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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
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P R O C E E D I N G S

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

1 10,000 years, and if the answer to that is yes, how will that
2 be done? If the answer is no, why not? A typical professor's
3 question, I guess you'd say.

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

7 Thirdly, how would the probability of attaining a
8 10,000-year waste package be influenced if the as-emplaced
9 heat generation rate of individual canisters was minimized?
10 And naturally, the accompanying documentation would be
11 required.

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

17 Well, now, those four questions are before us and I
18 think they bear strongly on the deliberations that we'll have
19 today and the things that the Panel will be working on in the
20 coming months. One item of considerable interest, and I think
21 importance, which has occurred in the interim is that NRC has
22 put out a position paper on long-lived waste packages which
23 provide considerably greater enlightenment and less chance for
24 misinterpretation of the requirement of 300 to a thousand-year
25 requirement as seeming to be restrictive on the amount of

1 credit that could be granted to a longer-lived package in
2 assessing ability to meet requirements. There is no
3 limitation as long as the proposed life can be qualified, and
4 anyone who hasn't seen that particular position paper, I'd be
5 glad to show them a copy.

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

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

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

19 This chart shows you the organization and who
20 reports to whom within our organization. I'd like to point
21 out that the project office, Carl Gertz is the manager. For
22 this project, the Engineering and Development Division has the
23 lead and Mike Cloninger is the Branch Chief responsible for
24 it, and working with him to resolve those issues are the
25 indicated organizations. It should be known there are other

1 divisions within the project office who have other
2 responsibilities, of course, but for this particular activity,
3 this is the way it looks.

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

15 This is an indication of the contractors and what
16 their responsibilities are. Waste package plan implementation
17 is the responsibility of the Lawrence Livermore National
18 Laboratory. Les Jardine is with us today, who is the TPO for
19 that organization and who will be presenting to you later.
20 Pacific Northwest Laboratories has responsibility for spent
21 fuel characterization and testing; Argonne National
22 Laboratory, the high level waste glass testing, and then
23 within the Office of Storage and Transportation, which is
24 another organization within the Office of Civilian Radioactive
25 Waste Management, there you have Pacific Northwest Laboratory,

1 who is looking at the reactor specific data base development
2 of spent fuel, and the Oak Ridge National Laboratory is
3 looking at high level waste characteristics and data base
4 development. And then, again, within the Waste Management
5 Projects Division there is the Hanford Waste Vitrification
6 Plant, West Valley Demonstration Project and Defense Waste
7 Processing, which are classification-type activities. There
8 are going to be representatives from most of the organizations
9 speaking to you at one time or another during these sessions.

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

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

24 A couple of things we need to bring to your
25 attention--disclaimers, whatever--as you well know, our

1 resources are governed by the Congress on an annual basis, and
2 so although we make plans to do things in years, next year and
3 the year after, we are subject, of course, to those
4 constraints and so any schedules or milestones that we might
5 talk about are constrained by whatever actions that are taken
6 in the budget area. And the activities important to safety
7 are performed in accordance with OCRWM and EM quality
8 assurance programs. That's the two major DOE organizations.

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

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

25 Now let's talk a little about the agenda, and it's

1 on five pages as you go through it and maybe I just won't go
2 through it all now, but suffice it to say that each one of
3 these is indicated in your information and we can follow those
4 along.

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

7 Any questions?

8 (No audible response.)

9 MR. MICHAEL CLONINGER: Thank you, Ted.

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

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

24 In the regulations from NRC, 10 CFR 60, part 2, the
25 Engineered Barrier System is defined as a regulatory boundary

1 in which we'll measure releases. It includes all the waste
2 packages, plus the underground facility. The underground
3 facility is the underground structure, including all of the
4 openings and backfill materials, but excluding shafts,
5 boreholes and their seals. Now, the focus of this briefing is
6 not on the underground facility, it's on the waste packages.

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

18 The area of interest and responsibility for the
19 waste package program does not stop at the engineered barrier
20 system boundary, however. There is a zone--normally 20
21 meters--around each waste package where the geochemical and
22 hydrologic characteristics of the geologic media itself will
23 be dramatically modified due to the heat and radiation from
24 the waste itself, and you see here a pictorial representation
25 of the waste package. This is about the floor of the drift

1 and there's a fairly large area where these properties are
2 dramatically modified, and that's what we call the near-field
3 environment or the service environment for that waste package,
4 in which it must perform the functions assigned to it.

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

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

22 The attainment of that goal is a program using an
23 iterative systems engineering approach that relies on a multi-
24 barrier approach as required by regulation--makes good sense--
25 the unsaturated nature of the Yucca Mountain site,

1 consideration of technical alternatives as well as design
2 alternatives and, most important, sufficient resolution of
3 technical and regulatory uncertainties.

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

18 The strategy itself is indicated in these five main
19 boxes here. Starting with the regulatory requirements and the
20 agreed to interpretation of terms between the Department and
21 the regulatory agencies, we begin a process of design basis
22 development where we develop design requirements, determine
23 what we need to do in terms of waste form characterization,
24 materials testing, environmental characteristics
25 determination, and scenario development, and these are the

1 scenarios that we would develop to analyze the waste package
2 performance against.

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

14 Well, the key regulatory requirements that drive the
15 waste package program are primarily limited to two. As part
16 of our licensing process, we need to show--through tests and
17 calculations for anticipated processes and events--which is a
18 regulatory term still subject to interpretation--substantially
19 complete containment within the waste packages. Dr. Verink
20 mentioned that earlier, that the NRC has said that the
21 required period for that is 300 to a thousand years, somewhere
22 in that range, but we're not limited to that thousand-year cap
23 for a containment function in order to demonstrate compliance
24 with other requirements. And after the end of the containment
25 period, controlled release of radionuclides from the

1 engineered barrier system. It's that somewhat imaginary
2 boundary that's defined by regulation.

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

17 The performance allocation and design development
18 steps go hand in hand. Once we have our regulatory
19 requirements well-defined, adjust the practical engineering
20 requirements that are needed in order to manufacture and
21 emplace the waste forms and packages, and the available
22 testing data base, we can identify design concepts, and it's
23 an ongoing process as well. And for each of those design
24 concepts, we need to select system elements, identify top
25 level functions for each waste package element. Containment

1 is one of those top level functions primarily assigned, of
2 course, to the container.

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

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

22 For the entire program--not just the waste package
23 program--the pre-closure performance assessment is fairly
24 well-established. The techniques have been used for decades
25 now, and primarily use real-time data and methods, just like

1 an automobile where you can predict, basically, how long an
2 engine will last, how long it will be before it needs a
3 rebuild, things like that. The post-closure performance
4 assessment, however, is the focus of the development in the
5 program and what drives that is the reliability paradox. The
6 reliability paradox basically says that the more reliable a
7 component or system, the less can be known about its failure
8 rates.

9 Well, we have some quite unprecedented time
10 extrapolations to do. They have never been addressed before
11 in engineering, or for engineered systems. We'll be having
12 time extrapolations in our performance assessments of 100 to
13 1,000 times the test period. What used to be considered a
14 very long-term test, ten years, is a very short-term test to
15 us when we have a system that we have to consider its
16 performance over a 10,000-year period. Therefore, that's led
17 us to seek a so-called "mechanistic" understanding of the
18 fundamental thermodynamic and kinetic processes at work in the
19 system, and apply that statistically to account for system
20 variation and uncertainty.

