they've moved from the fuel matrix to a large degree, and collected in the gaps in the fuel along the grain boundaries, and they're fairly accessible for dissolution release if contacted by water.

DR. PARRY: And are you going to do testing on the dissolution, or just to confirm your models?

MR. CLONINGER: Oh, yes. Yes, but first we need to select a representative set of spent fuels to do that testing on so that we can see what the rates of release could be expected to be.

This basic approach requires a lot of cooperation, of course, from the utilities and the fuel manufacturers, the vendors, and we're getting excellent cooperation from them. The burnup data we can get directly from the reactor-specific database, which you'll hear about this afternoon, which is developed by the Energy Information Administration based on information provided to them directly by the utilities. The fission gas release for that same inventory can be estimated based on available codes and vendor models, and then can be confirmed through limited testing of the samples selected.

You've seen this example before. Les presented it. It's just typical of what the distributions would look like for one of the selection criteria, burnup; the existing inventory and the predicted inventory for one case, which is the no new reactors and extended burnup, and that, coupled with predictions again over the population of the distribution of per cent fission gas release--and this is not based on any real data, by the way, although it's probably a very typical shape--would result in a combined histogram at some point--and again, this is for illustration only, it's not based on any real data--where we would have the distribution of burnups, combined burnup and low or high fission gas release for the entire population, and from that grouping we would make selections of approved testing materials for the program, which is the next step once we've completed the distribution and representative effort.

So, eventually we will have approved testing materials, or ATM's, in each of these four categories; low burnup, low fission gas release, high burnup, high fission gas--or low burnup, high fission gas release, high/high and low/high, and have available to us for testing, database development and model development representative samples in all of these categories. Currently we have 5 ATM in the low/low and 3 ATM's in the low burnup, high fission gas release.

Switching over to the high-level waste glass, again, there are characteristics data that we need for design and planning purposes, and pretty much the same as the spent nuclear fuel; inventory, inventory distribution, and physical and chemical properties, and in parallel to the spent fuel, we need the in-repository performance data and model development which we do in-house; again, dissolution, solubility behavior, alteration in a non-saturated environment or a water vapor air environment.

The acceptance process is a little difference with the high-level waste glass. OCRWM and EM have agreed that we will conduct this process through four documents. The first one is the waste acceptance preliminary specifications that say what OCRWM needs to know about this waste in order to accept it; the waste form compliance plan, which is the producers' response to the WAPS, saying how they will demonstrate compliance with that; the waste form qualification report, which, actually, its development was initiated before we even had a draft WAPS and it's a following of the process development at the waste producers that just documents what they've done and how it turned out in developing their manufacturing process, all of the testing they've done up to that point, and basically gives an evaluation as to how well they can actually do their waste compliance plan commitments; and then, ultimately, there will be waste form production records when they actually start hot production, fully radioactive waste form production, and for every canister of glass there will be a production record, complete traceability for that canister. These documents assure OCRWM that the waste that we accept is "as agreed" up here in the specifications.

DR. PARRY: Mike, do you expect that the--you mentioned each canister is going to have a record on it. Will it be samples retained?

MR. CLONINGER: There will be grab samples retained of the glass from selected canisters on a statistically designed basis.

DR. PARRY: Has the NRC--I know there was considerable discussion with them about the rate of sampling. Has NRC agreed to a grab sample or random sample?

MR. CLONINGER: I don't know whether or not they have agreed to random sampling. I know that there are staff members in the NRC who would prefer that we sample every canister and archive that sample. I might also add that NRC approval is not required for this process, and I'd like to discuss that a little more later.

DR. PARRY: Okay.

MR. CLONINGER: The waste acceptance preliminary specifications are currently drafted for high-level waste glass and will soon be issued to the waste producers, as well as other program participants for a formal technical review. These basically just delineate what technical information we will require about the waste that's produced. I won't go into any detail, but it just basically is similar to the information we need about spent nuclear fuel, everything you ever wanted to know about that product. A lot of these flow out of 10 CFR 60, Part 135 specifications for design consideration.

Getting back to Dr. Parry's question, finalization of the waste acceptance preliminary specifications depends on OCRWM and EM agreement on the WAPS and the response, the waste compliance plan, and the operations experienced for the Savannah River Defense Waste Processing facility and the status of their waste qualification report at that point in time. This will tell us whether or not it really is feasible to demonstrate compliance with the WAPS through the process outlined in the waste compliance plan.

A couple of things that finalization does not depend on is selection of any particular site as a repository, or the concurrence of any parties other than OCRWM, EM and the Secretary of Energy. However, we have requested NRC to review and input on that, not just the WAPS, but the waste qualification report and the waste compliance plan, and they have commented and asked some pretty good questions.

I'll be addressing just a couple of their questions. The first one was: What does WAPS compliance say about qualification for repository service? Not much. Compliance with the WAPS tells OCRWM that what we're getting is real glass, not foam or ceramic. The composition and geometry is bounded; therefore, the product that we'll be receiving is within our testing and modeling range and, furthermore, that it does comply with 10 CFR 60.135. Qualification for a specific repository site and repository EBS and waste package design is yet another step for OCRWM to perform, not EM. That'll be a part of the process once a repository site has been selected.

Another good question they brought up is: What about non-complying products? First of all, just looking at what the EM organizations, the waste producers are doing, we don't expect very many, if any, non-complying products. Their process and product control looks to be state of the art and we don't expect a lot of defects, but human systems are not perfect and there probably will be some. What we'll need to know is what fraction, how bad will they be, what corrective actions have they taken or can be taken, and someone--probably us--will have to obtain samples and determine what the performance limits of those products would be and what impact that would have on emplacing that in a licensed repository at some point.

That basically concludes the overview. This afternoon, led by Robert Brown from Richland operations, we'll be hearing from EM and the waste producers in their response to the waste acceptance preliminary specifications. They'll be telling you a little bit about how they're going about doing their business.

Any questions?

MR. PETRIE: This is Ted Petrie. We're running a little bit ahead of schedule. Do you have any questions at this point on the morning sessions?

MR. McFARLAND: Mike, one question. You mentioned early that the--about the agreement between the DOE and the waste producers on receiving the fuel. Can DOE, through this agreement, specify the age of the fuel to be delivered to the government?

MR. CLONINGER: I believe so. We have an ongoing dialogue with the producers and, in fact, we've done some systems engineering analyses, some of which were presented at Denver in March looking at what would be--from a repository standpoint--the preferred receipt scenario in terms of burnup and age of the fuel. Independent from that, but coordinated with it, as part of the OCRWM program, they've gone to the utilities and asked them what their preferred delivery scenario would be in terms of mix of age and burnup, and it doesn't look like we're all that far apart, and the utilities are very cooperative and appear to be willing to discuss various receipt scenarios.

MR. McFARLAND: Could the repository function without an MRS, without a means of storing?

MR. CLONINGER: I would say at this point, no, because we're obligated to receive waste in 1998 and there will not be a repository on that date. As far as if there were a repository in operation at that date, we probably could, depending on how much lag storage we wanted to build in to optimize our emplacement underground.

MR. McFARLAND: How much--

MR. CLONINGER: Lag storage; in other words, how much storage we would want to build in in the surface facilities to hold the spent fuel so that we could select from it as we wanted, rather than having to take what comes in the door that day and dispose of it underground.

MR. McFARLAND: Is that a feature of the surface facility, to store?

MR. CLONINGER: There's a small lag storage built in, yes, in the present conceptual design. To do true heat tailoring, that would have to be expanded somewhat if we did not have an MRS.

MR. McFARLAND: Thank you.

DR. DEERE: That's called lag storage?

MR. CLONINGER: Lag storage.

DR. JARDINE: Sometimes referred to as surge storage. In the requirements documents, they use the number, I think, less than 750 tons is the total capacity limit imposed on the current SCP reference design.

DR. PARRY: Who imposed that limit?

DR. JARDINE: It came from the mine geologic disposal systems. It was a constraint invoked through the systems engineering documents, or the requirements documents, and it was worded in terms of--I believe it was three months' storage capacity of the annual rate.

DR. PARRY: So then it wasn't a limit, it was what was necessary to maintain decent operation of the facility; is that correct?

DR. JARDINE: I recall roughly, since it was 1984, a document that had that constraint imposed on it, it was guidance to the designer of the surface facilities and the underground. It was a constraint.

MR. PETRIE: May I? This is Ted Petrie again.

We had to allow for surges, if you like, in receipts of material that we couldn't process immediately, but at the same time we could not build an MRS, clearly. So it was a number which we felt would satisfy most of our transportation or other kinds of unusual occurrences that would allow us to do some storage at the site consistent with maintaining a reasonable flow into the repository.

DR. PARRY: The MRS is limited to 15,000 metric tons; is that correct?

MR. PETRIE: Yes, that's correct.

DR. PARRY: And yours is 750?

MR. PETRIE: Yes. That's the number--remember, I'm with glass. I'm not positive of that number.

DR. JARDINE: But you have to remember, the objective of the SCP reference design is to put it underground, so this was just the surge capacity. In a combination of cask on site, the--I'm sorry. The combination of the shipping cask on site was counted in that 750 total, as well as the storage racks and the unloading hot cells, and as well as in the storage vault, which was in the design, to store canisters before they went underground. So it was a combination of those three sources of fuel that were summed up to less than 750 tons as a design constraint.

DR. VERINK: If there are two or three questions from the audience, we would be glad to entertain them now because of our time schedule. Anyone who wishes to ask one, please come to the microphone, identify yourself for the record and speak.

Are there any questions?

MR. MANAKTALA: My name is Hersh Manaktala. I'm from the Center for Nuclear Waste Regulatory Analysis in San Antonio.

You mentioned something about out of spec canisters containing glass waste form, and you said they would impact the repository, but you didn't mention any re-work procedures if you have to return it back.

MR. CLONINGER: Okay. There is a specification in the waste acceptance preliminary specification that addresses that very thing, and that will be coming out for technical review--

I think you people will be involved eventually--describing what the process will be. I can't recall the details, but there's a ten-day notification, ten-day maximum period after discovery after which--or within which that the OCRWM must be notified of the existence, and then there's a procedure that goes on from there as to what to do with the non-conforming product.

MR. MANAKTALA: Okay. Then I take it that if there is something going on to the fact that you can re-process it and not just decide it cannot go in the repository. If it cannot, how do you dispose it off? It's being addressed, I suppose.

MR. CLONINGER: Okay. Until we know what kind of non-conformances we might expect, we can't make any specific plans as to what we would do with them. Right now, we are not planning on reprocessing any of the high-level waste canisters.

DR. PARRY: Mike, isn't it generally expected that any further operations on any received canisters that were out of spec would actually be limited to re-packaging?

MR. CLONINGER: I would guess that would be most likely, Jack.

MR. BLANCHARD: I'm Max Blanchard with the Department of Energy. I'd like to make a comment about observations made by various Board members about program planning and critical path analysis.

Prior to the release of the sixty-day report by Secretary Watkins, we had maintained what we called a long range planning network which had on the order of about seven thousand nodes, which had details planned down to the sixth or seventh level of the WBS element. That was prepared about three years ago and has been operational from a program planning standpoint for things like waste package and site characterization activities, and was the basis upon which we built our anticipated FY-91 budget back a year ago when we submitted what we call the WAS.

At that level, we were proposing approximately a 229 million dollar budget for program planning basis only. It included both site characterization and moving forward on repository and waste package design. Since that time, there has been a lot of volatility in the approach to the budget and what should be funded in this program, and more recently, the Department, in discussions with OMB, has prepared budget scenarios as low as 99 million dollars. That was prior to the Gramm-Rudman reduction which we understand could be 35 per cent. So right now, our current year for FY-90 we're spending 194 million dollars approximately. Under the best scenario, we expect we may at the project level have 172, although it could be below 100 million.

MR. CLONINGER: Excuse me, Max. I would like to add that's project-wide, not waste package alone.

MR. BLANCHARD: Yes, project-wide. Thanks, Mike.

(Laughter.)

MR. BLANCHARD: Now, with those kinds of fluctuations, I think the several program planning activities that we've done, some of which have taken us approximately a year with our project control staff doing critical path analysis, it's all been lost. It's been lost several times over the past ten years, and we do it yet one more time.

I caution you at looking at some of these analyses, these critical path analyses. We've done them, we're not without numerous critical path analyses and networks. The problem is the conditions under which the program policy is implemented and changed drastically over several years. As a consequence of that, there is no real effective way to plan activities for periods more than one or two years at a time. At least that's been the past. It may be different in the future, I don't know, but I know that we've been dealing with this and it's been very frustrating for us and I'm sure that it's frustrating for you when you ask us questions about how well have we planned out detailed activities related to things like the overall waste package program, and what are the critical path nodes and the staff says, well, we're not quite sure what the nodes are.

The fact is, today, under the current conditions, we really don't. It would be misleading for us to give you that, but we have a plethora of planning documents that we were using not more than six to nine months ago that we thought were adequate for moving the program forward, but they're not now.

So, things just have to be re-thought in view of the alternatives that Les Jardine talked about, and that Mike Cloninger has discussed from an overview standpoint at this stage.

DR. LANGMUIR: When you go through this exercise, do you, I presume, given your past experiences, you must prioritize your aspects of the program, assuming cuts may occur, which would then permit you to move more readily towards those plans and not have to reinvent the wheel each time. I presume you do that.

MR. BLANCHARD: That's quite true, Don, but in those exercises, one assumes that the budget cuts are on the order of ten to twenty-five per cent, not fifty per cent. And, the kind of things we're experiencing are sufficiently large cuts where areas of the program may not move forward at all in '91 or '92. We may spend no money in repository design, or almost no money, and that could be true also for waste package, depending upon the programmatic requirements and the policy requirements.

Les Jardine had a view graph, when he was talking about alternative strategies, where he said a lot depends upon the technical requirements, but even equally important are the programmatic and the policy requirements. And, we need to all bear in mind that there is a lot of policy encompassed in the regulations, both NRC's and DOE's regulations.

For instance, the length of the retrieval time. It's really a policy call, how long you should make that. It then, once the call is made, it becomes a technical requirement and a challenge to design to. That's also true for a number of other things that are in the picture.

DR. PRICE: It would appear to me that in the area of allocation of funds, that if the approach we were talking about earlier, a rather generic approach to package development, were taken, that that would be an approach that the money spent could be fairly well planned, and you could end up with something down at the end of the pike. In other words, it would appear to me that--and this is just an it-would-appear-to-me-as--a process that you could engage in which you could get something for the dollars which were spent because it's something DOE can do, and can do without being stopped by litigation or something else.

MR. BLANCHARD: I believe your point is well taken about generic waste package design. The presentations by Les, I think, suggests that the alternative approach that we have or the approach to the alternatives for waste package design include that concept, or certainly don't preclude it.

That's not been the Department's direction heretofore, partly because of policy that's encompassed in the regulations, which calls for principal reliance on the natural system rather than the engineered barrier system. That's well embodied in the regulatory framework of the project and has been for about the last ten years.

It doesn't mean it couldn't be changed, and it doesn't mean that we're not looking at that through colored eyes. For instance, up until very recently the Department's understanding of requirements in 10 CFR 60 suggested to us that the three hundred to a thousand-year requirement for substantially complete containment was one where we would be assuming that there was no waste package after a thousand years for radionuclide releases to the accessible environment.

We've done numerous performance assessments on that basis and they've been reviewed by regulatory bodies. For instance, in the EA, we find it very enlightening and are quite pleased to find that perhaps we've been misunderstanding the regulations all along and that we can, indeed, have a large reliance on a long, robust life waste package.

On the other hand, there is still another part of that regulation which we are still addressing and is still encompassed in our program, and that is the point I just made about principal reliance on the natural barriers, even though we have a multi-barrier concept.

DR. PRICE: Is it necessary to conceive that a generic approach precludes reliance primarily? Are they mutually exclusive?

MR. BLANCHARD: There's no reason why they'd have to be. They should be mutually supportive.

Thank you.

DR. VERINK: Why don't we then leave about eight minutes early for lunch and get back here for sure by one o'clock and pick the program up.

(Whereupon, a lunch break was taken.)

AFTERNOON SESSION

1 p.m.

DR. VERINK: Let's reconvene.

MR. PETRIE: I'm Ted Petrie again. This afternoon, you can see there are quite a few people on the agenda. We're going to start with Bob Brown on the high-level waste producers' overview, two more discussions.

(Pause.)

MR. PETRIE: All right, we're ready to start again.

I'm Ted Petrie, and this afternoon we have several speakers. We have three of them before the break, and then some more after that. The first one is Bob Brown. Let me just show you what's coming on later on this afternoon.

You can see we have several that will be coming up here, and rather than trying to introduce them all at once, each one of the speakers will introduce the succeeding speaker and at the break I'll introduce the first one and he can introduce, then, the succeeding speakers.

So, first we have with us Bob Brown from Richland Operations Office.

MR. BROWN: Thanks, Ted, for that introduction, and I do want to thank the Board for this opportunity to present the DOE high-level waste vitrification program to you today. I will be presenting the overview of the waste vitrification program to you today, and then John Plodinec from Savannah

River and Ron Palmer from West Valley will be giving you a presentation on their actual specific waste qualification activities that they're performing at their respective sites and on their projects, the defense waste processing facility and the West Valley demonstration project.