21 The efforts in the current waste package program are
22 focused heavily on performance assessment development, as well
23 as providing input to design basis development, but a lot of
24 the work you'll be hearing about this afternoon and tomorrow
25 are to provide the bases for performance assessment sub-

1 models, provide data for use in those models and/or provide
2 partial validation for those models.

3 The application of performance assessment,
4 ultimately, is to assess that performance, compare it against
5 the required performance, and if the predictions are that the
6 design meets the requirements, then we can proceed towards
7 licensing and make our case before the Nuclear Regulatory
8 Commission. If we feel that the design does not meet the
9 requirements, including the uncertainty requirements, then we
10 have to evaluate and select alternative actions. These kind
11 of increase in complexity, cost and time requirements as you
12 go down. I won't go into any great detail, but we could
13 simply assign additional performance to components that exist
14 but we haven't taken credit for. Perhaps our computational
15 model is too conservative. We need a more realistic model.
16 It's predicting disaster when a realistic model might predict
17 quite full compliance. Perform more tests, get a better
18 database, or now you're talking a more costly and time-
19 consuming process, change the design. Once we do this, we
20 have to do all of the above as well, so we want to do the
21 design right first. Or, failing all of that, if we feel that
22 we cannot meet a requirement, we may have to go back to the
23 regulatory agency and propose a change in the regulations. In
24 order to do that, we will have to show we've done all of this,
25 we don't feel we can demonstrate compliance. That's one. We

1 also have to show that the regulation is not necessary and is
2 over-restrictive, and propose a different regulation that
3 still provides sufficient provision for public health and
4 safety.

5 DR. DEERE: Question.

6 MR. CLONINGER: Yes.

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

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

17 DR. DEERE: Okay.

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

20 There are five primary technical areas that we'll
21 proceed somewhat in parallel through those design phases,
22 beginning with the pre-advanced conceptual design phase, which
23 is the phase we are in now. The engineering and systems
24 studies is more the classic engineering efforts that go on,
25 including the design function. The Board heard some

1 information from that last March in Denver regarding the
2 thermal impacts of the systems analysis that we're doing, both
3 from Sandia and Livermore. Performance assessment, which is
4 the subject of a future meeting--and waste package will be
5 included in that. Materials characterization and selections,
6 these are materials other than waste forms. We discussed
7 that, as well as the near-field environment characteristics in
8 the meeting last January here in this same hotel, and the
9 focus of this meeting, particularly this afternoon and
10 tomorrow, waste form characterization.

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

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

17 MR. CLONINGER: Yes.

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

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

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

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

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

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

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

21 MR. PETRIE: Yeah, and the answer is yes, it is. It's
22 the service-based testing and the underground testing are, at
23 this point, considered to be higher priority items than at
24 least parts of this program. We need to do sufficient of it
25 so we can assure ourselves that the site is suitable, but

1 there are other higher priority activities associated with
2 early determination of site suitability.

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

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

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

22 MR. CLONINGER: Last August I showed this slide, but the
23 performance assessment has a feedback loop throughout the
24 process and it is ongoing, to the best of our ability.
25 However, you have to have a pretty good idea of what your

1 design is. You have to have developed design-specific
2 performance models and then apply them, and that's a time-
3 consuming process, and we are working this year and next in
4 the program to develop a little better turn-the-crank-type
5 performance assessment models that can be used as design
6 input.

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

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

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

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

21 Yes, go ahead.

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

23 MR. CLONINGER: Go ahead; sure.

24 DR. JARDINE: To support what Mike has just said, the
25 plan emphasizes other than performance assessment, but in the

1 waste package plan which has now been issued, even before Box
2 4 up there in the pre-ACD, there's a paragraph that makes the
3 commitment that you're looking for and that reads as a
4 preliminary assessment of the performance of the various
5 concepts will be conducted using the existing container
6 materials characterization, near-field environment, waste form
7 characteristics information. The purpose of these assessments
8 is to assist in establishing a screening and prioritization of
9 the concepts. Other aspects of the design concepts will be
10 considered in the prioritization process, including
11 manufacturing and feasibility costs and operational
12 implementations.

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

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

25 DR. NORTH: Good. We're anxious to see those as soon as

1 you can share them with us.

2 MR. CLONINGER: Very good.

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

5 (No audible response.)

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

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

24 The purpose, really, today of the talk, I've got two
25 parts and I've broken it into giving an introduction to some

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

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

1 going to implement that.

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

17 Moving into the organization of the plan, there
18 basically are ten chapters to that document. The heart of the
19 document is Chapter 3, which is the technical plan, and I'm
20 going to cover that in more detail, but I'd like to make the
21 point that the organization and contents of the plan are
22 derived from the DOE Order 4700.1, which requires that, or
23 it's based on a major systems acquisition of the repository
24 system, MGDS, or mine geologic disposal system, and that's the
25 format that was used to determine these chapter numbers and

1 the content that went into these. So there's additional
2 guidance in this DOE Order as to what goes into a waste
3 package plan.

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

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

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

12 DR. DEERE: Okay.

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

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

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

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

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

9 I want to put this up one more time to make again
10 the point that this was presented at Denver, but the point I
11 like is that the near-field environment is a very large
12 fraction of the underground repository. Now, it's very
13 difficult to put a definition on what this boundary is in
14 terms of its length, width or height or volume, and if this
15 cartoon can be used to show the waste packages are emplaced in
16 drifts, and then when they go into the repository
17 configuration, there are different drifts and panels that go
18 along with the emplaced waste. The blue zones are intended to
19 represent perturbed environment due to the fact that the
20 emplaced waste has been put into the site, and I remind you
21 that depending on a process--let me give you an example of a
22 stress may only go out a few meters. Things such as thermal
23 fields, if you want to pick a certain temperature value, may
24 go out ten meters or more, and the same with the water
25 content. The sites vary with distance. These processes vary

1 with time because of the radioactive decay process and the
2 change of the heat source that's associated with that, and
3 that's really the points I wanted to make, and then Helen is
4 going to turn down the lights. I wanted to give another
5 perspective to this that has not been shown, and Michael
6 Cloninger is going to pass out Xerox for the Board, but this
7 is an artist--

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

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

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

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

1 boundary could be established.

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

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

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

24 In addition, when you look down this alley or this
25 mid-panel drift, you can see the next tunnel and the next one

1 at 121 feet spacings in this direction. Depending on your
2 process, there is an overlapping influence of these packages
3 on the ones in the next emplacement drift, or among each
4 other, and it also adds another perspective to the--at least
5 in my mind, of should there be a failure of some package at
6 some point in time, you know, this is a very important
7 environment or region to have some characterization of because
8 that will provide the source term, which is then fed into the
9 total system modeling releases.

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

19 And the point is--and it would be at two years it's
20 closer in. As it moves out in time, at ten years it may be
21 this, and it moves out and then it moves back and, because of
22 gravity and other effects that we told you about in
23 Pleasanton, this cartoon is not strictly correct, but it makes
24 the point that if this is one of the phenomena you're
25 interested in, this boundary of this boiling point isotherm

1 varies with time and depends a lot on what's in the packages
2 and the interactions that take place.

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

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

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

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

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

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

1 done, and it's a matter of getting the question established,
2 then we can provide the answer.

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

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

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

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

18 I think I might like to add the comment that in
19 Denver we pointed out that for engineering calculations, a lot
20 of the time thermal conduction models showed that they're
21 within about a 10 degree delta centigrade of what you predict
22 with these more detailed two-phase, multi-phase flow heat
23 transfer models of the single package. So for a lot of
24 engineering scoping calculations, a thermal conduction model
25 is sufficient to deal with large arrays. You have to

1 understand something about the single package, multiple heat
2 sources in order to be sure that you are, indeed, conservative
3 for your more simplifying, conservative engineering
4 calculation.

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

25 This is the diagram that Mike showed you, and the

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

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

20 DR. PRICE: What are the brown ones?

21 DR. JARDINE: There's a couple boxes that touches on
22 Warner's earlier question that deal--this one particularly
23 deals with performance assessment, and it was somewhat an
24 ability to put it in the diagram and not get too far out of
25 bounds to show that, indeed, there is some performance

1 assessment when concepts are done or what some people perceive
2 as engineering evaluations may also be performance
3 assessments. If there was room on a diagram, as I read into
4 the record awhile back, Box 4 would have a box down that would
5 be do a performance assessment as you're doing this, and some
6 of the difficulty we have is defining what is a performance
7 assessment, what is a design evaluation, an engineering
8 evaluation. So that would be a performance assessment.
9 That's why it's a slightly different character, and it's also
10 the logic for why Mike's diagram or mine had five lines on it.

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

22 This process of developing design concepts means to
23 me to get things down on paper, to get a sketch or a drawing
24 in order to have the ability for materials people to say, yes
25 or no, for that concept there are materials available or we

1 have some closure problems, and so once a concept is
2 developed, it's that point where material selection criteria
3 and the selection of candidate materials is done and feeds
4 back to, yes, that is a concept, a design concept that you
5 have a chance of implementing.

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

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

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

24 But as you go on in the design process, you know,
25 the first step here, pre-ACD, is intended to get an early

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

14 Again, you've done a lot of work and you're
15 narrowing down your options and getting more constrained. I
16 need to point out that in parallel with this, the underground
17 site characterization program is going on. The plan says that
18 we will make continuous updates of the near-field environment
19 as we understand it, incorporating new information about the
20 site and have this available to continuously feed back up into
21 either the materials people or the design process, and the
22 same is true with the waste form, and we do this continuously.
23 And these boxes, which I'm not going to go into detail with,
24 but the schedule is tied to having available surface based
25 drill core from the surface based testing program. Also, it's

1 tied with having access to the underground in order to have
2 either larger pieces of rock available for near-field
3 environment characterizations, and some in situ field test or
4 ESF-type testing. The time is compressed, but the plan makes
5 a recognition of that and it's an important point I wanted to
6 point out, that these activities are tied to the availability
7 and access to the site to give us more confidence that we
8 understand the near-field environment, and then removes,
9 hopefully, some of the uncertainty in the selection of
10 materials and how we will do our analyses to show that those
11 things will perform well.

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

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

23 Now, to put words to what is the scope and the
24 nature of the engineering and system studies, what those
25 activities consist of is to define both the design

1 requirements and the design concept selection factors; second,
2 to develop alternative design concepts, more than a single
3 concept; thirdly, to evaluate the concepts against the
4 requirements and the selection factors that you'll use to
5 judge how you're going to select among different alternative
6 design concepts in order to come up with acceptable design
7 solutions; and fourth, for the selected concepts that are
8 narrowed down in this process--and I'm going to cover that in
9 the talk after this one, that what we have in mind as to how
10 we are going to do that--we will then develop increased design
11 details and conduct additional engineering analyses,
12 performance assessments, and also, this gets us into the
13 prototyping where necessary and appropriate, and I guess I've
14 labeled that here. And then we will continue, you know, the
15 design system studies and design analyses in order to get to
16 the license application design. That's the objective of that.

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

23 DR. JARDINE: Well, what happens, I don't know if it
24 collapses, but one of the things that happens is that the
25 people--and I'll tell you later--we're going to make the

1 commitment to write down what we know about the near-field
2 environment. It makes the assumption in January of '92, not
3 '91, surface based core is available for our scientists to do,
4 let's say, the near-field fracture test through the hydrology.
5 We're assuming that there's enough time to do those tests in
6 order to have a reasonable update to this point, so I think if
7 there is a significant delay, one of the things that will
8 happen is that this activities of the near-field environment
9 will become, you know, we will have to ask ourselves, are we
10 able to work around it? Is there things that we can do, not
11 having site-specific rock or media? And that'll be difficult.
12 It's another question for the waste form characteristics.
13 Those materials are around and you still have the question, do
14 you understand the service environment which those are going
15 to be in? So, yes, you do get into a scheduling problem as we
16 go out.

17 DR. PRICE: So the blue line there is basically a pacer;
18 is that correct? And if you can't realize going from Box 2 to
19 10, completely, then certainly above that you're pretty
20 impacted in ability to go forward from that point, in fact.

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

23 (Laughter.)

24 DR. JARDINE: But, I mean, this is the heart of the
25 question and I can't really answer it, but it's, you know,

1 what's driving this thing and it's a debate in the program
2 and, fortunately, I feel right now we're behind this line and,
3 I mean, in the pre-ACD period, and there's a lot of things
4 that we can do to establish and put some order to this and
5 hopefully be in a better position downstream to--I would like
6 to come back at some time later and have an opportunity to
7 answer that question.

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

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

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

12 DR. PARRY: Before the light goes out again.

13 (Laughter.)

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

24 There are different waste types that we have to deal
25 with, and these only show to and, of course, there are other

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

11 But the point you can make is that once--the way you
12 would read this is that for each time period, say, if you want
13 to deal particularly with the pre-closure period, and for a
14 waste type, for each high-level waste type, you have to
15 specify in the waste package design requirements to the next
16 step of design these pieces of the concept that are applicable
17 to the specific waste package EBS concept, and for each--and
18 so for pre-closure period, for the high-level waste and for
19 that container that contains that, then you have to, for the
20 container, specify all of these different requirements. And
21 so it's a very hierarchy-type situation and it's very complex,
22 and there is an order to that and we're proposing some
23 concepts, or we're actually implementing them as to how we
24 think we're going to handle this, but it really starts with a
25 functional analysis and works our way through to where we

1 derive a design concept. And then when we get all done with
2 the process, we're going to document it in something that
3 we're calling a specific waste package design requirements
4 document, and that will be the document that is, for the
5 selected concepts, handed to the next step of design, after
6 ACD, and would allow a facility designer, someone more
7 traditional, to go forward with the design process.

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

1 criticality calculations because of this--

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

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

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

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

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

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

1 DR. PARRY: But it's not planned?

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

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

7 DR. JARDINE: What I was going to do, let me put this up,
8 Dr. Price, and I will cover that down here. What I wanted to
9 do was, I was limiting that to strictly the engineering and
10 system studies, and then what I wanted to do was go to this
11 box and say something about the materials characterization
12 selections in the waste package plan, then I'll cover your Box
13 2 in this line. That's the way we structured this talk.

14 So let me switch from the engineering system studies
15 down to the activities that the waste package plan outlines
16 and gives guidance to on the materials characterizations and
17 selections corresponding to the Boxes 6, 7, 9, 12, 16, 17 and
18 22 on the logic diagram.

19 Again, in the same format, the objectives of the
20 materials and characterization activities are to develop the
21 methodologies and the criteria in order to be able to select
22 materials that satisfy the design concepts that are proposed,
23 and then to select materials--and the fabrication processes as
24 applicable--for those components and concepts that are to
25 become part of the EBS waste package system; identify the most

1 likely modes of component degradations after emplacement--and
2 also during the pre-closure period, if that's applicable--to
3 develop models for the prediction of component lifetimes--and
4 again, I'm speaking about the combination waste package/EBS-
5 type system; to perform the necessary materials testing that's
6 required to support either the selection of materials or the
7 development of those, what I call failure-mode models, and
8 then also has the general charter, is all of these activities
9 are to develop more detailed process models and the data
10 that's required to support performance assessments, site
11 suitability determinations and other applications that are
12 associated with this large mine geologic disposal system
13 activity.