A little background for you is that through the Public Law 96-368, the West Valley Demonstration Act of 1980, Congress mandated the cleanup and closure of the former West Valley commercial fuel reprocessing plant, where, as you know, commercial reprocessing of spent nuclear fuel was performed in the 1960's and 1970's.

Then, in accordance with Public Law 97-90, President Reagan submitted the defense waste management plan to Congress in 1983. This plan established a fundamental goal to end interim storage requirements and practices for defense waste, and to produce for permanent disposal by converting this waste into some form that will be suitable for shipment to a deep geologic repository.

To accomplish this goal, the plan described three major high-level waste facilities would be constructed and they would be constructed in sequence, and the first project would be built at Savannah River, and that was the defense waste processing facility, which has completed construction and they are readying right now for their cold operations, and John Plodinec will talk more about that in a little bit.

The second facility is the Hanford Waste Vitrification Project, which is the one I'm responsible for at Hanford, and this would be built at the Hanford site, in Richland, Washington. The third facility would be built in Idaho, and presently Idaho is in the feasibility study stage on their project.

Okay, the high-level wastes at the three sites are basically all very similar. All of the wastes are generated by nuclear fuel reprocessing at the different sites. DWPF and HWVP have been reprocessing defense fuels, whereas West Valley, as you know, has done commercial reprocessing of fuel. All of the wastes are stored. All of the wastes have been neutralized and they're stored in carbon steel storage tanks at each site in either supernatant and sludge form.

Within the Department of Energy, the Secretary of Energy has assigned the responsibility for the high-level waste activities to Mr. Leo Duffy, who is Director of the Office of Environmental Restoration and Waste Management, and Mr. Duffy has assigned the overall responsibility for the production of the canistered waste form to Jill Lytle, who is the Director of the Office of Waste Operations, and in turn, Jill has assigned the overall responsibility for the satisfactory completion of all of the vitrification projects down to Ken Chacey, who is the Branch Chief of the Vitrification Projects Branch, and of course, underneath Ken you would find the actual waste producer organizations who are actually accomplishing the day-to-day work on the different projects.

The program project objectives of the high-level waste program is to immobilize the high-level waste that's presently stored at each site for, ultimately, permanent disposal in a deep geologic repository. To do this, our goal is to utilize safe, high-quality, environmentally-acceptable methods of immobilizing the waste. We also want to do this in a cost-effective disposal method.

Now, in order for Environmental Management, EM, and RW organization to be able to accomplish all of their obligations underneath the Nuclear Waste Policy Act, we have to develop quality assurance programs that will ensure that our product that we're developing will meet all the waste acceptance criteria. Each site, each waste producer organization have developed or are in the process of developing a quality assurance program that will meet all of the criteria that's been established by RW in RW-0214, which is a quality assurance program description document.

Our goal of each waste producer organization is that our quality assurance program will help us to achieve a high level of quality in all of our high-level waste activities. We also want to operate in a way that complies with all federal regulations and requirements. Also, we want to protect the environment and the health and safety of all of our DOE employees, DOE contractors, and the general public, and we also want to operate in a way that instills confidence in our ability to safely operate our plants and operate them reliably.

Over the past several decades, DOE has conducted a lot of research on the waste vitrification activities or waste mobilization activities. This schematic here tries to show a chronology of the waste glass development. Back in the 1950's, in that time period, the three countries that had a nuclear capability at that time, started R&D work on immobilization of the waste products at their different locations, and the United Kingdom, I think, was the first country that really started this work and they started their effort working on the Fingal process. This was done at the Harwell plant in England.

France started work on the--I call it the Piver. I assume that that's the right terminology--at Marcoule, and they followed this approach for quite awhile. The Piver process actually operated, I think, from 1969 to 1973 time period at Marcoule, whereas the United States worked on the in-can melter process.

Then at approximately the 1965 time period, PNL started working on the spray calciner and the in-can melter technology, and after successfully proving that this concept would work, that technology was transferred to other countries, as you can see on this diagram.

Then about the 1973 time period, PNL started looking at the Joule heated ceramic melter concept, and this concept technology was adapted from the commercial glass industry where they've utilized Joule heated melters for some time. After PNL successfully demonstrated the Joule heated ceramic melter technology, this technology was also transferred worldwide.

The Soviet Union started utilizing this technology somewhere about 1974; Japan, somewhere about 1977. Germany picked up this technology in about 1976, and the three waste producer organizations that are represented here today, Hanford, Savannah River and West Valley, also started working on the ceramic melter technology, Joule heated ceramic melter technology. And at the present time, Japan, Germany and the United States are all utilizing the liquid fed ceramic melter as their technology for producing the glass waste form.

Following on down this line, the French are utilizing the AVM process--and don't ask me to try to pronounce that. It's a very long name. But, anyway, they are utilizing that at Marcoule, and the French are in the process of completing vitrification plants at Lahague, the R-7 and the T-7 line. They were able to process their radioactive waste.

England went from the Fingal process to the harvest process, then in about the 1980 time period they actually purchased the AVM process from France for adaptation at their plant in Selafield.

So, in summary, DWPS selected the liquid fed ceramic melter technology in approximately 1980, and the West Valley site assessed the use of the AVM technology versus the liquid fed ceramic melter technology in approximately 1982 to determine what was the best way for them to vitrify their waste at West Valley. Then in 1983, there was actually a DOE panel that was put together that actually gave the final decision on what technology would be used at West Valley, and that panel did endorse the liquid fed ceramic melter for use at West Valley.

Some of the factors that supported that liquid fed ceramic melter technology selection was a higher capacity. A liquid fed ceramic melter at DWPF has a throughput 100 kilograms per hour, whereas West Valley is approximately 45 kilograms per hour. The AVM process at Marcoule has a throughput capacity of about 15 kilograms per hour, whereas at Lahague, each one of the process lines there has a throughput of approximately 33 kilograms per hour. So the LFCM does have the capability of a much higher capacity.

The LFCM also has a longer unit life. The LFCM has an expected life of approximately three years, whereas the melter utilized in the French process has a life of anywhere between a thousand to two thousand hours. So there's a lot longer life period.

The LFCM also has the demonstrated compatibility with slurry feeds, basically in a neutralized form. The French, to date--to the best of our knowledge--has never proven their process that it will work on a neutralized acid feed.

There is greater industry acceptance of the LFCM. The United States, West Germany, Japan, Soviet Union, and we're hearing that the Chinese are also going to be utilizing the liquid fed ceramic melter technology.

The process is much simpler from maintenance standpoint, very few moving parts, and since it does last longer, there is real benefits there, and through all of the research and work that DWPF has done, West Valley has done and PNL has done, the LFCM has demonstrated that it improves the waste form quality that'll meet all the U.S. regulatory requirements.

This is a time-line thing that tries to show how we arrived at the selection of the borosilicate glass as the waste form of choice. Back in the early 1950's, there were early AEC studies where they utilized the clay-waste mixtures to yield glass-like waste form, required a melting temperature of approximately 1300 degrees Centigrade. Then in the 1960's, after research by the U.S. and the British and the French, all three countries zeroed in on the borosilicate glass, mainly from the standpoint of its process ability, and its lower melting temperature had many advantages.

Then here in about the 1966 to the 1970 time period, PNL did a lot of work on the waste solidification, the engineering prototype pilot plan up at Hanford. They basically looked at four different immobilization techniques. I only have two of them listed here, but it's the phosphate glass, borosilicate glass, and there was a phosphate ceramic and a pots calcine. Those were the four main immobilization techniques that they looked at in this program at PNL, and this was a full-scale radioactive pilot plan program where they did this work in this time period.

Now, before the projects that we're talking about here today really selected the borosilicate glass as their waste form, there was a lot of evaluations done on different waste forms. In about the 1977 to the 1989 time frame, somewhere right in there, DOE established the high-level waste program technology review board to look at the alternative waste forms that were available to immobilize the waste--immobilize the glass. They looked at 17 different waste forms, and at the same time they were doing that, West Valley and DWPF were also looking at different waste forms that could be utilized, and the high-level waste technology board, as a result of their evaluation, determined that borosilicate glass was the best waste form for utilization in immobilizing the waste.

About 1977, DWPS started conceptual design on their plant, and the borosilicate glass was the referenced waste utilized in that conceptual design effort. In 1981, West Valley issued their draft environmental impact statement, and in that EIS, borosilicate glass was the referenced waste form that was utilized. In 1982, both DWPF and West Valley issued their final environmental impact statement after going through the public comment review cycle, and the borosilicate glass was the referenced waste form in both of those final EIS's.

Now, in 1982, also in that time period, DOE wanted an independent peer review group to look also at the alternate waste forms that were available, so Dr. Hench--I think from Florida, University of Florida--chaired this panel that looked, once again, at 17 different waste forms that were available, and, once again, Dr. Hench's panel recommended that the borosilicate glass was the waste form that should be utilized.

Then in 1984, West Valley did another evaluation and looked once again at the 17 different waste forms that are available, and once again, the borosilicate glass was the recommended choice. In 1987, the HWVP, through their EIS, selected borosilicate glass as the referenced waste form. Then in 1990, this year, the EPA issued their final rule making on the land--I always get this fouled up--on the land disposal restrictions in the Federal Register. Basically, they indicated in the Federal Register that the vitrification technology was the best demonstrated available technology and that it is an acceptable form--I get this loused up, too--it provides an effective immobilization of the RCRA hazardous constituents.

So based upon this time line, hopefully I have satisfactorily walked you through kind of the chronology as to how we, the waste producers, arrived at the utilization of borosilicate glass.

DR. PARRY: Excuse me. That rule making, that wasn't--was that aimed specifically or only at West Valley, or was it RCRA hazardous wastes in general?

MR. BROWN: It was not aimed at West Valley. It would cover all the sites.

DR. PARRY: Why don't I speak to you later, and just give me a reference, please. Thank you.

MR. BROWN: I've got a copy of that with me.

DR. PARRY: With you?

MR. BROWN: I could give to--

DR. PARRY: Why don't you--I'll take it and see to it that the Board receives it.

MR. BROWN: Okay.

DR. PARRY: Thank you.

MR. BROWN: Now, Mike talked earlier about our strategy for--our high-level waste process strategy, and the first step in our waste acceptance strategy is for RW to give us a waste acceptance specification. Right now we call it a waste acceptance preliminary specification. That has been done. DWPF, West Valley has their specification that they have been working to. On the HWVP project, we have been also utilizing the same waste acceptance specification that DWPF and West Valley are using.

As Mike indicated, he's in the process of developing a spec that will be applicable to all three projects, and that will be out in calendar year '90. I just got a commitment on it.

(Laughter.)

MR. BROWN: The second step in the process is to establish a plan for meeting that specification. The third step is to qualify the product and the production process, and produce and certify each product unit.

So basically, what this looks like is this: The waste acceptance specification will be prepared by RW, and that outlines the administrative and the technical requirements that each canistered waste form must meet. That's our criteria on there. That's our main document.

The second step in our process is a waste form compliance plan which describes the processes, systems and techniques that ensure that the waste acceptance spec requirements are met.

The third step is a waste qualification report, and that compiles all the information and data from the waste compliance plan and implementation that demonstrate compliance with our waste acceptance spec.

The last step are production records, and that documents the production of each canistered waste form and it will accompany each unit to the repository when it's turned over to the repository.

Looking at the waste acceptance history, back in 1970, DWPF established an inter-site coordination group that was working with ONWI, and also, they were working with RW--I'm sorry--NRC at that point in time. The next step in the process was the establishment in 1984 of a waste acceptance committee, which superceded that coordination group.

Then in 1985, the three candidate repository sites got together and developed a generic waste requirements document that was issued in 1985. In January of 1989, that document was revised and issued again. The process I just described to you a little while ago was defined by DOE in July of 1985 as to how we would actually go through the waste acceptance process.

The first draft of the waste acceptance preliminary specifications for DWPF was released in December of 1986, and the revised draft of that was issued in 1988. West Valley received their WAPS in February, 1987. DWPF has issued their waste form qualification report, or they started that process with the technical review committee and that kick-off meeting started back in May of 1989, and DWPF has issued their waste compliance plan for review also by RW.

Now, what we've got here is a very, very, very simplified process flow diagram to try to show basically how the process works. The waste producer organizations are constructing waste vitrification plants that will handle a variety of feed streams; therefore, our process has to be developed, designed and constructed so it can handle these different feed streams.

Basically, our process has three major steps in it. First is feed preparation. The second is the vitrification and canister filling, and the last is canister decon and canister closure. What happens is the high-level waste will come into the feed preparation stage, where it will first be evaporated and boil off, you know, the water and try to get down the amount of volume we have. After we've concentrated it, we add the glass formers and additive to try to yield a concentrated--not try to--we will yield a concentrated waste slurry that will meet our qualified envelope that we've established at each site that will meet the waste acceptance specification.

After we have our concentrated feed slurry, the slurry is fed into the melter, where it will stay in there for approximately 40 hours at a temperature of approximately 1,150 degrees Centigrade. The off gas from that melter will remove all particulates, chemical gases, anything else that'll be coming off of that such that all emissions off our off gas system will meet all emissions standards that are applicable at this time.

After the molten glass inside the melter has reached a homogenous state, then it is poured into the turntable into a stainless steel canister, where it's cooled and then solidified. After it's solidified, it is moved to the canister decon station, where it is deconned to remove any smearable contamination that may be on the canister. From there it'll be moved to the closure station, where it will be seal-welded by some remote welding technology. After it's been sealed, it'll go into interim storage at each site until the repository is ready to receive it. As you heard Mike say a little while ago, the repository is on a--what did you call it--a first-served or received waste at the repository?

MR. CLONINGER: That's the oldest fuel first for the spent fuel.

MR. BROWN: This is just a look at the actual canister of waste from each site. West Valley will have approximately 300 canisters of waste that will be going to the repository.

Savannah River will have 5,750. Hanford will have approximately 1,960 canisters of what we refer to as our double shield tank waste.

Now, once the EIS is completed on the single shield tank waste at Hanford, we could have anywhere up to another 7600 canisters of waste from Hanford that would be going to the repository.

If you look here you can see the actual canister size itself is the same, and DOE put together a committee that looked at the actual canister size. They wanted to minimize the actual burial costs at the repository, but at the same time they wanted to maximize the throughput production from each production facility, so they arrived at these dimensions, and these dimensions are also compatible with the spent fuel casks that will be utilized by the repository.

This just shows the very summary schedule of the three plants that I've been talking about here today. You can see DWPF is scheduled to start hot operations in fiscal year 1992. They are going to start cold operations in this year. West Valley will go hot in '94; whereas, HWVP will go hot in December of 1999, and you can see with this sequential approach that we've got here, HWVP is in a very good position to be able to be utilizing lessons learned from DWPF and West Valley for design and construction of the facility, plus all of our waste qualification activity. And, by the way, this is going on. We are relying heavily upon what's going on with these other plants.

Now, in conclusion, we have a proven process. The LFCM technology is recognized worldwide as being utilized by many foreign countries. It's the EPA preferred waste form right now, based upon the ruling that was just published in the Federal Register. We have aggressive, logical schedules for each one of the projects and they are in place and we're working to them. Comprehensive requirements have been established in the WAPS, and all of our projects are being developed to meet--are being or have been developed to meet nuclear grade quality assurance. This is the NQA-1 and the RW-0214.

All of our management interfaces are well-defined, they're well-defined within headquarters, within the project, and laterally among each project. We have a very well-defined program of interface between DWPF, West Valley and HWVP, so that we're constantly exchanging lessons learned back and forth. Permanent formal records have been established to document everything that we're doing on each one of the projects.

That concludes my presentation, so if there's no questions I'd like to introduce John Plodinec from West Valley. I'm sorry, I did that again. I think I did that one other time, John; I'm sorry. But John is the manager and senior advisory scientist in glass technology at Savannah River. The manager is responsible for the DWPF waste acceptance program, the glass composition development, and the waste form testing there for the DWPF project.

MR. PLODINEC: We all have to have our introductory slide. There's mine.

What I want to do today is provide you with two forms of information. First, I want to provide you with some background of the DWPF process and product, and then, as well, give you an overview of our waste acceptance programs, including both our status and a flavor for how we're approaching waste acceptance. I'll use, as an example of that, our program to respond to Specification 1.3 on control and verification of radionuclide release properties, since that's certainly the most visible and is probably the most important.

As such things go, the DWPF is a fairly mature project. I've been with the program since '75, and I'm fairly mature. Glass was selected, as Bob talked to you about, in 1982 as the waste form for the DWPF for the reasons that you see here. I think it's important to establish in your minds the fact that the DWPF, the waste form producers in general are not part of RW. This has its good side; it has its bad. The primary objective of the waste form producer organizations is to get the waste out of the form of a slurry and into a solid form. By law, that solid form has to go to a repository, so our interface is somewhat colored by the fact that not only do we have to answer to the repository program, but we, in fact, have other drivers upon us.

Partially, I think, the comments that we got as we went through the NEPA process summed this up very well as to the rationale for starting up a vitrification facility. The EPA said that our facility was badly needed. It was an environmentally beneficial action in direct response to the idea of getting the waste out of this slurry form and into a solid form.

I should also mention that the NRC, in commenting on our NEPA documentation, also did not object--that's the best you've ever seen me get out of the NRC--but in addition, acknowledged that glass could be an acceptable waste form in a suitably engineered barrier system and, of course, that's what RW's all about, but in addition, urged us strongly to do site specific testing of our waste form and we've been doing that over the years, and since I'm up here speaking to you, obviously the results haven't turned out unfortunately.

Now, in '85, again, as Bob mentioned, DOE realized that there was this mismatch in schedules between startup of the vitrification facilities--which are manufacturing facilities producing a product which has to be compatible with a range of conditions. Right now, of course, it looks like

Yucca Mountain. When we first started this process, we actually thought, well, it might be salt, it might be basalt, or tuff, or shale, or a host of others. I guess in contravention to what you heard this morning, our program has been set up from the beginning to develop as robust a waste form as possible, since we never quite knew where we were going to go. We had a lot of people telling us where we should go, but never were quite sure where that was going to be.

(Laughter.)

MR. PLODINEC: DWPF has been working since the original set of specifications--and, in fact, before that--to establish compliance with the things that we have to do. Now, the program we've set up is working to establish compliance through a combination of specifications on individual components; for example, the materials of the canister, the FRIC (phonetic), the glass former that we add to our waste, as well as the product controls that we'll have in place. For example, how will you blend the waste streams and the glass form? And I'll talk a little bit more about that in a bit.

A very brief overview on the process. I wish it was all as simple as this says it is, but basically we have some 34 million gallons high-level waste in our waste tanks. I think the easiest way to think about the waste tanks for purposes of today's discussion is that they're overgrown beakers. They're on the order of about 1.3 million gallons, and we do a lot of chemistry in these beakers to reduce the volume of the waste and also to take the cesium out of the soluble portions of the waste to reduce the volume of the material that we have to solidify. That, in turn, of course, then, reduces the volume of material that the repository program has to accept and put into the ground.

Once the waste materials are brought into the DWPF, again as Bob said, it's basically a three-step process. First, we prepare the feed to be vitrified. We then melt it and pour it into a canister. Then we close that canister and store it on site until a repository is ready to accept it.

The next slide gives you some "gee whiz" kind of information about what our product will look like. I won't spend much time on this except to note that while I have the maximum radiation dose here of 5500 R/hr, probably a better measure would be the average, which is on the order of 2-3,000 R/hr. Compared to spent fuel, our waste is old and cold.

In terms of the chemical composition, this is shown on the next view graph in your package. The only point that I want to make here is that you'll see that the waste forms that we're going to produce, or the products that we're going to produce are not going to be of the same composition. The waste out in our waste tanks reflects processes, nuclear material-generating processes stretching back to the early

1950's. Of course, the ones at Hanford go back even further than that. The point I'm trying to make is that there's a tremendous amount of variability in what's probably the most important part of our glass product, the waste, and that we have had to have that uppermost in our minds in terms of how we're going to comply with the specifications.

In addition, Savannah River is not a closed system. We're continuing to generate wastes and we, hopefully, with the new production reactor, may be generating waste very different than we have generated in the past. As a result, our plans have had to take into consideration the fact that we are an open system and that the future waste cannot be very well predicted at this point because we don't know what the defense needs are going to be. If I'd given this talk six months ago, I'd be talking about the great lessening of tensions in the world. Today, that's a different story. So we just can't predict very well, so our plans for production, and especially for compliance, have got to keep in mind the fact that we're an open system and keep in mind there's tremendous variability of the product.

First, let me give you--as far as talking about our waste acceptance programs, let me give you the overall status of where we stand, and then I'll go into the specification on radionuclide release as an example of how we're approaching all of the specifications.

We've had several generations, iterations, if you will, of our waste form compliance plan. This has now been reviewed by the technical review group and I believe has been sent to the NRC for information purposes. They won't review and comment on it, but they'll have it there so that they can better understand what we're going to be doing.

In response to the waste form compliance plan, we are producing sections of our waste form qualification report, sort of a phased approach. We've prepared 16 out of the initial 24 sections, which include a lot of the information that Mike said that he needed as far as projections, information about what's going to come to the repository, and you see that information here.

Of those 16 initial sections, eight have been reviewed by the TRG and their comments have been resolved. Five of those have been issued; three more will be issued probably by the end of September. In addition, we've begun a very formalized and disciplined startup test program to demonstrate that, in fact, we can produce the product that we say we're going to produce.

Several parts to it, parts that I want to stress to this group today are that because of the fact that a lot of our design went on before there were even specifications, it's been very important for us to qualify that technology that was developed before there were specifications and show that, in fact, we can meet specifications with that technology. We also have several demonstration tests to demonstrate our ability to control the product and, in fact, the entire program in terms of its cost and schedule is driven by the specification on radionuclide release.

We quickly found--and I'll talk about this more in a moment--that the specified testing method for acceptance of glass samples was incompatible with production glass, and this pushed us into developing a test that would be compatible with production glass, which we're now working through the ASTM to get acceptance for. It appears that probably this fall we'll get acceptance by the committee, the responsible committee, and then it'll be submitted to the full ASTM probably next year.

As I said, I want to use the specification on control and verification of the radionuclide release properties as an example of how the entire waste acceptance programs--the entire set of waste acceptance programs at Savannah River are proceeding. As with all of the other programs, the program on radionuclide release starts with the specification. It's basically a three-part test.

First, we have to control our process so that the glass is able to limit release to less than the number you see here on the MCC-1 leach test. This is a static leach test developed by the Materials Characterization Center.

DR. LANGMUIR: Is that an ambient temperature?

MR. PLODINEC: No. That's a 90 degrees C., and I'll talk more about that in a moment.

During production, we have to verify to the 95 per cent confidence level that 95 per cent of the product would be acceptable or would be able to meet that limit. There's a semi-lab clause which says that we can use any means that we see fit as long as we can relate them to the specified methods to the repository program's satisfaction.

Now, the program as a whole, within DOE, has performed a large number of MCC-1 tests, and coming from all of that work, we have a good understanding of what are the factors that affect performance of the glass, not only on the MCC-1 test, but virtually any other set of conditions as well. You see them listed here.

The MCC-1 test actually fixes everything except for glass composition, so as a result, our job--quite simply put--is that we have to control our composition in order to meet the specification. Now, remember what I said before, though. We have a somewhat difficult problem to deal with there in that we don't have a single composition that we're trying to qualify. Our life would be a lot simpler if we could handle our problem the way West Valley will, and in addition, we have an open system. So we're not quite sure what the waste may look like or what the glass may look like in the future. So it became very important for us to develop a yardstick that would allow us to judge different compositions and determine whether or not they were acceptable.

The yardstick we chose to use--after a lot of pain and agony--was one that was actually developed by Amal Paul and Willie Newton at the University of Sheffield in England, actually to look at archeological-type glasses, ancient glasses. It's an approach based on hydration thermodynamics which assumes that the glass is an additive mixture of components, such as silica, B_2O_3 and what have you. Each of these components has a well-defined free energy reaction with water, and in order to come up with a number for the entire glass, we simply weight those component free energies of hydration by the amount of that component in the glass. It's the old story, if you can put a number on something, you can pretend you can understand it, and that's what the free energy of hydration allows us to do. It gives us a yardstick that allows us to take glasses of very different compositions and to somehow try to judge their performance.

We then look at glasses, again, of very different compositions on the MCC-1 test, and I've used as the response here the release of silica. I could have shown release of sodium or a host of other elements, but I used silica because all the materials that we've tested have silica in them, and you can see, I think, that there's a very strong correlation over a very wide range of free energies of hydration between this calculated parameter--calculated from the composition--and the release on the MCC-1 test.

I want to make the point here that this includes not only waste glasses, which fall in this range here, but also includes natural glasses, medieval church-window glasses, glasses that we glommed (sic) onto from the Corning Museum of Glass from the Near East, natural materials, commercial glasses such as Pyrex. You name it, we'll leach it.

The intent was to actually try to put our glass into a contest to show that it behaved like other materials, or to compare it to other materials. So that you can see, I hope, on this slide that our glasses, which fall in here, are very similar, in fact, to vitreous basalts.

All right. Now that we have a yardstick, how do we go about controlling the product using that yardstick? Well, process control--or product control, I should say--actually starts out in our tank form where, as I said, we have this 34 million gallons of job security for me. We analyze the material out there and determine its composition. We then use the free energy of hydration to set blending targets. We come up with different combinations in the glass form or composition whose free energy of hydration should be--should make an acceptable glass. We then actually will make samples of the material, simulated samples, to prove that that's so.

Then using these blending targets, we'll come into the defense waste processing facility with the material and start to prepare the feed. When we get to the last feed preparation vessel--what we call our slurry mix evaporator--we'll hold the feed, do complete analyses, go through the same measuring of that composition against our yardstick to determine if it'll make an acceptable glass. If it will, it passes on into the melter; if it won't, we hold it and adjust it. Then, of course, we go into the melter and then periodically we'll pull glass samples, but their only purpose, really, will be to provide demonstrations or confirmatory evidence that, in fact, the material's acceptable.

We're taking something I'd like to blame on Demi as far as rather than doing quality by inspection, trying to build it in and head in.

Now, in terms of meeting the 95/95 criterion, the details of how we'll do this are still being worked out. This is one way, and probably the way we'll start off when we begin cold testing. This, again, would be our correlation between the MCC-1 test and the free energy of hydration that would come from experimental evidence. We would have to roll into this, then, some idea of the uncertainties due to the factors that you see up there; sampling, tank uniformity, analytical uncertainties, uncertainty in this correlation itself, to come up with an upper tolerance limit so that while this is your best--line of best fit to the data, this is actually your 95/95 criterion fit.

Where this 95/95 line intersects the acceptance limit--which, as you can see, is a bit more to the good side of where the line of best fit crosses the acceptance limit--we'd set an operating limit, which means that any composition which falls in this area--in other words, whose composition when you plug it into the free energy of hydration model falls down here, should be acceptable to the 95/95 level.

Now, our test program--we will actually be demonstrating all this. I can throw some more words at it than what I've just used, but basically that's it to demonstrate all of this. We have the prepared detailed test plans for each of the testing activities that we will be performing starting next month. We're going to use these results to verify our ability to control over the set of conditions, the widest possible set of conditions that we expect to see.

First, we're going to take material very similar to what we start the melter up with and show that, yes, we can control and we just make small changes in the feed to the process. Then we'll make a large step change in the properties of the material going to the melter in one direction, and then going the opposite direction, and then, finally, we'll come back towards the baseline, towards where we expect to begin operation for the first batch of feed.

We'll produce some 460,000 pounds of glass. Anybody that wants some, they can have their own canisters. There'll be some 124 canisters. We're going to sample the glass--as I'll show you in a moment--from each of these canisters, and we'll cut up most of the canisters as well, approximately 100 of the 124 will be cut up. The purpose of that is to establish the relationship between the glass sample we're taking and what's actually going to be in the canister, and then, also, to compare the observed performance of glass out of the canisters to what we predict from the composition.

I was told that I could bring my own picture because it might be a little bit clearer than what you have in your handout. This is our glass sampler. It actually sits on top of the canister. You're looking down on it. Normally, this little cup here would be out of the way and the glass would fall right through this opening into the canister. At some point in the pour, we shoot the arm into the pour stream. The little cup catches a sample of glass and gets retracted back in and we pull it, and when the canister is rotated out from under the melter, this comes off the top. We pop it into a doorstop and bring it up to our lab.

To give you some idea of what the sample of glass looks like, it's--the best description I can give you is that it's something like a Keebler snack cake. It weighs about 20 to 50 grams and it's beautiful black glass, or at least it better be.

(Laughter.)

MR. PLODINEC: Now, one of the important activities that will be done with that sample is to test it, to actually confirm that it is acceptable product. When we got into trying to do this in hot cells, we quickly came to the conclusion that the MCC-1 test was not well-suited to hot cell operations, primarily because it requires that you cut monoliths out of the sample. The glass that we're reproducing will not be annealed, will not see any extra heat treatments, and therefore, we can't reliably cut MCC-1 type samples and get a well-characterized monolith.

As a result, we had to develop our own test, and what we developed was a grains test, if you will, much more closely in line with normal glass industry practice which is compatible with production samples, uses stainless steel vessels. The conditions you can see here, and I've tried to compare the conditions of what we call the PCT, or product consistency test, since that's its purpose, against those of the MCC-1 test.

Both tests use deionized water, which is actually a rather aggressive leach, at 90 degrees C. under static conditions. However, the PCT uses grains, where the--as I said, the MCC-1 uses monoliths. The PCT has a much higher surface area to volume ratio, which means that it's much more responsive to the glass than is the MCC-1 test. It requires the use of a standard glass so that you can be sure that you haven't screwed up the test, where the MCC-1 leaves that to the user's judgment. It uses stainless steel vessels versus the Teflon for the MCC-1 test. Teflon--or the MCC-1 does have the option of using like Dicore vessels, I believe it is. We like the stainless steel vessels because they are compatible with the radioactive environment.

As I mentioned earlier, this test--we've developed it. We've gone through several iterations in working on it. I mention a couple here; round robin testing, which was performed for us by the MCC--and which I want to publicly acknowledge their help. We've also had radioactive sample exchanges, in particular with John Bates, who will have the opportunity to put you to sleep later and, as well, what we're finding is that the precision, the in-use precision of the PCT is much better than the MCC-1 test. The MCC-1 test, in fact, requires a lot of manual dexterity that's hard to achieve in a hot cell.

As I mentioned, the ASTM Committee acceptance for this test we expect to get this fall, and then it will be submitted to the full membership. I should also mention that the EPA is interested in the use of this test as a replacement for their TCLP test for mixed high-level waste.

So in conclusion, we're going to begin non-radioactive testing later this year; in fact, the end of next month. Our feed, our primary component of feed, the waste is variable in composition, but we're reasonably sure we're going to meet the specifications and we're working very hard to provide that assurance to everyone else through a detailed program that we've set up to ensure that we will make an acceptable product.

Yes, sir?

DR. LANGMUIR: Looking at your leaching test, I'm wondering if your--for example, the MCC test is 28 days and I'm wondering if you've reached some sort of a steady state condition with respect to the sample leaching process or whether you're still on a kinetic dissolution process curve?

MR. PLODINEC: We believe that that's one reason why we'd get better statistics with the PCT. As I mentioned, the PCT is more surface area to less volume and we think, if you plot out concentration in the leaching as a function of surface area to volume times time, the MCC would fall somewhere, let's say, on the order of a number of about 50, where the PCT would be a number on the order of, oh, 14,000.

The curve that you get is sort of a regular parabolic reaching a plateau, and we're--to characterize where we would fall with the PCT, we're just about at the turnover point to the plateau. So what I'm trying to say, with the

MCC-1, you're seeing small changes in technique, for example, can lead to big changes in response, where the PCT, since you're out towards the flatter portion of the curve, small changes in technique leads to much less of a variation of response.

DR. LANGMUIR: I'm presuming the high release rate examples would correspond to high release rates of encapsulated radionuclides. You've got them within the structure of the glass.

MR. PLODINEC: Yes.

DR. LANGMUIR: So you don't want to have a line of free energy of hydration of that material if you can control it.

MR. PLODINEC: That's correct.

DR. LANGMUIR: That's the wrong direction to go.

MR. PLODINEC: Okay. If there are no further questions, then I have the pleasure to introduce Ron Palmer, who will do what I just did--hopefully better--for West Valley.

DR. PALMER: As John said, I'm going to tell you a little bit about what West Valley is doing compared to what the DWPF has done, show you where we're the same and, in some other places, where West Valley is unique.

The West Valley Demonstration Project's objective is to demonstrate the process of vitrifying high-level waste. As Bob said earlier, this is Public Law 96-368, the West Valley Demonstration Project Act, and what we're doing under that

Act, under that authority is solidifying the high-level waste. We've got two systems; the vitrification system that I'll spend a lot of time on, and I want to mention a little bit about the cement solidification system as well. Then when we're all done with that, that's phase one, essentially. Then we have to clean up the site and decontaminate and decommission.

Our process overview has two parts to it. The top part is the cement solidification system and the bottom part is the vitrification. I want to talk a little bit about the cement because it has been essentially blessed by the Nuclear Regulatory Commission. We've put together a process control plan for this system that the NRC likes and endorses heavily. We've also found that it works very well.

What we have in the way of waste, compared with Savannah River and Hanford, we have one tank. We've got sludge with supernatant, so we've got peanut butter on the bottom and some liquid on top of that. We're taking the supernatant and putting it through zeolite ion exchange capsules or cartridges to remove the cesium. Then we take that water and make cement out of it. At this point in time, we've made over 9,000 drums of cement. About five of them have been found to be bad from the standpoint that we didn't follow the process quite right, but we've looked at those drums, those five drums, and their product is just fine. So we're very happy with that kind of production, that kind of productivity from this system. Those drums are temporarily stores in a drum cell.