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

21 DR. JARDINE: Well, as we showed you in our Pleasanton
22 meeting, we are operating under that assumption, and we have,
23 since our January meeting, actually have laboratory testing
24 under the highest quality assurance levels ongoing. So what
25 we have is some materials testing activities that we feel

1 confident would match up as to when this report is to be
2 written, which is this fiscal year or this calendar year, that
3 we will show that we are within the bounds of what we would
4 expect the site conditions to be and, if not, then we will
5 have to make some adjustments to the ongoing materials testing
6 activities.

7 DR. PRICE: So once again, it does appear that the Route
8 2 and 10 there is very critical to the satisfactory and
9 complete completion of so many other things; is that not true?

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

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

23 MR. CLONINGER: Is it possible?

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

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

7 DR. PRICE: Present design concepts.

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

12 DR. PARRY: What if the site fails?

13 MR. PETRIE: You mean it's unsuitable?

14 DR. PARRY: Yes.

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

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

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

19 DR. JARDINE: Yeah. I hope you will see in the next
20 talks--not this one--we have set out a strategy--and we're
21 beginning to implement--as to how we can deal even with the
22 conditions of being wet, and I need to get to that talk to
23 maybe let you bring up your questions, and I think we will be
24 showing you some concepts that we expect to come out of the
25 process that if the site was suddenly unexpected--if

1 tremendously unexpected conditions in some fraction--not the
2 whole thing, some fraction--then there are some concepts that
3 could be available to put into those regions or areas of the
4 repository.

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

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

21 MR. CLONINGER: Yes.

22 DR. DEERE: That's the problem.

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

25 DR. LANGMUIR: I guess we'd like to see the engineered

1 part of the system more robust, so that it was less dependent
2 on anything that might be found down there. That's one
3 thought.

4 MR. CLONINGER: I hear you.

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

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

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

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

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

22 These reexaminations will include looking at the
23 current and different design concepts and the associated
24 different materials that go with those, and the underground
25 near-field environment as we establish it from our site

1 characterization program, or the lack thereof if we get into
2 that mode, but as I've tried to say, we have a lot to do
3 between now and the '92 time frame to get our ducks lined up;
4 and then to carry out the appropriate experimental test and
5 failure mode models.

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

17 So to try to summarize, the current basis of 1 to 3
18 centimeters is consistent with that it is thick enough that it
19 can be handled and emplaced. It doesn't have hydrostatic or
20 lithostatic loads to contend with. It's thick enough with
21 that. It's thick enough for the corrosion allowance--again,
22 assuming that it is warm and dry for a large fraction of the
23 time period that you need to worry about; that it was based on
24 reasonably available standard material, such as Schedule 40
25 plate or pipe; and that you could close this thing. And I

1 think as we told you at Denver in response to a question,
2 there was a constraint that the DWPF glass pour canister being
3 round and about two feet, had an influence on the dimensions
4 of the containers that we've been showing you, nominally two
5 feet to 28 inches, but not on the material, so that's really
6 the basis as we are, and we've told you that as we go through
7 the process, we're going to reexamine these things and be sure
8 that the reference case falls out as the number one preferred,
9 as selected by the process and DOE, or some other thing.

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

15 DR. JARDINE: Yeah, I need to get to my second talk and I
16 can take that question. In the hierarchy of requirements, we
17 show some non-technical factors--that is what we've labeled
18 them in the next talk--that can be used by the Department to
19 deal with those questions that you're asking, be it
20 programmatic, policy or public acceptance. But beyond--at a
21 certain level down in the requirements, they become technical,
22 and so I think the next talk recognizes this and has a
23 mechanism in place to sort those out, not how you're going to
24 make the decisions of what the balance is of how much effort
25 you want to spend in the wet conditions as opposed to the dry

1 conditions, but the process I'll show you in the next talk
2 makes that acknowledgement, and those are labeled--as you will
3 see--non-technical factors. There are three of them.
4 Basically, it deals with the wet/dry, the hot/cold, and the
5 300 to a thousand years versus an extended lifetime. Those
6 three things are labeled, in the next presentation, non-
7 technical factors, although technical thing comes in, but the
8 reasons for going one path or another is--may not be
9 technical.

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

23 Secondly, this will be developing the necessary
24 fluid flow and transport models that are based on a
25 mechanistic understanding of the phenomena of the near-field

1 environment and the geochemistry, including the radionuclides
2 that will be associated with any fluid movement, or should
3 there be a breach of a package downstream in time.

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

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

22 I wanted to take a minute on Box 2 on the logic
23 diagram, and the waste package plan makes this important
24 commitment that an initial report will be generated, and it
25 will be based on what is currently known about the site as all

1 of our scientists understand that site, and the kinds of
2 information that will be put into that will be the existing
3 knowledge about the different hydrology parameters, the
4 thermal parameters, or the geomechanic properties around the
5 package, and it also will take into account what we expect or
6 the effects the emplaced waste will have on the near-field
7 phenomena and properties of interest. We'll also identify
8 where there is gaps or where information is needed in order
9 to--as we go in and fill in this process. This would be what
10 is available to assume that the development of design concepts
11 has its surface environment documented and available, and also
12 that the materials testing people that are doing tests are
13 within the bounds of what we think is there today.

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

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

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

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

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

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

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

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

7 MR. NIEDZIELSKI: Phil Niedzielski-Eichner.

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

21 Secondly, to develop the predictive models for the
22 release of radionuclides from the waste package and EBS that
23 incorporate the appropriate effects of waste form degradations
24 in the service environment, the waste package component
25 interactions, you know, as you make waste package EBS systems

1 more complex, you get more components and you have to deal
2 with that, and also, the near-field environment interactions,
3 including radiation effects will be taken into account, or
4 that's really the charter of these set of activities, and to
5 assure that the appropriate data required by the models are
6 available in the programs that are carried out in the
7 laboratory. As appropriate, we'll validate the models and the
8 data using natural analogs, laboratory experiments and peer
9 reviews as, again, appropriate.

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

16 Now, again, Box 3 is this very first thing that's
17 important before you're developing design concepts, has the
18 same commitment as the near-field environment report, that an
19 initial report will be produced based on what we currently
20 know about the waste forms, be it glass or spent fuel. The
21 kinds of information and the structure that we're choosing for
22 this document involves information on waste form structural
23 information--in other words, the sizes, the weights, maybe the
24 composition of the unirradiated material, the kinds of things
25 that the engineering and systems people need, or perhaps some

1 people even doing more follow-on origin calculations of
2 radionuclide inventories.

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

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

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

24 This represents the distribution of the quantity of
25 tons of fuel that exist today in the inventory; in other

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

19 So there's a unique challenge here of dealing with,
20 this is what we've got today. We think, if everything goes
21 well, this is the projected inventory. Now, what kind of a
22 sampling plan, if you like, needs to be available to have in
23 place an approach so we know what our test matrix is and how
24 we're going to do tests? And I'd put this point on here
25 today, that a lot of the fuel you're going to be hearing about

1 today is done on either Robinson or Turkey Point fuel, which
2 falls in this bin of 30-35 megawatt days per ton.

3 You can ask yourself the question, you know, what is
4 the relevancy of that testing that's done on those particular
5 burnup specimens, given--looking at this diagram the way I do,
6 there is a lot of stuff in different burnups, and this--and
7 the associated things that go along with it, the decay, the
8 radionuclides, grain sizes change. This may have or may not
9 have effects on the release of radionuclides from the waste
10 package EBS system, and the waste package plan makes this
11 recognition and says that we will make the commitment to
12 establish a test plan, a plan of how we're going to deal with
13 the representative in this question of future projected
14 inventories, and how we're going to deal with that both in our
15 testing program, as well as in our approach to designing a
16 waste package. It's a difficult challenge, but it's something
17 that's very important to be aware of, and it has impacts, of
18 course, way beyond the waste package. I mean, it's of
19 tremendous importance, also, to the repository designers if
20 you're doing a simple shielding calculation and setting hot
21 cell wall thicknesses, you know. How do you deal with
22 administrative things versus pouring more concrete, or hard
23 engineering decisions that have to be made. So the plan is
24 going to deal with this and--not the plan, but the Box 3 is
25 also going to make an attempt--not an attempt--it's going to

1 address what we know about this and put in the existing
2 information and we have Oak Ridge, under our technical
3 direction, is contributing to giving us information that we
4 think will be in the right format that the waste package or
5 the engineering designers would need to know, out of their
6 database.

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

1 make a readjustment based on our access to the underground,
2 and move into the next more-detailed design, which as I'll
3 show you a few designs, maybe two to four concepts will be at
4 this point.

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

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

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

25 (Whereupon, a brief break was taken.)

1 DR. VERINK: Let's reconvene, please.

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

6 DR. VERINK: Fine.

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

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

20 So let me move into the very first part and make the
21 point that to establish the number and the kind of design
22 concepts for the EBS and waste package that will be carried
23 forward, we will use a systems engineering process. This
24 diagram I talked about earlier, and really, all I want to say
25 here is that the process I'm going to be describing will focus

1 on what's required to define the design requirements and the
2 design options, how those will be developed. So these are the
3 two parts of this thing that I'm going to be talking about,
4 and we can put this up for just a minute and say that the
5 process that I will be describing really involves the pre-ACD
6 and the activities that are considered in this portion of the
7 diagram; namely, starting with the definition of some
8 requirements, recognizing there's inputs on the environment at
9 which you have to do your job and the kinds of materials you
10 handle. That allows you to develop concepts, identify
11 requirements and verify or be sure that materials are, indeed,
12 available and in this--implicit, although not shown here but
13 will be done--are the nature of the design evaluations, trade
14 studies as appropriate, and performance assessments that are
15 required to be sure that the concept will work, which is the
16 objective.

17 Now, to begin the point that we will be using a
18 systems engineering process, this is a diagram that is taken
19 out of these two references here, and it's intended to say
20 that systems engineering has a lot of different definitions.
21 This is a textbook definition, and our mission now is to
22 convert this and apply it to the repository waste package/EBS
23 subsystem elements, and the point I'd like to make here with
24 this textbook example is that the very initial things you have
25 to do are come up with a set of input requirements that are

1 not overly constraining. This consists of some general
2 statements of what the objectives, mission objectives are, the
3 environment at which you have to perform that mission, and
4 what are the constraints and how are you going to make your
5 measurements of how well you have to do.

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

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

24 Now, let me begin to say how we're taking this
25 textbook example and beginning to tailor it, if you like, to

1 the repository or the mine geologic disposal system, and what
2 I've done is these letters here correspond to the same points
3 on the previous diagram.

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

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

25 This is the Box C here, these three activities in

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

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

24 You then move into this functional analysis, trade
25 studies and synthesis, and the term I'm going to introduce

1 today is a requirements hierarchy, which is an ability to
2 trace through the process requirements that are invoked, and
3 you can pick different pathways or combinations of
4 requirements through this in order to constrain and design
5 downstream. When you do this, what you end up producing is
6 drawings and specifications and performance as appropriate,
7 and, of course, you carry out the kinds of analyses you need
8 and have information that you need to support how you're going
9 to go through and rank and select among the alternatives. And
10 F is really--for the preferred option, there's a reference
11 pathway through this requirements hierarchy that leads you to
12 an ability to write a more specific set of requirements which
13 you pass to the next phase of design. And I hope I can show
14 you--and I'll be rather specific of what we're planning on
15 doing there, but this is another way to say the same thing;
16 the flow of the process that you go through, and the key part
17 is this ability of tracing the requirements when you invoke
18 them and showing that there are multiple choices, but we have
19 to capture those and document them.

20 So moving into the mission requirements thing, I
21 want to make a point that when you develop the waste package
22 mission requirements, Step A, there is a definite flow-down
23 and a hierarchy that starts with the Waste Policy Act itself,
24 which says geological disposal, among other things--and
25 perhaps it says concern yourself with Yucca Mountain right

1 now, if you get into the Amendments Act--and there's a mission
2 plan in these waste management systems requirement documents
3 which are hierarchy-type system documents in Volume 1 and 4.
4 Four is specific to the mined geologic disposal system, and
5 the systems requirement document, which is a project document
6 in Las Vegas. We have to extract out of that the necessary
7 constraints and requirements, and write Step 1 or Step A, the
8 waste package mission statement or requirements.

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

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

22 The requirements analysis can be viewed as a
23 hierarchy of things that you invoke and starts, of course,
24 with the Waste Policy Act and flows down. The requirements
25 can be classified as of two types. This first type are the

1 non-technical factors like we heard this morning from Dr.
2 Langmuir, which could be programmatic, policy, public
3 acceptance or other kinds of things. There are things that I
4 think I can show you are purely more technical, where the
5 engineers and the scientists can get involved and get down
6 into more of the nuts and bolts, but it's important to
7 recognize that there is a hierarchy, so that some things are
8 subject to detailed technical trade studies, and some have to
9 come from other sources, those kinds of decisions and
10 constraints, and those are what we are labeling non-technical
11 things for this talk.

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

1 to, how did you get to what you've got?

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

20 As you drop down to the thermal conditions, which is
21 another kind of thing, this is intended to represent for the
22 selection of a wet environment, is that constraint? I think
23 of them as constraints or additional requirements imposed on
24 the design process. Give me a design concept that is cold,
25 cold meaning--and we have to define that, and not intending,

1 again, the illustration only to define that, but it could be
2 taken to be below the boiling point of water as opposed to
3 warm, hot being above the boiling point of water. And then as
4 you work your way down this hierarchy, another thing is kind
5 of a general constraint, the containment period. How long is
6 it you're going to invoke as a requirement or a design
7 requirement on your designers? Is it going to be the 10,000-
8 year type lifetime--or containment period, I guess--excuse me
9 --is what we're using--as opposed to the 300 to a thousand-
10 year, and let me take you down this path because it represents
11 what is viewed as in the current site characterization
12 program.

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

19 This continues down in more detail--and I'll show
20 you in the next slide. Now, there are other pathways through
21 here, and again, we've intended this to show you three
22 potential combinations of requirements that could be invoked
23 from this process, and I prefer to think of these as more non-
24 technical factors. They may be things that are invoked, you
25 know, somebody going down this path--or let's take this path,

1 which maybe I didn't talk about, but if you went down the dry
2 path and you decided to, for different reasons, go to a
3 concept that would be colder than the normal current
4 referenced concept--and there a lot of reasons why that could
5 be, from MRS's to less kilowatts per can, to increased spacing
6 where the real estate of the repository is not that important,
7 and again, these are not all technical things, and then maybe
8 this process would invoke these as constraints in the upper
9 hierarchy and give it to the people down below as, do it that
10 way. And the choices can be made by others, by the Department
11 in a programmatic or policy sense as to how much effort to go
12 down these different pathways, and to build and have other
13 options and contingencies besides just the current SCP
14 approach. And that's really the thinking of the way that we
15 want to approach the waste package/EBS system.