These are square drums, like 55-gallon drums, only made square, about 71 gallons, and they stack very nicely, three or four high in a drum cell. Eventually, they'll go into some kind of low-level waste disposal site.

When we're done with the supernatant treatment, we will take the zeolite and mix it back in with the sludge, along with the second tank. We've got a second waste tank that has some thorex waste in it, about 15,000 gallons of that. This totals--there's about 600,000 gallons of sludge in supernatant. And we'll go into the vitrification, make canisters and glass--I'll talk about the vitrification on the next slide--interim storage, and eventually we'll ship it to a repository.

Basically, this is the same kind of flow sheet that John and Bob have showed you earlier. Again, we've got about 15,000 gallons of thorex waste that we'll mix with the sludge, supernatant and zeolite, mix it all together and homogenize it. At this point it will be roughly 5 to 10 per cent solid. It'll be piped into a concentrator feed make-up tank. It's called a concentrator because we heat it up and we drive off a little bit of the water, quite a bit of the water. We check the composition here and we add glass formers, silica, boric acid and other raw materials to make the glass composition that we want to make.

We've run this a number of times now. We've had an operation up and running for five years. It's been full-scale, the melter, the tanks, everything has been up and running and has been full scale that we expect to operate when we go into full operation in several years. We know the composition we're shooting for. We boil off some of the water and we take the sample here and we make sure it's in the range of composition that we know we can melt. If it's not in the proper range of composition, we add the glass formers according to what we feel we need.

When we know it's right, then we'll ship it to the--or pump it to the melter feed hold tank. Effectively, we will make no glass before its time.

(Laughter.)

DR. PALMER: If this isn't right here, we're not going to pump it to the melter feed hold tank. We'll also take samples here to make sure--to go into the production records to make sure we haven't lost anything there. We know that we're going to have heels left over from pumping from the CFMUT to the MFHT, and when we go from the MFHT into the melter, there'll be a heel left there, but, again, we've run this system for about five years and we know that it works.

Then there's a feed delivery system into the slurry fed ceramic melter, an off-gas system, and into the canister. The important parts, besides taking samples here, we'll also take a sample of glass from the canisters to make sure that we've got the glass right that we hope to make from the composition we put in. We'll also control the temperature of the melter, and it's these samples and the control of the temperature of the melter that assure us that we'll have the right composition of glass when we come out the other end to meet the specifications.

As John talked about, the specification of 1.3, the radionuclide release spec, controlling the temperature of the glass, controlling composition of the material going in, we believe we can meet that spec by controlling the composition. We've done a range of studies of quite a few glasses. We've worked with Battelle Northwest, Catholic University and Alfred University looking at literally dozens, up to hundreds of glasses, and if you look at this in multi-dimensional composition space, we've found a lot of glasses that are durable enough, meet that MCC-1 spec or whatever the 1.3 spec is going to be. We've also found another range of glasses that we know we can make; that is, if we put that particular composition into one end of the melter, we know we'll get glass out of the other end, so what we looked for is the overlap of these two sets, and then we have what we consider a qualified region, again, in multi-dimensional space, and we know that we're going to get operational variations if we pick some target in the middle of it.

If I could reduce that down for you a little bit into two dimensions, let's take a cut there through the alumina silica field, and here we have the composition range that we expect for silica and alumina, a target composition, a range of expected variation due to processing the materials, and we want to stay within the bounds of viscosity. 100 poise is too thick to pour; 20 poise is too thin to have a reliable melter life, so we want to be in that range of viscosity. That's our processing variable, and we also want to be more durable than some value. We've picked a boron release of 100 mg/L to be above--that meets the specifications, so we know we want to be above this line and then in the durable glass region, and we want to be between these two in order to meet the processing range.

For an example, this is one of our reference compositions that we've run through our melter. These are the oxide per cents, and you can see this particular set of bounds is from a study done by PNL in 1988 or thereabouts, where we had a range of glasses and we tested glasses that were statistically selected within this range and they were all found to meet the specifications.

What this basically leads up to is our strategy for meeting the radionuclide release spec. We've established a range of compositions that we know are suitable for meeting the spec, are sufficiently durable, but which are also processable, and we've also established a sampling regimen; in other words, we've had our various runs through our melter system and we've established a method of taking samples so that we know we get good glass when we pour it into the canister. We've tested these methods during the qualifications run. We've compared the melter feed with the output glass so we know when we put in a specific composition, we will get out a specific composition, and we've done this using statistical process control techniques and setting that up for when we go hot so that we know we're working with our analytical laboratory to make sure that we've got the statistics down.

We do feed tank sampling, both at the CFMUT before we ship it to the MFHT. We've done temperature control at the melter. We sample glass and, if necessary, we'll do durability testing on the glass that we sample at the end.

How do we know this is going to work? We've done quite a bit of durability testing. We've worked all along with the Materials Characterization Center and with John down at Savannah River on both the MCC-1 and PCT test. We're prepared to do either, whichever way the specification finally reads. We're also following the work that's being done on glass modeling. You'll hear a little bit more about that this afternoon from the folks at Livermore. We've also been doing some of our own work, especially in empirical models, Ian Pegg and Pete Macedo's laboratory at the Vitreous State Lab at Catholic University, and we've also been doing experimental confirmation of these models as we go along.

Again, as I've said, we've also been working with our analytical laboratory in setting their QA/QC program to make sure that what we're doing during the qualification runs with the statistical process control will work when we finally make our production runs.

DR. LANGMUIR: Question.

DR. PALMER: Sure.

DR. LANGMUIR: On your leaching, durability testing, it seems clear that your acceptable criteria has nothing to do with release rates of radionuclides, but rather, strictly how fast the glass, as such, dissolves. That's the impression one gets. So when you assign some sort of a standard or acceptability criteria, it apparently is not based upon release rates of the radionuclides contained in the glass; is that correct?

DR. PALMER: At this point, the boron release is--has been considered representative of what the radionuclide release rate is.

DR. LANGMUIR: So they are tied in?

DR. PALMER: They are tied in together. John based--

remember, his slide had it based on silica release, and it's all tied in together there. That's basically the way the spec reads.

DR. LANGMUIR: And that's assuming the glass itself would be exposed to leaching, without a canister, without any kind of an engineered barrier protection?

DR. PALMER: Yes; sure. These tests are run the same way John's are run.

Our melter, we had a full scale melter operation set up in December, 1984, and it ran off and on for five years. The melter was up at temperature for five years and during that period of time we ran about 20 different runs that lasted from a day or so to 45 days to test the system, to test our method of making the glass, to test our methods for scrubbing the off-gas, to test everything about the system.

During that time, we ran a wide range of feed rheology, glass compositions, different redox conditions of the glass and different, and different temperatures. We analyzed virtually everything. At this point we've got stacks of data on feed versus glass composition, the final glass compositions in the canisters, the glass durability, final melter condition. The melter is now shut down. We've taken it out of the cell and in about a month or so we're going to start taking it apart to make sure that the refractories we've used have survived sufficiently so that we can use that design again when we build the new one.

All this now is a function, we know this information is a function of processing conditions. So what this does is feed into our process and product models so that when we finally go with our production, we'll know what the critical variables are and we can monitor just the critical variables and keep our quality assurance tasks to a minimum.

In summary, then, we've tested a full-sized integrated process. It's been five years and we're very happy with the campaign that we've had and we have great expectations for when we finally go with the real campaign. The glass composition region we feel we've defined, and now over the next year we're confirming where the edges are so we can stay away from those edges, and our target will be near the center of the region.

We've got statistical process control methods in place and we're finalizing the details there so that our analytical laboratory can help us out there in terms of our composition control. We've done qualification testing. We feel we've completed that. In a couple years when we get the new melter on line, we expect about a one-year shakedown of the melter, which includes all the equipment check-out as well as some final composition checks and that sort of thing.

That was pretty quick. Can I answer any more questions?

(No audible response.)

DR. VERINK: Thank you very much. I think the time fits right on the schedule. Let's break until two-fifty.

(Whereupon, a brief recess was taken.)

DR. VERINK: I'd like to mention for the record that Dr. Parry has received a document which was promised to him by Bob Brown.

MR. PETRIE: This afternoon we're going to have some speakers talk about high-level waste glass characterization and more information on glass. Without further ado, our first speaker is Henry Shaw, from Lawrence Livermore.

DR. SHAW: What I'd like to do this afternoon is give a brief overview of the sorts of work we're doing for the project, the Yucca Mountain Project, on characterizing the behavior of glass waste forms. What I want to do in my talk is to give an overview, set the stage for the three talks that will follow me. This work is work that has been done at Livermore and by subcontractors at Argonne National Laboratory for the Yucca Mountain Project.

The purpose of the glass task in the Yucca Mountain Project is to develop the data and models that are needed to predict the behavior of the glass waste forms, the high-level glass waste forms, in a repository at Yucca Mountain over the period of regulatory concern, and we need this information in order to use it in performance assessments to calculate the release of radionuclides from breached glass waste containers over time.

Those assessments are required to demonstrate compliance with the containment and controlled release requirements of 10 CFR 60, Part 113, and as the basis for the source term from glass in assessing compliance with the cumulative release limits of 40 CFR 191.

I should point out that though the ultimate goal of this task is to come up with the data and models needed to perform these assessments, in the context of Yucca Mountain, the types of models that we are developing have broader application because we are developing to the extent possible mechanistic models that, in some sense, have a fundamental basis in chemistry and physics that describe the degradation and behavior of glass.

The path that we're following towards achieving those goals, the first steps are to acquire data on the site and other waste package characteristics from other project tasks, as well as acquire waste form characteristics data from the waste producers--this would be Savannah River and West Valley--through the mechanism of the WAPS, the waste acceptance preliminary specifications and the waste compliance plans, and those types of data would include things like the dimensions, the radionuclide inventory of the waste, the chemical composition of the waste.

We then take those pieces of information, design and conduct what we call site-relevant experiments to identify the phenomenology of the glass degradation; that is, the mechanisms, the interactions between different materials in the waste package and engineered barrier system, the qualitative and semi-quantitative distribution of radionuclides after the glass is altered among the secondary phases and the form and solution, and then after examining those types of tests, come up with conceptual models that describe the important processes that we've identified in those site-relevant experiments.

Next, once you have a model like that, you inevitably need certain pieces of information, certain parameters, numerical values for things. We conduct a totally different set of tests that are not necessarily site-related to provide data for use in those models. For instance, you might need a diffusion coefficient, or you might need a rate constant, or activation energy. The types of tests that one performs to obtain those data are very different from the site-relevant tests.

We then take those data, compare the model predictions with other long-term site-relevant tests and natural analogues, if we can find applicable natural analogues, identify missing data or model deficiencies if these predictions don't agree with what we actually observed, go back to the beginning and re-think our models, reexamine or conduct new site-relevant tests to see what we're missing, and continue that process until you come to some closure.

And diagrammatically, it simply shows if you take input data, come up with conceptual models using input from site-specific experiments, use the models--take the models that one develops, identify what sources of parameters one needs to have, use those models, conduct additional experiments to develop those parameters, crank through the models and test them, and ultimately, one comes out with a validated model which is then used in performance assessments of the waste package and engineered barrier systems.

Right now we are somewhere in a first pass through this system in about here. We have a model developed and coded. We can do calculations with it. We're in the process of conducting model specific experiments and testing the models.

The sort of model that we've been concentrating on to date has centered on understanding or modeling the nature of the water and glass reaction that occurs at the interface of the glass in either a bulk solution or filled with water adsorbed under the surface, or water vapor in the air. Bill Bourcier, who will give the talk following me, will present in much more detail the nature of this model and the types of results that we're getting from it.

It's based on the idea that what is controlling the ultimate reaction rate of the glass with the solution is the reaction of actually a gel layer, an altered glass layer with the bulk solution. We developed a kinetic model incorporating that idea, coded it in a computer code, and right now its predictions are being tested against various experiments. This framework, this calculational framework can be extended to include other processes, other mechanisms for degradation or other processes that would affect the degradation of the glass and the next view graph again shows that process.

The model of which I've been speaking is a kinetic model for the degradation of the glass. It basically tells you how fast elements are released from the glass, titrated from the glass into a solution. Once the elements are into solution, we use another code called EQ3/6, which you'll hear more about this afternoon and again tomorrow when we talk about fuel. EQ3/6 calculates or looks at the solution composition and determines if mineral phases, solid phases are super-saturated. If they're super-saturated, it precipitates those phases, takes the elements that are present in solution out of solution and sequesters them in those phases, recalculates the solution composition and goes back and this rate model, this kinetic model is a function of the solution composition, as well as other variables like temperature. Using this modified solution composition, you then calculate the next increment of dissolution of the glass and you go through this until you run out of glass or you go on as long as you wish to in time.

That framework can be easily extended. Instead of just having one subroutine that calculates how fast elements are titrated from the glass into solution, you could also have other modules that would account for the production of radiolysis products or corrosion products from the canister or other waste package materials that go on in parallel with the glass dissolution, and would also affect the solution composition and the types of phases that might precipitate at secondary phases.

I mentioned we're doing model-specific experiments. The second talk following mine will be given by Kevin Knauss. He'll talk in detail on these experiments, the types of experiments we've been conducting. The purpose of these experiments is to determine, really, not what the parameters are, but the numerical values of key parameters that are needed by the mathematical models. These tests are not repository simulations by any means. They're designed to isolate specific processes so they can be studied in the absence of other parallel effects or other compounding effects that go on at the same time. For instance, you might want to look at the dissolution rate of a glass as a function of pH, so you have to design the experiment that will control the temperature, the solution chemistry and the pH as the glass continues to dissolve because the process of dissolving the glass will affect the pH. So you must design an experiment that is controlled by the solution rather than by the glass.

Another role of these experiments is to determine the functional dependence, the form of the function, mathematical form of the function on dissolution rates or other degradation--other processes as a function of various individual parameters--for instance, the pH--while you hold all the other parameters, the value of all the other parameters constant.

These are very different types of experiments than what I've been calling site-specific experiments, and John Bates, in the last talk of the afternoon will discuss these. These experiments are designed to look at interactions between the various components of the waste package, to try and simulate in some manner the conditions or the micro conditions that one might find in a glass waste package.

These experiments are not adequate as a basis for long-term predictions. In most cases, or in many cases, they're simply too complicated to interpret simply. There are too many processes going on at the same time. What we do use these experiments for are to provide simulations of the relevant processes and, as I said, provide the phenomenology of the glass alteration process; what secondary phases form, how much of them, what are their compositions, what are the compositions and textures of the alteration layers that form on the glass, what sorts of interactions occur between, for instance, the stainless steel pour canister and the glass, chemical interactions, and these do provide an overall release rate of elements to solution when you take into account all these different processes occurring at the same time.

In addition, they provide an independent database against which to test the model predictions. Since we are going to take the numerical values that go as inputs into the models from a different class of experiments, we should be able to predict the results of these experiments, and therefore, it's an independent test of how well our model's doing.

And that's all I really want to say. I think that sets the stage. You'll hear more, much more detail on all these topics the rest of this afternoon.

DR. LANGMUIR: Henry, before you go on, a question?

DR. SHAW: Go ahead.

DR. LANGMUIR: Ron Palmer pointed out that his concerns in terms of formulating glasses for processing glasses was that they be durable, that they have certain operational properties that are useful to him. Can you feed back--let's say you find a glass, or the following speakers discuss glasses that appear to be more soluble, more degradable than they might wish, is there any way to feed back that information into the processing and manufacture of the glasses, or are you--or is the glass that comes from the plant a given? Do you have any kind of feedback that can allow you to suggest different formulations of glass?

DR. SHAW: There is a mechanism. They are fairly severely limited by their processing constraints. One of the waste producers could correct me; however, there is a mechanism by which we could feed back. If we really had a disaster, we discovered one of the formulations wasn't going to work, wasn't going to perform well at all, there is the waste acceptance process. There's the waste acceptance committee, the waste acceptance preliminary specifications could be revisited and revised. I don't see that as likely to happen.

Recognize that there is no--other than the constraints or the prescriptions for the waste form that are contained in 10 CFR 60, Part 135, there is no performance prescription for any of the waste forms in any of the regulations. The performance is a function of an entire waste package or engineered barrier system, or the entire repository system, so that the waste form has no prescribed release rate, the bare waste form.

DR. LANGMUIR: So you don't expect to come back with suggestions as to how to optimize performance at all from the chemical tests that are done on the leachability, for example? You're just going to have some information that allows you to predict what it would be?

DR. SHAW: Right. That's correct.

The next talk will be Dr. William Bourcier from Livermore. Bill is currently the glass task reader for the Yucca Mountain glass task and he will talk about modeling of glass dissolution.