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

1 system that come from the repository, or perhaps elsewhere,
2 that also can invoke constraints.

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

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

22 As you drop down in this tree--and I'll try to aim
23 down this one, which takes us down the SCP path--there's
24 another choice that if it is in a borehole, is that borehole
25 horizontal or vertical, and what is your technical basis for

1 making that selection? As you continue down in the hierarchy
2 --and in the SCP, a vertical borehole was assumed as the
3 reference case--is there or is there not packing material
4 around the waste package? And the way packing is defined in
5 this program, Dr. Verink, as you know, I guess the buffer
6 you're using when we talk sometimes, but packing means the
7 material outside of the container between the borehole wall.
8 But for the SCP and for the reference concept, no packing is
9 what was selected for the design concept.

10 And finally, as another level here, is there or is
11 there not filler material inside of the container? And let me
12 give you an example where you may put a material in that could
13 help you with the radiation effects in the outside
14 environment, such as, you know, I don't want to get into
15 materials, but you could put different materials in with high
16 density that could be viewed as a filler, among other things,
17 to reduce the shielding or either the near-field environment
18 effects or perhaps for operational safety aspects, and maybe
19 you can reduce wall thicknesses, and if you're into the self-
20 chilling concepts, which leads me over--I wanted to go down
21 this other path that is if you took a choice of a concept and
22 a constraint, give me a design concept with no borehole.
23 Don't constrain me to get into the borehole. What would that
24 package and EBS system look like? If it isn't in a borehole,
25 let's assume it's in a drift. I mean, it's not in a borehole

1 is what I'm trying to communicate. How do we lay out those
2 packages? Are they side-to-side, you know, kind of like a
3 bunch of pencils in a row; or are they end-to-end? Because,
4 nominally 15-foot length of packages means you could put them
5 kind of one after the other in the center of the drift for
6 spent fuel, and the reason is the nominal spacing is 15 feet
7 among spent fuel packages. But that's a choice that you have
8 to look at from operational considerations, retrievability
9 considerations, things that are much more broad than strictly
10 the waste package EBS.

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

18 This part of it deals with the kinds of things that
19 you have to fold in in the engineering and design sense, or
20 the kinds of considerations that you have to pay attention to
21 in order to make trade decisions about viable or workable
22 solutions; namely, thermal limits come into account, the
23 criticality considerations as you put more fissile material in
24 a package, and there's very serious and important handling and
25 emplacement considerations which you have to take into

1 account. You need to be able to get that in the ground, and
2 then depending on your mission requirements--and I think
3 retrievability is a very fundamental constraint--you need to
4 have that in mind as there's a trade-off between
5 retrievability and some of the concepts that you may want to
6 pick through this tree.

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

24 So there's a point to be made. As you work down
25 what I again have chosen to be the SCP thing, the designer has

1 an ability to pick--and should--how many assemblies really go
2 in the container, you know, what is really the shape of that
3 container, for instance, and then the question about the
4 length of the container. Is it really best to have a single
5 length for handling, or is two lengths an equal solution,
6 recognizing there's a significant but--to some people, might
7 be a significant difference in the length of PWR and BWR
8 elements. But for handling operations or other things, maybe
9 you want a single length, and so this is intended to represent
10 that there are multiple choices, and you may come out with
11 solutions that the designer may pick for a host of other
12 reasons--particularly these interface considerations--back
13 over to the surface facility designers and the subsurface
14 designers, and those portions of the whole system that have to
15 be brought in and constrain, in some cases, the choices that
16 are made, or support the choices that are made by the
17 designer.

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

1 let me take you to a concept that is a possible outcome for
2 one of the pathways of a self-shielded package.

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

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

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

24 Also, if you take a cross-section through here, this
25 is intended to represent if it was intact fuel--again, there

1 will be some of both. The ratio has to be determined and
2 planned for in the design. You have an option of putting some
3 filler materials within the package, and then the packing
4 material. So, again, these are illustrations of what we would
5 expect to come out of applying this process, and the reference
6 would also come out and we would have our traceability
7 available to us of how we got to the reference concept and
8 what, indeed, were the constraints and interfaces.

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

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

1 thousand?

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

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

1 underground, which may assist in the modeling of the EBS
2 system.

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

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

18 We've looked at some textbook examples, and we're
19 focusing in on the type that's been used in the aerospace
20 business, and we are applying it or bending it to our portion
21 of the mined geologic disposal system, and that requires that
22 we have the mission requirements stated up front, come up with
23 the methods or the criteria that we're going to use to select
24 and rank among these different possibilities, go into the
25 systematic functional analysis trade studies and synthesis,

1 paying attention, knowing that we have to maintain the
2 documentation and not drown in the documentation, but maintain
3 the ability to have the traceability for what are the
4 constraints and the choices we make so that we can--and we're
5 proposing to use these decision--not so much decision trees as
6 hierarchy trees, or I've seen them referred to as trade study
7 trees. These become note points that you can identify if a
8 trade study is suggested, in order to support your choice
9 downstream.

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

24 So in summary, this is a status of where we're at in
25 implementing this process, that we have implemented it; that

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

23 We recognize that's a significant area of how are we
24 going to pick among a self-shielded concept and a tunnel drift
25 versus a concept with a packing, or perhaps the current

1 reference concept. That methodology is something that is
2 going to be developed over the next year, and I'm sure we'll
3 have an opportunity to elicit your inputs on that, as well as
4 others.

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

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

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

20 DR. JARDINE: Our intent is to re-do the process and take
21 it down the path which would include the reference, and if
22 everything was, you know, when we repeat the process, if it
23 still comes out to be an acceptable solution, then out would
24 come the current reference design. So the intent is to run it
25 through, I think, rather quickly and not belabor it, but we

1 would intend to run the current--run a set of constraints up
2 that would lead you to the current reference concept, but we
3 may find in this process there's some choices that were made
4 that were introduced as outside constraints that are hard to
5 put in a hierarchy or a traceability.

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

11 DR. JARDINE: Right.

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

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

25 DR. DEERE: And when you come to decisions, wet or dry,

1 maybe you should have one alternative that says wet or dry.

2 You certainly would increase some confidence.

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

5 DR. VERINK: Both.

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

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

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

12 DR. PRICE: Robust, regardless.

13 DR. JARDINE: Okay.

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

24 MR. PETRIE: This is Ted Petrie. I'm not sure we can
25 answer your question today, is that will we come up with some

1 kind of a, with a concept which would be able to fit all of
2 those or not. I don't think we can answer that today. I
3 think you're suggesting should that be considered, and I would
4 say yes, they need to be considered. Is that fair, Les?

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

13 DR. DEERE: It also seems that a couple of places, or a
14 number of places you have shown 300 to 1,000 years versus
15 greater than 10,000 years. I think the NRC's statement that
16 came out a couple weeks ago, that we really didn't mean 300 to
17 1,000, within that range, if you want to take credit for more
18 than a thousand and not go to 10,000. You have the choice of
19 5,000 to 8,000, or 3,000 to 6,000. Do you think you can cut
20 it any closer than having to go to 10,000?