DR. BOURCIER: Just as a comment to Don's question after Henry responded to it, I think the status of the glass modeling activity right now is such that we can't provide that sort of feedback to the producers. We're not sophisticated enough in our understanding of the compositional effects of glasses on their dissolution behavior to do that. We'd like to be able to do that, and that's one of our goals, but at this point in time we can't. But on the other hand, we do know from a lot of tests done mostly at the Catholic University of America that there's a certain range of compositions where glass behavior is good, and there are certain sort of plateau regions where small changes in composition drastically affect its performance. So as long as we stay down in the valley, we're in good shape and we pretty much have outlined where that valley is, so we just haven't been able to quantify that effect in our modeling at this point.

But what I want to do today is continue on from where Henry left off and be a little bit more specific about the modeling work we've done at Livermore, and use that as an entrance to looking at some of the experimental work that Kevin Knauss will present.

I've divided my topic into three parts. The first part I'd like to go over in sort of a real broad treatment of how glass dissolves, what happens when you put glass in water, what are the chemical processes that occur. In the second part, I'd like to show you how we tried to quantify those in a computer model, and thirdly, I'd like to sort of critique that model and show how we need to term some of the assumptions, how we need to test some of the predictions that it makes, and what future work, what kind of experimental work and modeling work we intend to do in the next couple of years.

Okay. What does a validated release model require? Sort of reiterating what Henry said, we need to have a conceptual model based upon a fundamental understanding of the glass dissolution mechanisms. In order to make long-term predictions of glass performance, we need to have a model that's firmly based in the chemistry of what's happening. We can't extrapolate empirical models. We need to know the essence of what's happening as the glass dissolves.

In order to do this, we need data to support the model from simple experiments designed to isolate individual glass dissolution mechanisms. Once we have figured out what's happening as glass dissolves, we need to go and do some simple experiments to quantify each of these mechanisms, and by doing that, we're in a position that we can take this variety of mechanisms and figure out what is controlling the rate in the long-term of glass dissolution.

And finally, we need a database of site-specific and natural analogue data to test the model. Once we've put it together from all these pieces, we need to test the model with something that's totally independent of experiments that went into designing the model.

Getting kind of specific now with things, glass compositions, what is a typical radioactive waste glass? Here I've got the composition in cation mole per cent of Savannah River Lab-165 glass, and if you're familiar with geology, the composition of this glass is a lot like a basalt. It's silica content, aluminum and iron contents are pretty close to that of basalt, but of course, it's full of boron and a lot of alkalies as compared to basalt. But what we find is that natural basalted glasses and many of the waste glasses dissolve at about the same rate. So this is one of the glasses I'm going to show you results of tests from. We also have here a simple glass. In some of the tests we've made up an analogue of SRL-165 glass that's simpler in composition, makes it easy to interpret the test results, and also, does not have any redox sensitive species in it, so we don't have to control the redox data to excess. This is a glass we've used in some tests to get some fundamental parameters that at some point in the experimental program we'll go back and do those tests with SRL-165.

We basically have divided up SRL-165 into six components; silica, aluminum, boron, sodium, calcium and oxygen and made the glass up in such a way that, for example, all the monovalent ions in SRL-165 glass such as sodium, potassium and cesium are put into the simple glass as sodium, another monovalent ion.

So what happens when you put glass in water? And this is going to be sort of a nutshell summary of a lot of different types of tests in glasses and different things happen to a different extent at different temperatures and different glass compositions, but we can sort of summarize it all to say that when you put a glass in water, the water reacts with the glass and starts to break down the network of the glass. When it does that, very soluble components of the glass, like sodium, potassium and the alkalies, lithium, come out of the glass readily and go into solution. A lot of the rest of the components are enriched in alteration layers that cover the glass surface.

So in this diagram, fresh glass is essentially, as the reaction proceeds, forms these alteration layers and they can be sort of divided up into two zones based on ion probe or sends profiles through the glass. We have a diffusion layer where there are a concentration of gradients in such elements as calcium, sodium and hydrogen. You can see from hydrogen that this is water diffusing into the glass. This is sodium diffusing out, and this is an enrichment of calcium relative to the insoluble component in the gel layer.

MR. CLONINGER: Excuse me, Bill. Just briefly, can you give us an indication of about how thick that combined gel and diffusion layer are?

DR. BOURCIER: Okay. These layers are commonly in the range of a few tens of microns thick for the general diffusion layers, although it varies again with the temperature and type of glass. Coating these layers, though, you'd form secondary phases, clay, zeolites, a lot of different phases that John Bates will talk about in awhile. This layer itself can be a few microns to hundreds of microns thick and, in fact, in tests at high temperatures, the entire glass is converted into these secondary phases.

So with that in mind, the kinetic model that we incorporated in EQ3/6 takes account of these observations. To give some of the assumptions in the model, as the glass starts to dissolve--though it doesn't show up on this view graph at all, this is the two layers, the diffusion and gel layer forming on the glass surface. As this process happens, basically you have two coupled competing processes. You have what they call etching, or simply a dissolution of the glass surface layer at the surface of the gel layer, where the SiO and boron oxygen and iron oxygen bonds are broken down. These components are released in solution. And you also have, further into the glass layer, the alteration layers, the zone where the alkalis are diffusing out of the glass.

These two processes are coupled, because the faster the rate of etching of the glass, the more steep are the diffusion layers and--are the diffusion gradients, and the faster things diffuse out of the glass, and vice versa. If diffusion were to speed up, the diffusion layer would get more broad and diffusion would slow down and the etching rate would keep up with it. So, in fact, you have sort of a steady state coupling of two processes which sort of maintain a steady state condition where this diffusion and gel layer are formed, and maintains more or less a constant thickness as it migrates into the glass.

What we assume in the model, then, as far as with--there's various pieces of evidence we use to come to this conclusion. It's with that, the overall rate in the model quantitated by assuming that it's controlled by the breakdown of the SiO, the tetrahedral framework of the glass at the gel surface. That's the assumption we've incorporated into EQ3/6, and the fact if you--what we use is the composition of the gel layer and this dissolution affinity as the overall control of the reaction rate, the dissolution of the glass.

DR. LANGMUIR: Bill, a question. Presumably your secondary mineral phases on the surface are going to impede that diffusion process, or could at some point, and they can just close off the whole process, can they not; say, an iron oxide?

DR. BOURCIER: They could and that's the concern, but I think the best answer to that question would be John Bates' talk and the last one of the session. We don't see that happening and we don't see any indication from the solution analyses that that's happening. I think in the long term, what very likely happens is that that thickness of secondary phases gets very large. You actually have inhibition to dissolution by transport of ions through fluids contained in the secondary phase, in between them, or that electron microscope work that John has done, there seems to always be permeable pathways through those phases, and they tend to flake off. They actually get zones behind them, and it's a potential problem but we don't see it at least in the one or two year tests that we've done.

But that's another thing. In the long term, we need to find out if that is going to be problem and it's going to slow down the rate. It's something we could count on to do that.

Let's look at some results. Let me show you some results of some tests that I want to show you of how I've modeled. In this case, this is a time versus normalized weight loss for components in an SRL-165 glass. This dissolution test was done in .003m of sodium bicarbonate solution. This, again, is a simple analogue of the J-13 water up at the Yucca Mountain site. It has the same pH and pH buffer capacity as J-13 water.

DR. LANGMUIR: What's the pH?

DR. BOURCIER: It is about 8.3 to start for this solution, but it hasn't have the complexities of all the minor and trace components. Normalized weight loss normalizes for the amount of each component in glass such that if the glass dissolved stoichiometrically, everything came out at the same time it went into solution, all these elements would plot on the same curve.

So, first of all, you can see they don't. Some elements are released faster than others. The more soluble elements are released faster, and the elements that are released slower are those that are concentrated in the alteration layers or in the secondary phases. And it turns out from looking at test results, most of the non-stoichiometry of release is due to the incorporation of these elements in secondary phases, not their incorporation in the alteration layers. That's where most of the mass of altered material, aside from fresh glass, is. It's in the secondary phases.

The second thing to notice is that these curves start out, dissolution is fast at the beginning, slows down with time, and becomes nearly linear. Most tests don't become strictly linear like these, but are still slowing down a little bit with time.

The first interpretation of this phenomenon was that this is a diffusion controlled region. This is some other surface reaction controlled region. What I want to show today, in our current model we can show that this entire region can be successfully modeled using simply the affinity control or surface reaction rate control without any call on diffusion to be the rate controlling mechanism for glass dissolution.

Also, to confirm one other assumption that we made in the modeling, which is that you have a steady state condition where these alteration layers achieve some thickness and maintain approximately constant thickness with time. These are results from some tests John Bates performed where we look at the thickness in microns of these alteration layers versus time. Again, it's a test on SRL-165 glass at 90 degrees C, this time in EJ-13 water, which is a water that's been reactive with the tuff for about a month at 90 degrees C. You can see that the total amount of glass that's been dissolved is relatively large compared with the thicknesses of the diffusion and gel layers. This is based on Simms analysis of the alteration layers, so that essentially much of the glass has been dissolved. These residual layers are about, you know, developed in the first couple weeks and then maintain an approximately constant thickness after that. So we can confirm a couple other assumptions that we have in the model.

Okay. So let's get on with how we actually do this. Well, actually, historically, what approaches have people used to perform these models? One way to go about this is to look at solubility limits of species. This sort of simulation, we assume pure crystalline phases precipitating and controlling radionuclide solubilities. In other words, another way to model the glass dissolution process is just to assume glass starts dissolving at some arbitrary rate, let the elements come into solution and reprecipitate as the stable phases. This acts to sequester the potentially harmful elements and what sort of limitations can we place on the waste form performance in the repository with some simple assumptions in that sort of model, and I think you'll see tomorrow some modeling results where that's been applied to spent fuel. This has been done for glass by Carol Bruton of Livermore. It was published just a couple years ago in the MRS. And so that's one approach and that's one approach that's been incorporated in our current kinetic model, is to allow the secondary phases to precipitate and control those concentrations of elements.

Another piece that John Plodinec talked about just before the break, hydration theory, where you like to have some sort of thermodynamic framework to decide relative stabilities of glasses, and hopefully that will relate to relative performance in the repository, and he showed you plots showing that you can calculate the hydration of free energy of glasses and it correlates nicely with composition. Unfortunately, there's no way to turn that directly into a rate of glass reaction, though you can get relative durabilities. You want to put that in some sort of model where you can quantify it and turn it into grams per time units.

So in the model we have in EQ6, we've combined both of these in a way. We assume secondary phases can form and sequester some elements. We also have sort of a modification of the hydration theory in that we look at the free energy of this gel layer and use some simple principles from irreversible thermodynamics to turn that into a reaction rate.

And the pitfall, of course, with mechanistic models --or not really pitfall. There's more work involved because you have to measure all those parameters with the generic experiments.

DR. LANGMUIR: Bill?

DR. BOURCIER: Yes.

DR. LANGMUIR: It seems like an important unanswered question right now would be if you included cesium or some other radioactive elements in your incongruency story and looked at them coming out of the glass, they might well have quite a different behavior because of the incongruency, and so what secondary phases--if that's what's controlling different release rates--might limit the cesium release from the site, for example? And you're going to have to ultimately get to that, it would seem to me, to get at the important questions here.

DR. BOURCIER: Right, and that's why we've, in the last year or so we've paid a lot of attention to identifying the secondary phases that form. Cesium will probably go into the clays, where ion exchanges on the zeolites, and we've had a lot of effort that we've contracted to Argonne to do analytical electron microscopy of these reaction zones, identifying the phases and looking for patches where these are concentrated. We haven't got to that stage in the modeling yet, but we hope with the database that John's going to supply to get to that stage, but it's obviously the key question in all of this. We're starting out with the simple problems that we think we can solve, and then we'll add those other elements once we have the foundation laid for it.

This is the approach we're taking. Identify the processes, like the formation of alteration layers, ion exchange, all those things that I mentioned; perform experiments that isolate and quantify these processes. That's the next talk that Kevin is going to give you, an example of how that's done. Generate model of glass dissolution, probably we should have put this first. This is actually an iterative cycle where you generate a model, perform these experiments and quantify it and see if it works out and go back, re-do it until you've got something you're confident of, and then the last stage is to validate the model with site-specific tests and natural analogues if you can find appropriate ones

Let me be real brief about this. These are all--I've listed here processes that take place during glass dissolution. They key question, then, in developing a long-term model is what controls the rate, and ion exchange, that's relatively rapid and we don't expect that to control the rate. Network hydrolysis is the mechanism that we've chosen to work into here and see if that really is controlling the rate. Many people believe diffusion of ions or water through the glass or alteration layers controls the rate. We have not incorporated that in our model at this point, and then I alluded earlier to chemical transport through fluids in alteration layers in long time periods may be important.

That's going to be a difficult one to get at experimentally.

A little bit about what's behind all this, we use a rate law that's based on some simple assumptions of irreversible thermodynamics and detailed balancing, the fact that at equilibrium you have a forward and reverse reaction proceeding at the same rate. The rate law, you can derive a rate law based on a couple simple assumptions and you get that, the rate of change of any component in solution in a section of time, is proportional to the surface area of the solid sample divided by the volume of the solution to correct for the--this is a concentration. Use the stoichiometric factor for the amount of that component in the glass, simply to normalize for each element contained in the glass.

A rate constant, which is a function of pH, and this is the topic of the next talk, essentially how you get that rate constant as a function of pH independently of everything else going on during glass dissolution, and then what's called the affinity term, and this has to do with as components build up in solution, the rate of dissolution slows down because the affinity term becomes closer--gets smaller and smaller. The affinity term is, in fact, the concentration quotient of activities of ions in solution for the dissolution reaction of, in this case, the gel layer, divided by the thermodynamic equilibrium constant. So as species build up in solution, this value gets bigger and bigger and this term gets closer and closer to zero, where at equilibrium, this term would be zero and the rate of dissolution would stop. We don't see that in glass dissolution because glass is intrinsically unstable, so you never approach where that term becomes zero. But, obviously, it's very critical to know how that term varies with time in order to calculate how fast the glass is being dissolved over long time periods.

Okay, all this has been incorporated into EQ3/6 codes, which you'll hear more about tomorrow. It's a set of computer programs and thermodynamic bases to simulate fluid-solid interactions. There's actually two codes, EQ3 and EQ6. EQ3 simply computes the chemical speciation, accounts for complex formation, gives you saturation states of minerals. EQ6 is the code that actually takes starting conditions and evolves the system as the solid or liquids to the other liquids, lets them react according to whatever rate value you give it, and gives you as a result pH solution speciation, amounts and types of minerals that form as a function of time.

So when we apply this to glass dissolution, in the simulations that you'll see in a second, what I include is the glass and fluid composition and the rate constant for dissolution. What the code then generates is essentially the glass dissolution rate, the concentrations of components in solutions as a function of time, which you also measure in the tests and compare with, and the types and amounts of secondary phases so that you have a way--you make these predictions and you go back to your experiment and see how close you are, how far off you are in a particular model and do what you need to do to be able to fit as wide a variety in as many, as most accurately as possible for the experimental results.

Some results. Now, I've done the simulation for the experimental results I showed you a little while earlier for the SRL-165 glass at 150 degrees C. You can see that versus time, the pH, the curve is the EQ6 calculated pH. The data points are the pH's measured in these tests. They're actually the 25 degrees CPH measurements recalculated at 150 degrees to compare with the code-predicted results. You can see fairly good agreement.

Also, we look at essentially the driving force of the reaction, the affinity for gel dissolution, which we're assuming is the rate controlling mechanism here. It starts out very high when solution is very sparse and the concentrations of all the components in the gel. As the glass dissolves, things build up in solution. The affinity gets smaller and smaller and at some point it approximately levels out. So as things build up in solution, it slows the rate of reaction and it's very critical, of course, to know how low it gets and, more importantly, what happens as you go longer and longer in time periods. What controls the concentrations of components in solution? Because that, in fact, controls the overall rate of lasting solutions, so it's really critical to know, especially what secondary phase is precipitated, because secondary phases are going to control what's in solution. What precipitates out of secondary phases will be removed from solution. What builds up in solution and doesn't precipitate won't, and it's the balance between glass dissolving and secondary phases forming that ultimately tells you what the affinity is.

According to this model, it's really critical to know--be able to predict in long time periods what secondary phases are forming and what the solution composition is going to be. If they're not controlling it, what is? So we have basically some good ways to test this model then because of these predictions that it makes, and I'll just go through a couple more results of the simulations.

I'll have to add that these simulations were done by using the rate constant as a fitting parameter, so the equation you saw a couple view graphs ago, we have assumed that that rate constant has dependence on pH or something we used to best fit experimental data. What we're doing now, or have recently done--and Kevin will report on the next talk--is some tests to determine the rate constant independently, the rate constant and its pH dependence so we can plug back in and that way apply this model without the use of fitting parameters. And, as Kevin will show you, the rate constant we got by regressing this data and the one he measured independently in flow-through tests are very close, so we're very happy with those results. It lends credibility to the approach.

The other point I want to make is because there is a fitting parameter in it, what we're mostly interested in in these curves is the shape of them. Does the shape of these curves fit that of the measured release rates of elements? And we do get a very similar--we can't predict that early what looks like an infusion control and later linear regime, that people have ascribed to a surface reactor control, all with surface reactor control without having two processes.