21 DR. JARDINE: Yeah, and just so we don't get this on the
22 record, but I think you did say at one point greater than
23 10,000, and you didn't mean that; greater than a thousand
24 years, correct?

25 DR. DEERE: Well, I forget if you said thousand or

1 greater than 10,000.

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

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

9 DR. JARDINE: Okay.

10 (Laughter.)

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

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

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

1 integrating with all elements of the program in that effort.

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

6 MR. CLONINGER: Those meetings are already ongoing.

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

11 MR. MCFARLAND: Could we request a schedule of those
12 meetings?

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

15 MR. MCFARLAND: I'll talk to Max.

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

24 MR. PETRIE: There is a project control organization
25 within the Department in Nevada, whose--one of their functions

1 is to provide a integrated logic. Does that--

2 MR. McFARLAND: They work for you?

3 MR. PETRIE: They work for Carl Gertz.

4 MR. McFARLAND: They work for Carl Gertz.

5 MR. PETRIE: Yes.

6 MR. McFARLAND: Thank you.

7 DR. JARDINE: Any other questions?

8 (No audible response.)

9 DR. JARDINE: Okay. Thank you.

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

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

23 An outline of my presentation. First, I'll just
24 briefly describe the obligations that the Office of Civilian
25 Radioactive Waste Management has in the waste acceptance

1 process, and a brief description of the process itself;
2 discuss the waste acceptance requirements that are being
3 developed from our waste disposal information needs
4 perspective for both spent fuel and high-level waste glass,
5 and then I'll give a brief discussion of the waste acceptance
6 preliminary specifications that are currently under
7 development for high-level waste glass.

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

24 For the high-level waste glass, there are other
25 agreements and they are within the Department of Energy and

1 include the State of New York and West Valley facility up
2 there in New York. These are for vitrified high-level wastes.
3 Acceptance dates are currently uncertain and the primary focus
4 of the program right now is in developing these waste
5 acceptance preliminary specifications--I'll refer to them as
6 the WAPS from here on--and the waste producers' response to
7 those specifications.

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

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

1 and dispose of these wastes.

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

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

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

1 needs.

2 Starting with spent fuel, our information needs lie
3 in two general areas: One I'll call characteristics, and
4 that's just basically everything you ever wanted to know about
5 spent nuclear fuel. It's inventory, distribution,
6 microstructure of the fuel, existing rod gas pressure, et
7 cetera, et cetera, et cetera for the entire population of fuel
8 that needs to be disposed of. Furthermore, there are what we
9 call in-repository performance data and models that need to be
10 developed, and those are primarily the oxidation, dissolution
11 and gaseous release behaviors of the fuel as emplaced over a
12 10,000-year period. The characteristics data we obtain from
13 others, and the performance data we develop ourselves within
14 the waste package program.

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

24 There are two basic requirements for a spent nuclear
25 fuel sample to be called an ATM, and that in order for our

1 test results, characterization data and models to be valid,
2 these ATM's that we receive and test must, one, be
3 representative of the entire spent fuel inventory that we'll
4 have to dispose of; and two, they have to have characteristics
5 that are representative of nominal or average spent fuel, as
6 well as bounding fuels. Les showed you a chart earlier that
7 showed the very large distribution in just burnup, one
8 category. In fact, that is one of the criteria for selecting
9 ATM's, which is the exposure in reactor and the distribution
10 thereof, where we'll need to select samples that are
11 representative of that entire distribution.

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

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

24 MR. CLONINGER: Oxidation, dissolution and gaseous
25 release behavior in the repository itself. It looks like

1 these at burnup and per cent fission gas release can be used
2 as criteria for selecting fuels that would be representative
3 of those characteristics across the entire spectrum of the
4 commercial spent fuels that we'll be disposing of.

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

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

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

21 MR. CLONINGER: No. There are models, actual models--in
22 fact, my next slide addresses that a bit--to predict, given
23 the fuel design and the reactor operating history, what
24 fission gas release during operation would have been. At our
25 temperatures that we'll receive the fuel at, store it at and

1 dispose it at, these are no longer volatile materials, but
2 they've moved from the fuel matrix to a large degree, and
3 collected in the gaps in the fuel along the grain boundaries,
4 and they're fairly accessible for dissolution release if
5 contacted by water.

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

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

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

22 You've seen this example before. Les presented it.
23 It's just typical of what the distributions would look like
24 for one of the selection criteria, burnup; the existing
25 inventory and the predicted inventory for one case, which is

1 the no new reactors and extended burnup, and that, coupled
2 with predictions again over the population of the distribution
3 of per cent fission gas release--and this is not based on any
4 real data, by the way, although it's probably a very typical
5 shape--would result in a combined histogram at some point--and
6 again, this is for illustration only, it's not based on any
7 real data--where we would have the distribution of burnups,
8 combined burnup and low or high fission gas release for the
9 entire population, and from that grouping we would make
10 selections of approved testing materials for the program,
11 which is the next step once we've completed the distribution
12 and representative effort.

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

22 Switching over to the high-level waste glass, again,
23 there are characteristics data that we need for design and
24 planning purposes, and pretty much the same as the spent
25 nuclear fuel; inventory, inventory distribution, and physical

1 and chemical properties, and in parallel to the spent fuel, we
2 need the in-repository performance data and model development
3 which we do in-house; again, dissolution, solubility behavior,
4 alteration in a non-saturated environment or a water vapor air
5 environment.

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

1 waste that we accept is "as agreed" up here in the
2 specifications.

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

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

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

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

18 DR. PARRY: Okay.

19 MR. CLONINGER: The waste acceptance preliminary
20 specifications are currently drafted for high-level waste
21 glass and will soon be issued to the waste producers, as well
22 as other program participants for a formal technical review.
23 These basically just delineate what technical information we
24 will require about the waste that's produced. I won't go into
25 any detail, but it just basically is similar to the

1 information we need about spent nuclear fuel, everything you
2 ever wanted to know about that product. A lot of these flow
3 out of 10 CFR 60, Part 135 specifications for design
4 consideration.

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

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

21 I'll be addressing just a couple of their questions.
22 The first one was: What does WAPS compliance say about
23 qualification for repository service? Not much. Compliance
24 with the WAPS tells OCRWM that what we're getting is real
25 glass, not foam or ceramic. The composition and geometry is

1 bounded; therefore, the product that we'll be receiving is
2 within our testing and modeling range and, furthermore, that
3 it does comply with 10 CFR 60.135. Qualification for a
4 specific repository site and repository EBS and waste package
5 design is yet another step for OCRWM to perform, not EM.
6 That'll be a part of the process once a repository site has
7 been selected.

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

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

1 doing their business.

2 Any questions?

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

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

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

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

25 MR. CLONINGER: I would say at this point, no, because

1 we're obligated to receive waste in 1998 and there will not be
2 a repository on that date. As far as if there were a
3 repository in operation at that date, we probably could,
4 depending on how much lag storage we wanted to build in to
5 optimize our emplacement underground.

6 MR. McFARLAND: How much--

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

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

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

18 MR. McFARLAND: Thank you.

19 DR. DEERE: That's called lag storage?

20 MR. CLONINGER: Lag storage.

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

25 DR. PARRY: Who imposed that limit?

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

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

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

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

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

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

23 MR. PETRIE: Yes, that's correct.

24 DR. PARRY: And yours is 750?

25 MR. PETRIE: Yes. That's the number--remember, I'm with

1 glass. I'm not positive of that number.