Okay, so what do we need now? We've got a simple model. It may or may not be right. We need to really test it rigorously, and to do that we need experiments that isolate the processes taking place during glass dissolution and use these results to plug into the equations in the code, and then test a lot of different experimental results, a lot of different glass compositions, solution compositions, temperatures, and see how applicable the model is to a large variety of experimental results.

We have done some flow-through tests that provide the rate constant and the pH dependence of the rate constant. Another thing we want to do that we're doing right now, in fact, is do flow-through tests with doped buffer solutions.

The model makes specific predictions, for example, if you'd flow a lot of kinds of glass that contain silica. It should have a measurable effect on the rate that you measure, rate constant for glass dissolution. According to our model, we should be able to test it by doing a variety of these tests, doping it with different elements, elements that are not contained in the gel layer, should not affect it; elements that are--should affect it based on their abundance in the gel layer. So the model makes some specific predictions we can test there.

We can also test it by doing more closed-system tests with doping it with secondary phases. At this point, we've always allowed secondary phases, those that want to precipitate to precipitate. We can dope it, nucleate it with certain secondary phases that will affect the reaction path in a way that our model predicts and again test it in that way.

And also, there's some tricks we can do like, for example, doing the tests in a deterring oxide rather than water; that, again, the model predicts a certain effect for this and we can test the model with that sort of experiment.

DR. LANGMUIR: Bill, I presume you're going to have thermal gradients in the real system. How do you deal with that?

DR. BOURCIER: Try to minimize them? I haven't thought about that. So far we've done isothermal experiments in modeling, and I mean, conceivably, you can put in a function to give the temperature variation of the reaction path. You can do that in EQ6 now, but that's something we need to address at a later point.

I've really covered that. Let me just add at this point that one of the things that's really lacking at this point that we need more work on is the glass composition. We've used one or two glasses in our generic tests. We need to get at that and get a handle on how the glass composition affects this rate, and test whether or not different compositions, that as they alter to form gel layers of different compositions, is it that gel layer composition that really accounts for the differences in dissolution rate between those different glass compositions. So that's something we have planned, but not started experimental work on yet.

Fortunately, a lot of the other groups, like at Catholic University, up at Pacific Northwest Labs are doing suites of tests on glasses of a wide range of compositions that will help out, so there's quite a few different people doing experiments that will help answer that question.

DR. LANGMUIR: Are they doing that work, or has their funding just been discontinued this year?

DR. BOURCIER: That's mostly Defense high-level money and that's continuing, I think. I never know from day to day, but

I think it's there.

Okay, and the other key thing here is what happens to the actinides? We haven't pursued that. John Bates will talk after Kevin. He has pursued this and identified a lot of phenomenology of what happens to the actinides. We haven't incorporated that in the modeling yet and we need to do that. Don asked a question relative to that at the start. Where do they go?

Another big problem is, how do we apply this to the Yucca Mountain conditions that are unsaturated? And we have some ideas about how to do that, but we haven't tested it yet. So far it's been all saturated modeling, and one of the big--a topic now in people doing mineral dissolution--which is a hot research topic right now in geochemistry--they're finding a very--a great importance in surface chemistry. What components in the solution, sort of under the surface of the solid dissolving and affect the dissolution rate--and sometimes very drastically. We haven't incorporated or accounted for that yet or used that to sort through our data, so it's another aspect that needs to be addressed that we'll get around to eventually, I hope.

Okay. In summary, then, we've incorporated this network hydrolysis model, EQ3/6, and shown that we can predict model results in closed system tests. We have started up experiments to isolate and quantify glass dissolution processes, and we need those for further model development. Right at this point we really need to do a whole batch of these tests to do the sort of the next phase of geochemical modeling of this process, and then improvements are needed in order to better account for the dependence of the dissolution rate on glass composition and glass surface chemistry, two of the things that we really haven't addressed yet in the modeling.

That's it for me. Questions?

DR. LANGMUIR: Just one last comment. I would sort of--it'd be kind of fun if you would jump head first into this thing, too, and--in the sense of taking some glasses in which there are radionuclides and right now doing a lab dissolution study under the similar conditions to see what the radionuclides are doing, rather than building a structure and not knowing whether it's going to matter or not in terms of the consequent behavior of radionuclides.

DR. BOURCIER: Those tests have been done and are being done by John Bates at Argonne, and you'll hear more about that.

The next speaker is Dr. Kevin Knauss, a geochemist at Lawrence Livermore, and he will be speaking about experimental bases for glass modeling.

Kevin?

DR. KNAUSS: As Bill mentioned, I'm going to be describing some simple experiments that we've been doing to try and assist in the model development effort that Bill was just talking about, and to provide some of the parameters that are required to use Bill's model.

Bill started his talk with this slide, and I'd like to start mine with it as well. These are the things that are required in order to develop a validated release model for glass dissolution. Bill addressed principally the first bullet on this view graph. The experiments that I'm going to be talking about today provide information that's useful for the first two requirements in generating that release model. Henry mentioned that this is an iterative process, where the simple experiments that I'm doing can provide information to the conceptual model development and, in turn, can also provide information that are used in that model. The last bullet is the type of information that will be supplied by John Bates, who's doing site-specific experiments.

I'm going to be proceeding in this talk in the following way: What I'd like to do is start out by describing very simply the experimental design that we've come up with for a number of experiments to provide information useful in developing models and in providing the parameters that are needed to use those models, and then I'd like to just step back and very quickly describe why it is that we might need to do experimental work at all; I mean, there is a very large body of data that's been generated in the nuclear waste industry and other industries concerning glass dissolution.

Then I'd like to return and describe some of the results of the experiments that we've done to measure the dissolution rate constant in the model that Bill described, the activation energy for glass dissolution, and the pH dependency of that dissolution process, and I'll be referred to both fluid chemistry, analytical results and the solid phase analyses that we've done in glasses that we've reacted in various experimental apparati that I'll be describing.

I'd then like to compare the rate constants and activation energy that we've measured with--and use Bill's modeling approach basically to compare the rates that we measured for. In this case, my talk will be confined to experiments that have been done with the simple glass that Bill described, compare those results with ones that other people have obtained for natural and synthetic glasses.

And then I'd like to just conclude by describing some of the work we're doing at the moment to validate the model.

During Bill's presentation, he described a rate equation that's been incorporated in the reaction progress model, EQ3/6, and in that equation there are a number of parameters that have to be measured, and these include the rate constant, this pH dependency, and then, of course, we have to account for the chemical affinity for dissolution as the reaction proceeds.

What I'm going to describe today are some experiments that we've done where we have simplified this rate equation to the form that's shown on the right by driving this chemical affinity term to one, and we do that by making Q zero, basically, and the way that's done is to use a flow-through cell in which we keep the concentration of glass components very, very low so that the glass is dissolving at essentially its maximum rate for that equation. If you do a number of experiments like that at a variety of pH's where the pH is fixed, what you end up with are a series of data points which one can plot a measured rate versus a pH, and a simple linear relationship at this point to derive a rate constant and the functional dependency on pH.

The way we go about convincing ourselves that, in fact, we are able to use reduced forms of this equation is by calculating for each of these experiments the--using the solution compositions that we measure in the effluent fluids, the chemical affinity for precipitation, basically, of all potential phases that might form in that system, as well as for the gel that might be present in that experiment, and convince ourselves that we have, in fact, driven this chemical affinity to one. We've also used the same code beforehand to design the buffers which we use, dilute buffers, to control the pH in these experiments.

I'll also be describing experiments that we've done, basically the same experiments that I just talked about, at a number of temperatures in order to calculate an activation energy for this dissolution process. We are working now on some experiments that have been designed to investigate this chemical affinity effect, so we're no longer going to be doing experiments where we can convince ourselves that this is now one, and Bill described the way in which we're going to go about doing those experiments, and they involve two approaches.

One is experiments analogous to the first type here; in other words, dissolution kinetics experiments done in a flowing system, but in this case the buffers that we'll be using will contain some of the glass components so that we have a known chemical affinity. And other experiments will be done in closed systems where we allow solution components to build up in concentration--I should say the glass components to build up in concentration and fluid.

And finally, we're going to be doing some experiments where we look in some detail at the surface chemistry of reacted glasses.

If I can just back up for a second, I'd like to try and justify why it is we felt we had to do some experiments using a simple glass as opposed to trying to back out fundamental information about glass dissolutions from the enormous amount of data that's available in the nuclear waste literature.

You heard John Plodinec describe some of the MCC-type tests and other tests that are used primarily as a simple quality control vehicle in a production process. Those experiments were designed with a specific purpose in mind, and the specific purpose was not necessarily to understand in any fundamental way glass dissolution. In experiments of that nature, it's been shown by other people that it's very difficult to isolate forward and reverse reactions, because in many of these experiments, if they progress for any period of time you see the effects of both dissolution and precipitation. In experiments of that nature, obviously, then, you cannot isolate the various parameters that have to be determined to use a model such as the one that Bill has described; things like a rate constant, a pH dependency, or any chemical affinity effects.

In site-specific types of experiments, you not only have the problems I just described, but they are further compounded by the presence of other repository-type materials such as canister materials, rock, and so on. In experiments like that, site-specific experiments, the solution compositions then that one observes are a complicated sum of a number of processes that are taking place, and it's very difficult to unravel the input from just dissolution, for example, if what you're trying to do is develop a glass dissolution model.

That data, however, is, of course, very useful in testing a model that one would develop perhaps based on some more simple models, some more simple experiments. It's just not particularly useful in developing the model itself.

The glass composition that I used in the simple experiments that I'm going to be talking about was already described by Bill. It's a five-component glass designed to resemble in its major constituents, anyway, SRL-165 waste glass. The buffers that we used to control pH were all dilute buffers which we designed using EQ3nr to have sufficiently low ionic strength that there would not be an ionic strength effect on the dissolution rate, and to contain components for which we had good thermodynamic data which would allow us to account for, if any, interactions between the buffer components and the glass component, and as you can see, we can essentially span the pH range with this suite of buffers. I should also add that the buffer, capacity for those buffers is sufficient in our flowing cell to fix pH constant. What goes into the cell essentially is the same pH as what's coming out of the cell after it's dissolved in glass.

I thought I'd also just mention very quickly the types of equipment we're using because they're not MCC-type of tests. The closed-system test that Bill talked about with SRL-165 was done in what's called a Dickson-type autoclave, which contains a flexible gold bag from which you can extract the fluid and quench it through room temperature and pressure conditions in the absence of a solid, and this prevents a lot of the problems that were described by Means and Spinoza, for example, in MCC-type tests at any significant temperature. The reaction, of course, can be sampled as reaction proceeds. You can take multiple samples from a vessel of this type.

The flowing cell that I'm going to be--well, the results that I'll be describing in the rest of this talk, really, were all obtained using a flow-through cell in which the glass grains are reacted with--in this case, since we were trying to drive the affinity term in Bill's rate equation to one, just the dilute buffer solutions with no glass components present. That fluid then dissolves part of the glass, leaves the cell. It has the same benefit of, of course, quenching the fluid to room temperature conditions, divorced from the solid. It allows us to control the activity of glass components in the influent fluid, and it also allows us to avoid any potential sample preparation artifacts which, in effect, get locked in in a closed-system experiment; that is, any accelerated dissolution rate that's just due to the mechanical destruction of the material that you're preparing if one is using crushed material, for example.

Now, what we've done are a number of experiments, essentially at unit pH interval and at three temperatures, 25, 50 and 70 degrees C, where we've reacted this simple glass with the buffer solutions that I described earlier, and I'm going to just show two typical plots which really describe two general types of behavior that we see in experiments of this nature.

For all of the experiments that were done at low to neutral pH, almost all of the plots would look very similar to this one, and what I'm plotting here is the normalized glass dissolution rate based on the release rate of each element present in the glass to the fluid, and this is, in fact, a rate with time involved in it, and so what one sees is that if a rate is constant with time, of course, it will be horizontal on a plot like this.

We also can see things like, for example, in early time in the experiment, if there is an accelerated dissolution of material, perhaps fine-grained material or disturbed material on a glass surface, that will show up as an elevated rate early on in the experiment, and then the rate at which the bulk glass is dissolving would be reflected by this linear and flat portion of the curve in longer time. This, by the way, is the rate that we're interested in for Bill's model.

The other thing that one can see using a normalized plot like this is when, in fact, one is forming a gel layer on the surface of the glass. If, in fact, all the elements are released in their stoichiometric proportions, all those lines are coincident and, in fact, they are in this particular case for all the glass components with the exception of silica, so obviously, an experiment like this, we're developing a gel layer through the entire run.

We also changed the flow rate twice during the experiment. We essentially doubled it at about Day 50, and then two weeks later, doubled it again to look for any transport effects.

DR. DEERE: I wondered what caused that change at the end of the program there.

DR. KNAUSS: Yes. What tends to happen is there is a slight change in the rate, and then it assumes the same rate as prior to changing the flow rate, and if we're not looking at a diffusionally-controlled process or transport-controlled process, those rates, of course, should be flow-rate independent.

The other type of behavior we see at all the temperatures in mildly alkaline and strongly alkaline solution is typified by this particular dissolution rate plot, and in this case, we have essentially congruent dissolution; that is, a stoichiometric release of all the glass components right from day one. In this type of an apparatus, we're taking a cumulative sample so we can account for the total mass of all the glass components that are released throughout the run, and so our first sample point is after 24 hours, and whatever signal would have been generated in the fluid from the gel formation has obviously just been swamped out by the stoichiometric release that occurs once the gel and diffusion layer that Bill described has achieved some constant thicknesses and is now just progressing into the glass at the rate at which the gel itself is dissolving; that is, at the rate at which network hydrolysis is taking place.

Again, we changed the flow rate at a couple of points. The rate we're interested in here is, of course, this steady state, which you might call limiting dissolution rate.

If I take the limiting rate for all of the experiments that we did based upon the release of each element in the glass, you get a composite plot that looks something like this, and again, these are normalized glass release rates based on the release of each element in the glass to the fluid, and before I describe the important points within this plot, I'd like to mention a couple of caveats here; several caveats.

The data at pH 1, you might notice, don't tend to progress along the same trends as the other acid experiments, and the reason for that is that in calculating these rates, I'm assuming a constant surface area, and that is the surface area that I measured at the start of the run. The rate of dissolution is so high at pH 1 that, in fact, significant amounts of the glasses have dissolved in each of these experiments at all three temperatures, so that rate is not legitimate.

There are a few open boxes here which are a borate, or I should say the boron data in the borate buffers, and we've measured those and so I've plotted them here, and that's a situation of calculating a very small number that's a different of two very large numbers, so they're very uncertain.

And finally, there are--the calcium points here in the highest pH buffers are obviously falling off the trend. When we did solution speciation calculations on those fluids, we found that those fluids were, in fact, super-saturated with a couple hydrated calcium silicates, and we subsequently found those using the SEM after the experiment.

Other than that, what you might notice is there's kind of a break in behavior here at about pH 8. It actually depends upon the temperature, and what you see is that above, say, a mildly alkaline to the strongly alkaline pH, dissolution is congruent, basically; and below that point, there's obviously gel formation taking place which is incorporating in this particular glass aluminum and silica, whereas the other components in the glass--sodium, calcium and boron--are being released quite rapidly and at the same rate.

Now, if you recall, if we can use the reduced form of that equation, what we should see are lines, basically, on a plot like this, and we can use those lines to calculate the rate constant and the reaction order with respect to pH. And so what I've done here--I should have mentioned, on that prior plot there were actually two different breaks in scale. On this plot, I have plotted just the silica normalized glass dissolution data on a single scale, and a plot like this could be used to calculate reaction--rate constant and reaction order with respect to pH. And, in fact, we've done that and calculated rate constants and the reaction order for both sides of that plot, basically, an acid side and a basic side of the plot, and also, the reaction order at the three temperatures.

Now, before I describe how this data compares, how you'd use rate constant and reaction order determined from these experiments to calculate a rate, compare that to some other data, I'd like to just quickly turn to the solid phase analysis that we did.

After each experiment, we recovered the glass grains and look at them both in SEM and analyzed probe mounts that we made, and what we found was that, in fact, that at low to neutral pH, we generated gel layers in all of the experiments, but none were obvious--at least in SEM--at high pH. The gels that we analyzed were, in fact, silica-rich at very low pH and contained aluminum and silica at more neutral pH's.

What we also found was that in those alkaline experiments, at the highest temperature where the rates were very rapid, we found etch pits that were present on the surface of these glass grains, indicating a surface reaction control that is dissolution at specific points, and we also did, in fact, find the calcium secondary mineral that had precipitated at pH 13, and the other thing we noted was that this was a discrete phase and not a coating on the glass grains, and so that's why the other elements were all being still released to solution in stoichiometric proportions.

The next thing you have is probably a blank. I'm not real sure why that is, but all I wanted to use this slide to illustrate was the fact that a lot of recent work has shown that there's really not a heck of a lot of difference between the processes that are involved in glass dissolution and mineral dissolution. You have basically the same three or four processes taking place; ionic in range, a hydration process that involves polymerization of silicon oxygen, boron oxygen, aluminum oxygen bonds, and then a condensation of silicon oxygen bonds that form an amorphous silica-type gel as the basis for examples.

And then you have network hydrolysis, which is the final breaking of those silicon oxygen bonds, and then the release of silica and other gel components to the fluid, and it's that network hydrolysis which we're keying on as a rate controlling process, and the rate equation that we're using has a form that's very similar to the one that's used in mineral dissolution kinetics where, in fact, mineral dissolution appears to be a surface reaction control-type of process, and you see evidence for that in things like localized corrosion at etch pits, for example. These happen to be aligned more or less along conchoidal fractures that are created when the glass grains were crushed.

We also analyzed the solids, the glass grains in this case, using both FTIR and NMR after the experiments, and what we found was more or less in accord with the fluid chemistry results, and that is that the experiments that were done in highly alkaline solutions produced glass surfaces that looked very similar to the unreacted glass, whereas the experiments done in strong acid produced surfaces that, in FTIR, contain, of course, abundant water and hydroxyl, and in NMR, the aluminum and silica environments were different from that in the unreacted glass in a way that kind of suggested the shifts that were observed were due to the boron release from those gels.

Now, if you recall, Bill described a fitting exercise in which he took an experiment in which he had dissolved SRL-165 glass in a dilute sodium bicarbonate solution at 150 degrees C. And in that fitting exercise, he was trying to calculate by fitting a rate constant using the rate equation that's been coded into EQ3/6, and he also in that exercise was assuming that there was no pH dependency or, in effect, another way to look at it is to say that he rolled up any pH dependency into the rate constant that he was going to calculate by that fitting process.

When he did that, Bill showed the data and the curves that were generated in that fitting exercise, and I don't think he mentioned the rate constant that he calculated, which was about 6 x 10^{-9} g/cm^2 second for that glass at that temperature at that pH.

With the simple glass that we used in these dissolution kinetics experiments, if we use the rate constant that we measured, if we use the pH dependency that we measured, and if we use the activation energy that we measured, we would calculate a--what I'll call a rate, but what Bill called a rate constant in his fitting exercise--that are essentially the same number, and what that suggests is that for these two glasses, at any rate, there's certainly no compositional dependency in the rate constant that one would measure in an experiment like this, Don. I think we have to do that experiment, but the suggestion here is that we shouldn't see much of a difference and, in fact, the rate, again, that one would calculate using the simple glass rate constant, pH dependency and activation energy are also very similar to rates measured using natural basalts.

The activation energy that we measured, 20 kcal/mol, is another indication that in glass dissolution in--certainly in the alkaline range, from neutral to alkaline pH, has an activation energy that is on the order of those that are measured in reactions that are known to be surface reaction controlled, and I've just listed a few here; some mineral dissolution reactions and some glass dissolution reactions which we feel were controlled in a way that an activation energy that was backed out from those experiments really reflect a glass dissolution, and I've just contrasted that with a process here, iodine formation, which is very definitely a diffusionally controlled process, and what you see is, of course, that reaction activation energies on the order of 15 to 20 kcal/mol are indicative of the surface reaction-controlled process.

What we've concluded from the experiments that we've done thus far, and also from work that's been done in the past five years or so in glass dissolution experiments, are the following: It's pretty clear that glass dissolution is strongly pH dependent and any model that we develop must explicitly account for that pH dependency.

The glass dissolution process that we're trying to model, again, in alkaline solutions, seems pretty clearly to be a surface reaction-controlled process based on a number of lines of evidence. The activation energies are quite high, similar to those for mineral dissolution, for example. We see release rates that are linear with time, which is something that one would not see in a diffusionally-controlled dissolution process, and we even see--in cases of extreme dissolution, we even see the formation of etch pits, demonstrating a surface reaction.

We've also found that the rate constants and activation energies and reaction order with respect to pH that one determines in simple experiments, can, in fact, be used to feed into a model such as that described by Bill, in which a term is included to account for the chemical affinity of the dissolving and rate controlling phase--in this case, the gel layer--and that that affinity term can account for the parabolic release trends that are typically observed in closed-system experiments.

In terms of the model-supporting experiments that we're doing, we're in the process of doing two experiments now that are designed to investigate this chemical affinity effect, and I described these very briefly earlier. We're doing dissolution kinetics experiments using the flowing cells in which we intentionally have added known amounts of the glass components, and we're making those dissolution measurements at a number of pH's and at a number of temperatures. And we're also doing closed-system experiments, similar to those that Bill described for SRL-165, using the simple glass under basically the same sort of conditions that Bill had used earlier.

We also will be making dissolution kinetics experiments, doing those experiments using SRL-165, and that concludes my talk and I'd be glad to try and answer any questions.

DR. LANGMUIR: Kevin, looking at some of your data, you show that in your experiments, that the lowest dissolution rates are right around pH 7. Is that what you'd recommend, that if we could buffer the pH of a repository, would that be the ideal pH for you to have if you want to avoid glass breakdown and release of radionuclides? Do yo know that much yet; if you could buffer it?

DR. KNAUSS: I don't know whether that's necessary because it really depends on this performance criteria that we're trying to meet, and that next calculation we haven't done. So, for example, if other components in the system acted in some way that the release rates were within those required by the regulations, one wouldn't need to buffer the pH necessarily to achieve that. Certainly, something on the order of mildly alkaline to neutral pH is far better in terms of glass durability than either strongly alkaline or strongly acidic solutions, so something on that order, 8 plus or minus a half or one pH unit is probably better.

DR. VERINK: Are those pH's measured in the experiment at temperature or at room temperature?

DR. KNAUSS: The pH's for all the buffer solutions were both calculated and measured. In the cloying systems, we typically measured the pH. We could calculate the pH a priori based on the thermodynamic data, and practically speaking, in the two higher temperature experiments that I talked about here, we just calculated what the pH would be, although at that temperature range, one could easily measure it. It's a bit more difficult to measure pH in experiments like those that Bill did, for example, at, say, 100 or 150 degrees C, and so that's why this approach that is calculating it, as long as we can convince ourselves it works at a lower temperature, thermodynamic data's good, that's about the only way we can go at the moment.

The next speaker is going to be Dr. John Bates, who's been doing a large number of site-specific tests which are, as Bill described, very important in the model development, and also very important in testing any model that we might develop.

DR. BATES: I'd like to thank the previous speakers, starting with John Plodinec, who have been referring to my talk. Hopefully, that kept you around.

(Laughter.)

DR. BATES: You've heard about the waste producers describe how they're going to produce a well-characterized, consistent glass. You've heard Bill and Kevin describe how they're going to model that glass performance. A logical question is: What have we been doing to determine how that glass is going to behave in the repository? That's essentially what the topic is that I'm going to talk about, integrated glass alteration tests, and to put this in perspective for the two previous talks, one of the things my tests can be used for is to generate a database of site-specific and natural analogue to test the model. That's only one of the purposes, and when I get to the purpose section I'll expand on that a little bit.

Here's an overview of the talk. I'll go over what the purpose of these tests are, give you a little bit of the background and perspective I use in doing testing and performing the tests, give you three examples which relate to the purpose and to the background and perspective, and these three examples will be what I call vapor hydration and leach testing, static leach testing combined with surface analytical studies, and then something I call drip tests to simulate conditions that might exist in the expected repository horizon. And then we wind it up with a summary which tries to go back and look at how we're addressing the purpose.

Now, in a general sense, the purpose of the tests, I think, were pretty well put by the National Research Council in their recent report where they identified structural uncertainty and parametric uncertainty. Structural uncertainty answers the question of do we understand the system well enough to model it? Parametric uncertainty is: Have we chosen the right variables to describe the system, and do we have the correct measurement techniques? Or to paraphrase that, do we have any idea what we're doing, and if we do, do we know how to do it? So I think starting off, that addresses some of the most simple questions that we want to ask.

We want to identify site-specific processes and mechanisms, degradation modes that might occur and be important in a repository environment. We want to identify materials interactions that occur because, after all, the glass isn't going to be the only thing that's in the waste package environment. We want to stress measuring radionuclide distribution and radionuclide release trends because, after all, it is the radionuclides that we're most interested in. We have to look at that. And then we want to provide validation of mechanistic models.

Okay. To give you a little bit as to the background and perspective I use, I feel that you can't do performance assessment or waste package design without knowing something about basic reaction and release processes. So use this simulated plot here of reaction progress versus time is what

I'm trying to describe.

Essentially, for glass, if you look at all the tests that have been done, you can see that you get essentially three different types of reaction progresses: One, if you do the bathtub-type test, that's an MCC-1-type of test, for the length of time that we've been able to do that test, you get essentially what looks like a reaction that starts off fast. It slows down with time, and for the length of time we've been able to do these tests, it keeps on looking as though it's not reacting very much at all. So if you did that test and thought that was a good representation of your repository, then you'd be down here in the slow process.

But if you could accelerate that test or if you could continue it for a longer period of time, based on what you hear Bill Bourcier describe in his model, you're going to start precipitating secondary phases. Those secondary phases will increase the affinity for glass to react, and you will start back up on a fast reaction track.

Or, if you look a little more carefully at the conditions that exist in the repository, low volumes of water, you will find that you can start forming those secondary phases very rapidly so that if you did experiments that are representative of conditions that might exist in the repository, you don't even see the slow portion of the curve. Essentially, what you see is the fast portion of the curve.

So my point here is when you're doing performance assessment or waste package design, you have to know on the repository conditions which one of these events is going to be controlling the reaction of glass. What I'm going to look at in the examples are site-relevant tests, radionuclide release and reaction mechanisms, trying to relate it back to where we are in this curve.

Okay. How do we go about doing tests in an unsaturated environment? Well, it turns out that the variability of conditions that exists at the Yucca Mountain site really offers a challenge to designing and performing tests to evaluate waste form performance. That's because instead of having a lot of water around that we would have in a flooded repository, perhaps, which homogenizes all the interactions, we've got in some cases the expected condition, which would be humid air. We've got the potential for dripping water with intermittent flow. Then we've got the potential for small amounts of standing water, and we have the potential for each borehole to be different from every other borehole in the repository, a combination of each one of these processes, or perhaps another process, but these are the only ones we've been able to think of.

The important point is, that we've gotten out of our testing, is that the small amount of water really has a dramatic effect on the way the glass reacts. Now, this is a hard point to come up with a priori, but after you see the results, it's pretty clear based on the test results and then based on how Bill's going about modeling the reaction processes.

Now, to just put that into perspective--and again, I've got a different view graph than you've got on your slide, but that's because the color didn't show up very well on the slide, so read the words on the view graph and look at the micrograph on the slide.

What happens when you react glass and water vapor is that you condense a thin film of water on the glass surface. It becomes concentrated very rapidly in the components from the glass. Secondary phases form very rapidly, and this is what you see here on the glass surface. These are the alteration products, the secondary phases that are going to form in a leach test after a long period of time, but in a vapor environment, they form much more rapidly. Then you have the altered glass under here.

And what we find when we compare the rates of reaction in vapor with rates of reaction in liquid, is that under certain circumstances we can actually find the stable phases promoting the reaction, and as Bill's model describes.

Let's take a look now at the three examples. Start off with the first example, which is what I call vapor hydration leach. What's going to happen in the repository is the glass is, first of all, going to be in contact with humid air. So if we're doing our modeling or our leach testing based on fresh glass--which most of our testing has been done on--and yet the actual glass in the repository is going to be somehow changed by aging process, which is a vapor hydration process, what we have to demonstrate is whether this vapor hydration process affects the glass such that all the work we've been doing on fresh glass is relevant or not.

So here we have an example of site-relevant testing combined with radionuclide release. It's the leaching of aged glass, and the goal here, these are really just "let's look and see"-type experiments. Do we need to pursue this any more than we already have? Is this an important factor to look at?

DR. LANGMUIR: John, before you go on, interesting--your comment that you're making secondary phases much more quickly under these conditions sounds to me like perhaps you're talking about adsorbed water, which is then very readily saturating, as opposed to water moving over the system in large volumes.

DR. BATES: Oh, yes, that's exactly what I'm talking about. It's if you have a vapor environment, what will happen? And we've done thermogravimetric tests to measure this, is you will adsorb water out of the glass surface. That will then become concentrated in the--mainly the alkalines initially. It will attract more water to the glass surface.

It'll allow the--

DR. LANGMUIR: It's hydroscopic.

DR. BATES: It's hydroscopic. It then becomes rapidly concentrated and the secondary phases precipitate. Yeah, that's exactly the process.

So what we're trying to do in these tests is simply compare radionuclide release, because, again, what we're interested in is not so much how the glass is reacting, but what's happening to the radionuclides, from tests where we vapor hydrated the glass first, to those where we're using fresh glass, and to put this in perspective, the conditions for storage in the repository are essentially going to be humid air, so that's an expected condition for aging.

The leach test, which is a bounding condition for release, is that of a flooded borehole. So we're really hitting it hard. I don't think anybody would ever admit that we expect any boreholes to be flooded in the repository, but to see whether this is an important effect to look at, that's the way we're doing the test.

What the test looks like is as follows: It's got two parts. First is the hydration aging part. We accelerate the aging process in the test because we don't have enough time to duplicate aging that would occur in the repository, so we use saturated water vapor and we use temperatures up to 200 degrees C to accelerate the reaction process. And what we've got is a closed bomb. We have a very small amount of water in the bottom of the vessel. We have pieces of glass hanging from a support stand, and we perform the vapor hydration aging experiment for a certain amount of time to impart a certain amount of aging to the glass.

Then we immediately fill this up with liquid water to do the leaching test, and the conditions we use in these preliminary tests are MCC-1-type tests so that we can compare glass performance for aged glass with glass performance for fresh glass in the same type of test the waste producers use to characterize their glass. So it's an MCC-1-type test. We use groundwater. The temperature is 90 degrees C. The surface area to volume ratio was about 10 meters^{-1}, and to put that in perspective, that's about something the size of a dime in 40 milliliters of water. So it's a lot lower surface area to volume ratio than we'd expect in the repository, and the tests went on for 28 days.

Okay. Again, here's what the glasses looked like after we did the initial hydration process. The hydration was done in three ways: One, we hydrated the glass at 90 degrees for periods up to a half a year. You can't see that very well, but there's a very slight haze on the glass. Not very much has happened. At 150 degrees, now we're starting to form some secondary phases. You can see them on the surface and you can see that the glass is now becoming even more hazed.

That's a reaction layer forming. It's losing its black color, and then we did additional hydration aging experiments at 200 degrees. Now we see discrete secondary phases forming. We can identify what these phases are. We can pick them off the surface. We can determine what their radionuclide content is and we've done that, so we know where the radionuclides are going, and then you can see that the surface of the glass is now brown, and that is actually the reacted layer that has formed during the hydration aging process.

Okay, we then do the leach test, and here's what those same three pieces of glass look like after leaching for 28 days at 90 degrees C. You can see the top one--well, if you could see the top one, you would see that it doesn't really look very much different than it did before we did the leach test. The 150-degree aged one--now, all these tests are all leached at 90 degrees, but this glass was vapor-phased, aged at 150 degrees. You can see there's a slight cracking in the reacted layer and some of these secondary phases are being dissolved. But the real thing that happens is for the glass that has undergone the greatest degree of aging, the hydrated layer is now falling off the glass and the white secondary phases, which are calcium silicates, are beginning to actually dissolve.

What are the results and conclusions from this type of testing? And remember, these are just preliminary tests to see whether this is a process we want to look at in more detail. Looking at the actinide release patterns, we find if you compare the leaching from the vapor phase aged glass to that from fresh glass, that the americium and plutonium releases from the glass increase up to 2,000 times when you leach the aged glass compared to when you leach the fresh glass, and that's because, as I showed on the previous view graph, the layer is simply falling off the glass. It's undergone X number of years equivalent reaction. That layer is not adhering to the glass. It spalls off the glass when it's contacted by liquid water.

Perhaps the more important point, though, is that the actinide release under these scenarios is not solubility limited. It's limited by--or, in other words, dissolved in solution, but it's associated with particulate material which is suspended in solution. So now when you go to do performance assessment, you have to take a completely different process into account from how actinides are going to be transported away from the waste package. If we had continued the leach test for longer than 28 days, what would have happened is the hydrated layer would have spalled completely off the glass and instead of having a value of 2,000 up here, we would have had a value of about 4,000. But you can fix this number however you want to depending on how much you age the glass.

DR. LANGMUIR: What do you mean by associated particulates, John; adsorbed, co-precipitated, what? In what form are the radionuclides?

DR. BATES: Most of the actinides are associated with clay phases. The layer is a smectite-type clay. What happens is that smectite clay begins to disintegrate--not dissolve, but just break apart--and you get very--you get big particles, you get small particles, but it's particulate, and so the plutonium and americium are actually incorporated into the structure, or--I won't say that. They're associated with the clay. I don't know at this point in time whether they're incorporated in the clay structure, and are released that way.

Now, some of the plutonium and americium are actually in the secondary phases that you saw on the surface of the glass. Those that don't dissolve, presumably they're still associated with those secondary phases. Since they're more stable than the glass, what we've done is created a more stable waste form essentially, but we have to account for that in our performance assessment.

The second example I want to look at is static leaching tests combined with surface analytical studies. This is an example of testing done to measure radionuclide release and to provide mechanistic interpretation for Bill's model. The tests I'm describing here are very simple tests because the first type of thing you want to apply your model to is the most simple type of experimental results that you can get, so that's why we're starting off here. So the goal is to perform simple tests to measure reaction processes, measure radionuclide distributions, and the present tests addresses bounding conditions for the amount of water. Again, these tests essentially simulate a flooded borehole, a lot more water than we'd expect, and we're looking at the expected range of glass compositions.

The test is a simple batch test. It's an MCC-1 leaching test done at 90 degrees. The surface area to volume ratio in this case is about 30 inverse meters, but still an awful lot of water. Time here, it's been up to four years and these tests were done by Savannah River Laboratory. John described a little bit that they were doing site-relevant tests. We've done tests up to about a year and a half for these types of glasses. All these tests were terminated many, many years ago and we're looking at archive samples now to see how the glass reacted using newly-developed analytical techniques.

We're looking at two glass compositions, at least that I'll present here. One is 131 glass and one is 165 glass. This would be construed as a poorer glass and this would be construed as a better glass from the standpoint of how the glass reacts, how rapidly the glass reacts.

Okay. What we've done is a detailed analysis of the layer, and that's required to establish the reaction mechanism and the secondary phases that are forming during the reaction process. We're using analytical electron microscopy, which is a foundation of transmission electron microscopy, together with energy-disbursive spectroscopy, and electron defraction, scanning electron microscopy and secondary ion mass spectroscopy to look at the way the glass is reacting.

The first thing to look at when you do a leach test is what's leaching from the glass? That's the standard way of evaluating glass performance. What do you see with these two glasses? Well, we find that solution analyses indicate as I described earlier--go back to my original plot, that if you did a bathtub-type test, you're going to see things slowing down, well, that's what we see what happens. Even after four years, things are still slowing down, but does that tell the whole story?

Let's take a look at what we're observing for each one of these glasses. The 131 glass, and what we've got plotted here is normalized elemental release versus time, and you can see lithium, which is not incorporated in the secondary phases, is a measure as to how fast the glass is reacting, and it's reacting after four years of a normalized release on the order of 200 g/m^2. But uranium, which is an element that we're interested in, has a normalized release of only about 10 or 20 g/m^2.

We then look at the 165 glass, which is a much better glass from the standpoint of how the glass reacts. You can see the lithium value is now about 20 to 30. The uranium value really isn't very much different from that that we found in the 131 glass. So from the standpoint of can you judge how well a glass is going to perform in the repository with respect to actinide performance based on how lithium is released from a glass, well, what we find is the lithium is always released faster, but it's not really a true measure of what's happening to the actinides, and what we want to know is, indeed, what's happening to the actinides.

Let's see if we can't figure out now what is happening to the uranium in that glass. Again, I've got this so that you can actually see the micrographs. First of all, we've looked at the glass using an SEM. This is the 131 glass, and this is typically what we find in an SEM. Now, this layer is about 25 or 30 microns thick, and what you can tell from an SEM is yes, we've got a layer structure and it looks as though we've got things precipitating from solution out here. This is epoxy that we've mounted it in, we've cross-sectioned it. This is the glass, and here's the reacted layer structure.

We kept saying, yes, we've got things that look like they precipitated out of solution. Those would be phases that Bill would be interested in. And then we've got all kinds of interesting structures here that looks as though it can tell us something about how the glass is reacting, but from the SEM we don't have a clue. We can get the composition of these, but without knowing whether these are multi-phase or single phase or homogenous, the composition really doesn't do us any good.

So this is where the AEM comes into play. We've only been able to develop this so that we can apply it to glass really over the last year or so, and again, AEM includes lattice fringe imaging of the phases that are forming to identify them, micro diffraction, and nanoprobe composition, and that way we can actually go in and identify what those phases are.

So now if you look in detail at Layers 1, 2 and 3 that I identified over here, you'll see that we now get a very nice structure as to what those layers are. If we do high resolution lattice imaging, we can actually see that we do have crystalline phases here. We can identify these as manganese oxides. We can identify Layer 2 as a clay. You can't even see Layer 2 on the--from the SEM. We can identify an iron-rich stain covering the surface and to answer your question, Don, the iron-rich stain is not acting as a barrier to transport. You can see there are diffusion--well, I won't--not diffusion pathways, but transport pathways breaking through the iron layer in many places. You can't tell it at all from the SEM. From the SEM you would have been tempted to say, based on the solution results because things are slowing down, oh, the iron layer is going to form a protective barrier. You look at it in more detail and you'll find that, indeed, that's not at all the case. It's the affinity for reaction which is slowing down the process.

You then take a look in more detail at what these layers are and you can actually get a handle on how the reaction's occurring; for example, Layer 4, which is this bright layer running through here, actually contains two phases. One is a smectite-type clay and the other is a serpentine phase. This information has only been available to us for about the last year based on the results of AEM.

If you look now for the 131 glass again, what's happened to the uranium, again, you see the same type of layer structure as I showed you in the previous slide, and you better, because it's the same glass. But now if you look for what's happening to uranium, you can see that it's forming very small nanometer-size grains that are a uranium-titanium oxyhydroxide phase. We don't know what this phase is yet because it's not very, well, crystalline, but we know that's what's tying up the uranium. So as the glass reacts, the lithium comes out of the glass, but the uranium ties up with titanium, never makes it through the glass layer, and so with respect to uranium the reacted layer is acting as a protective barrier. It's tying up the uranium as a uranium-titanium phase.

DR. LANGMUIR: That's fascinating stuff from a scientific point of view. It may not be terribly important in the broad sense, but I'm intrigued that titanium oxide is one of the best adsorbents for uranium that's been measure by anybody, so that fits beautifully.

DR. BATES: Yeah, it does. Now, the 165 glass where the uranium was released as fast as it was in the 131 doesn't have any titanium in it. When we look at that glass structure--and I'll show you that in a minute--we didn't find any uranium-titanium phases.

DR. LANGMUIR: It would help to have a little TiO_2 around in these systems.

DR. BATES: Well, I think John is now putting TiO_2 in his glasses, but I don't think for that reason. But I think he's got some in there.

Let's take a look at the 165 glass, which was the good glass, and see what we can determine from AEM examination of it. Okay, here I've got 56, 91 and 280-day samples and we're looking at temporal trends in layer growth, trying to figure out how the glass is reacting.

Okay, at 56 days we see what is essentially a--well, it's close to a homogeneous, but it's certainly not crystalline--gel layer. If you compare this layer to 131 glass reacted at 40 degrees for four years, the layers look exactly the same. So you would say to yourself, based on your knowledge of 131 glass that I showed on the previous slide, oh, the 165 glass is going to react by the same process. We're going to get a layered structure. We know exactly what's happening. Wrong.

After 91 days, we were totally amazed when we looked at what was happening. We now get a precipitated phase forming on the outer surface, but what's amazing is we get the glass reacting from the layer inward, and at 280 days--if these were a little bit better, you could actually see it and for those of the Panel that want to see it afterwards, I've actually got the originals--this layer isn't attached to the glass at all, at least the way I've presented it here. It actually is in a few places, but if we continue this test for a longer period of time, it would spall off and so, again, the release of radionuclides which were associated with the layer would not be by dissolution, but would be by the release of this clay phase as it is spalled from the glass.

So using AEM, we can really back up the types of mechanisms that Bill and Kevin--I don't know who came first, but we're pretty sure that the mechanisms we're using in our modeling are the mechanisms that are actually occurring with the glass.

Let's take a look now with 165 glass as to what actually does happen to the transuranic, or to the actinide elements. We've used SIMS to profile what's happening. Now, this is the same glass that I showed you in the previous view graph, and just translate yourself a little bit. Here we've got the glass, and here we've got the layer. SIMS profiles the concentration of these elements throughout the layer, and what we find is uranium and neptunium are completely depleted in the layer. There isn't any titanium in this glass. We don't form the uranium-titanium phase. Uranium-titanium are leached and they're contained in solution.

Plutonium is constant throughout the layer. What that means to us is that it isn't leached from the layer, but as the layer etches, it can be released from the glass. Now, what actually happens to the plutonium is this is stainless steel and it goes straight to the stainless steel. It isn't in solution, but it's not on the glass.

In contrast, americium, which, if you look at the americium profile, as the glass etches, it wants to go into solution, but instead of going in stainless steel, it goes right back onto the glass. So if you were doing performance assessment, you would know that the americium was associated with the clay phases as they spall off of the glass. You'd know the plutonium was associated with the metal components of the test. You'd know the uranium and neptunium were dissolved in solution.

Okay. What would I say with respect to results and conclusions from these types of tests? Well, I would say the layer structure that we're getting from AEM really provides a mechanistic insight and phase identification that we need to support the modeling that Kevin and Bill described. We get a good distribution of radionuclides between solution and solid phases so we can account for that during performance assessment, and if we have long-term test results, they're required to increase the confidence level of all the results I've presented.

In other words, if you go back to the 280-day test that I showed previously, you can easily ask: Well, what happens after 280 days and this layer spalls off? Does it form again? What happens? Unfortunately, we don't have any tests longer than 280 days for this type of glass, so we can't answer that specific question.

Let's take a look for the last example, which is the drip test that we've done, and this is an example of site-relevant testing combined with radionuclide release and mechanistic interpretation. The goal here is to identify materials interactions that occur in the repository. Remember, the glass is not the only thing in there in the waste package, so we're looking as to whether these materials interactions can affect glass reaction and radionuclide release. They provide data for mature model development.

Now, remember that I said we did the simple leach tests so that Bill could apply his model to those first. He certainly wouldn't want to try applying his model to a test like this because, as Kevin described, it's quite a complicated test.

It addresses a potpourri of water/glass contact modes, all three of those modes that I addressed earlier on in my--one of my first view graphs; humid air, dripping water, standing water are in the test, and we're looking at metal/glass interactions.

The test looks something like this. Now, this isn't meant to simulate a waste package design. As Les described, we don't know what the waste package design is. What it is meant to simulate are the interactions that we expect to occur in the repository. I think we know enough about that now to do these types of tests.

What we do is we have a waste form that's encased with sensitized 304L stainless steel. The stainless steel's perforated, and we inject water through the top of the vessel, one drop every three and a half days, which is actually a lot faster than the expected rate in the repository, but when we started these tests about five years ago, that was the information we got from the hydrologists.

The water contacts the top surface of the glass, flows around the side surfaces of the glass, collects on the bottom surface here and then eventually drips into the bottom of the vessel. We can terminate this test after a year or two, analyze the glass, analyze the solution in the bottom of the vessel to get a mass balance between what's happening in the glass and what's happening in the solution, or we can continue this test by taking the waste package, putting it in another vessel, starting the test--or continuing the test and analyzing the solution in the bottom of the vessel, and so we get a continuous trend as to what's happening with respect to how the glass is reacting and how the radionuclides are being released.

From the standpoint of what are we finding, we've done these tests over a whole range of conditions, and essentially what we find is we've conducted these now for five years. They're still ongoing, but we see a range of reaction rates of about 40 fold. The fastest release is when we see spallation of a layer occurring. Okay, when we do this test on 165 glass, we do AEM examination of the glass surface, we find the exact same thing that was happening in the static leach test, except for now the layer is spalling off the glass.

We see an intermediate release--now, this is compared to our standard conditions of one drop every three and a half days with no sensitized stainless steel. If we sensitive the stainless steel, we see an increase of about twofold due to the fact that the stainless steel and the glass are interacting to form iron silicate phases, which accelerate the reaction of both the stainless steel and the glass.

We see the slowest release, about a twofold decrease, due to evaporation from the water off the glass surface. This is when we put one drop of water every 14 days on the glass. What it would prefer to do is to evaporate from the glass surface on the sides of the vessel walls, as opposing to dripping off the glass surface, and that's actually going to be what happens at the repository because the glass will always be hotter than the surrounding environment. You'll have an evaporative driving force away from the glass. And then what we find is the radionuclides sorb to the metal corrosion products.

Then in summary, going back to the four specific points I had as far as my purpose for doing the tests, yes, I think we've identified processes and mechanisms that do occur under repository-relevant conditions, and we find that AEM is particularly useful in determining mechanisms. We've only had that technique around for a year, so most of our data are really preliminary.

We've identified materials interactions, but we've got a lot of quantification still to go on. We've monitored radionuclide release and distribution and developed methodology to track radionuclides, but we have to apply this to a full range of testing and to a full range of glass compositions.

And then, to do model validation, we have to be able to perform long-term tests.

Now, to address the generic questions or the general questions that I said, do we have any idea what we're doing and do we have any idea how to do it, I would say once we recognize that the unsaturated conditions really do have a dramatic effect on the way glass reacts, we can now enable to go in and identify which variables are important to include in our modeling processes, and yes, we have been able to develop techniques that are very useful. So I would say yes, we are making progress, and I would think I can speak for all of the previous speakers, we are now anxious to go ahead and find out what the final results are going to be of our studies so far.

DR. VERINK: Does this suggest, then, that assuming perforation or moisture entry into a canister, that there is a greater likelihood of loss of radionuclides to the miosphere?

DR. BATES: Not at all. My tests simply demonstrated that in humid air, glass reacts. We then give that information over to Les and the people who are doing performance assessment and say, okay, either design a robust container or a robust engineered barrier system, or, as I was talking about the clay phases, what I would expect would happen would be they could plug up the container, and once they plugged up the container, nothing else could get out of the container. So I'm not going to address in my tests what's happening. I'm simply trying to identify things as to whether they're important or not, or processes as to whether they're important or not and then go ahead and, if they are, evaluate them further.

So, for example, in the hydration leach tests, one of the things we'd like to do would be what's the distribution of particulate material? Is it large? Is it small? Does it depend on how long the test's been done? Does it depend on the glass? Answer questions like that, which we really need to know.

DR. VERINK: Your comment about titanium and its effect on the response of the glass, does that suggest a handle for something that might be useful?

DR. BATES: Well, not really because I think the composition of the glass is pretty well set by the sludge and the processing factors that go into it, and one of the things we want to look at is are other transuranic elements, other than titanium--other than uranium--associated with these phases. Just because uranium is doesn't mean that americium and plutonium would be, and it turns out uranium really is one of the lower elements on the totem pole of importance from the standpoint of what's happening.

DR. PARRY: Might an alternative be to consider a titanium container?

DR. BATES: If uranium in solution reacted with a titanium container, yeah, perhaps; but, again, that goes back to Les's alternate design approach that he discussed this morning, and my point is in order to do reasonable alternate designs, you have to know what kind of processes are even going to be occurring. So, yeah, if somebody who had the expertise with uranium in solution in titanium containers came along and let's say it actually happened for americium and plutonium, they could say all the americium and plutonium is going to be tied up by a titanium container, then that might be an argument for a titanium container, yes.

DR. PARRY: Have these type of tests been done on spent fuel or container materials?

DR. BATES: I think you're going to hear about the spent fuel tests tomorrow.

DR. PARRY: Container materials?

DR. SHAW: 304L stainless steel has been tested.

DR. BATES: I had 304L stainless steel in my tests because that's what the DWPF is going to be using as their pour container. I don't have it in my tests because I think the Yucca Mountain Project is going to use that as the container. I don't know at this point in time what the container material is going to be, and it would be premature to use any one of their materials in my tests.

Hopefully, what we'll do is when we identify what that material is, go ahead and see how it behaves.

DR. LANGMUIR: John, in your drip test, did you have any information on the chemistries of the waters involved in the process?

DR. BATES: Oh, yes.

DR. LANGMUIR: At the end of the test.

DR. BATES: At the end of the tests, no. Unfortunately, the water at the end of the tests has been sitting in the stainless steel vessel for X amount of time, which does affect the chemistry. But, yes, we've been able to monitor that now over a period of five years.

DR. LANGMUIR: What's it like?

DR. BATES: It's depleted in alkaline earths because they're precipitating out on the surface of the glass as calcium silicates, magnesium silicates. It's got lithium, boron. It's got the alkalis in them because they are being released as the glass reacts. It doesn't have very much transuranic in it because those are essentially either sucked up by the glass reaction products or by the metals.

DR. LANGMUIR: What's the pH?

DR. BATES: The pH's are on the order of 5 to 6, and I think that has to be the effect of the metal, not the effect of the--we know that if we just measure the pH on the glass surface, it's going to be 10 or 11, so it's an effect of the metal.

DR. VERINK: Thank you.

I want to especially thank all the speakers and presenters today for their efforts on some fascinating work. I apologize, I seem to have lost my voice coming to California, but in any event, this concludes the activities for today and we'll reconvene tomorrow morning at eight o'clock for the next session.

I would like to remind the members of the Panel that we're going to have a closed meeting after this, the people have had a chance to get their things and it'll be a fairly short meeting.

So thanks very much. See you tomorrow.

(Whereupon, the meeting was recessed, to reconvene at 8 a.m. on August 29, 1990.)

I N D E X