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

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

16 Are there any questions?

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

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

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

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

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

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

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

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

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

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

11 At that level, we were proposing approximately a 229
12 million dollar budget for program planning basis only. It
13 included both site characterization and moving forward on
14 repository and waste package design. Since that time, there
15 has been a lot of volatility in the approach to the budget and
16 what should be funded in this program, and more recently, the
17 Department, in discussions with OMB, has prepared budget
18 scenarios as low as 99 million dollars. That was prior to the
19 Gramm-Rudman reduction which we understand could be 35 per
20 cent. So right now, our current year for FY-90 we're spending
21 194 million dollars approximately. Under the best scenario,
22 we expect we may at the project level have 172, although it
23 could be below 100 million.

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

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

2 (Laughter.)

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

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

24 The fact is, today, under the current conditions, we
25 really don't. It would be misleading for us to give you that,

1 but we have a plethora of planning documents that we were
2 using not more than six to nine months ago that we thought
3 were adequate for moving the program forward, but they're not
4 now.

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

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

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

24 Les Jardine had a view graph, when he was talking
25 about alternative strategies, where he said a lot depends upon

1 the technical requirements, but even equally important are the
2 programmatic and the policy requirements. And, we need to all
3 bear in mind that there is a lot of policy encompassed in the
4 regulations, both NRC's and DOE's regulations.

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

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

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

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

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

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

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

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

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

6 Thank you.

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

10 (Whereupon, a lunch break was taken.)
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AFTERNOON SESSION

1 p.m.

1
2
3 DR. VERINK: Let's reconvene.

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

8 (Pause.)

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

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

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

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

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

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

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

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

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

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

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

15 Within the Department of Energy, the Secretary of
16 Energy has assigned the responsibility for the high-level
17 waste activities to Mr. Leo Duffy, who is Director of the
18 Office of Environmental Restoration and Waste Management, and
19 Mr. Duffy has assigned the overall responsibility for the
20 production of the canistered waste form to Jill Lytle, who is
21 the Director of the Office of Waste Operations, and in turn,
22 Jill has assigned the overall responsibility for the
23 satisfactory completion of all of the vitrification projects
24 down to Ken Chacey, who is the Branch Chief of the
25 Vitrification Projects Branch, and of course, underneath Ken

1 you would find the actual waste producer organizations who are
2 actually accomplishing the day-to-day work on the different
3 projects.

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

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

21 Our goal of each waste producer organization is that
22 our quality assurance program will help us to achieve a high
23 level of quality in all of our high-level waste activities.
24 We also want to operate in a way that complies with all
25 federal regulations and requirements. Also, we want to

1 protect the environment and the health and safety of all of
2 our DOE employees, DOE contractors, and the general public,
3 and we also want to operate in a way that instills confidence
4 in our ability to safely operate our plants and operate them
5 reliably.

6 Over the past several decades, DOE has conducted a
7 lot of research on the waste vitrification activities or waste
8 mobilization activities. This schematic here tries to show a
9 chronology of the waste glass development. Back in the
10 1950's, in that time period, the three countries that had a
11 nuclear capability at that time, started R&D work on
12 immobilization of the waste products at their different
13 locations, and the United Kingdom, I think, was the first
14 country that really started this work and they started their
15 effort working on the Fingal process. This was done at the
16 Harwell plant in England.

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

23 Then at approximately the 1965 time period, PNL
24 started working on the spray calciner and the in-can melter
25 technology, and after successfully proving that this concept

1 would work, that technology was transferred to other
2 countries, as you can see on this diagram.

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

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

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

25 England went from the Fingal process to the harvest

1 process, then in about the 1980 time period they actually
2 purchased the AVM process from France for adaptation at their
3 plant in Selafield.

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

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

23 The LFCM also has a longer unit life. The LFCM has
24 an expected life of approximately three years, whereas the
25 melter utilized in the French process has a life of anywhere

1 between a thousand to two thousand hours. So there's a lot
2 longer life period.

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

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

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

19 This is a time-line thing that tries to show how we
20 arrived at the selection of the borosilicate glass as the
21 waste form of choice. Back in the early 1950's, there were
22 early AEC studies where they utilized the clay-waste mixtures
23 to yield glass-like waste form, required a melting temperature
24 of approximately 1300 degrees Centigrade. Then in the 1960's,
25 after research by the U.S. and the British and the French, all

1 three countries zeroed in on the borosilicate glass, mainly
2 from the standpoint of its process ability, and its lower
3 melting temperature had many advantages.

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

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

1 was the best waste form for utilization in immobilizing the
2 waste.

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

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

20 Then in 1984, West Valley did another evaluation and
21 looked once again at the 17 different waste forms that are
22 available, and once again, the borosilicate glass was the
23 recommended choice. In 1987, the HWVP, through their EIS,
24 selected borosilicate glass as the referenced waste form.
25 Then in 1990, this year, the EPA issued their final rule

1 making on the land--I always get this fouled up--on the land
2 disposal restrictions in the Federal Register. Basically,
3 they indicated in the Federal Register that the vitrification
4 technology was the best demonstrated available technology and
5 that it is an acceptable form--I get this loused up, too--it
6 provides an effective immobilization of the RCRA hazardous
7 constituents.

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

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

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

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

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

20 DR. PARRY: With you?

21 MR. BROWN: I could give to--

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

24 MR. BROWN: Okay.

25 DR. PARRY: Thank you.

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

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

14 (Laughter.)

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

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

24 The second step in our process is a waste form
25 compliance plan which describes the processes, systems and

1 techniques that ensure that the waste acceptance spec
2 requirements are met.

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

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

11 Looking at the waste acceptance history, back in
12 1970, DWPF established an inter-site coordination group that
13 was working with ONWI, and also, they were working with RW--
14 I'm sorry--NRC at that point in time. The next step in the
15 process was the establishment in 1984 of a waste acceptance
16 committee, which superceded that coordination group.

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

24 The first draft of the waste acceptance preliminary
25 specifications for DWPF was released in December of 1986, and

1 the revised draft of that was issued in 1988. West Valley
2 received their WAPS in February, 1987. DWPF has issued their
3 waste form qualification report, or they started that process
4 with the technical review committee and that kick-off meeting
5 started back in May of 1989, and DWPF has issued their waste
6 compliance plan for review also by RW.

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

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

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

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

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

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

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

4 Now, once the EIS is completed on the single shield
5 tank waste at Hanford, we could have anywhere up to another
6 7600 canisters of waste from Hanford that would be going to
7 the repository.

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

16 This just shows the very summary schedule of the
17 three plants that I've been talking about here today. You can
18 see DWPF is scheduled to start hot operations in fiscal year
19 1992. They are going to start cold operations in this year.
20 West Valley will go hot in '94; whereas, HWVP will go hot in
21 December of 1999, and you can see with this sequential
22 approach that we've got here, HWVP is in a very good position
23 to be able to be utilizing lessons learned from DWPF and West
24 Valley for design and construction of the facility, plus all
25 of our waste qualification activity. And, by the way, this is

1 going on. We are relying heavily upon what's going on with
2 these other plants.

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

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

22 That concludes my presentation, so if there's no
23 questions I'd like to introduce John Plodinec from West
24 Valley. I'm sorry, I did that again. I think I did that one
25 other time, John; I'm sorry. But John is the manager and

1 senior advisory scientist in glass technology at Savannah
2 River. The manager is responsible for the DWPF waste
3 acceptance program, the glass composition development, and the
4 waste form testing there for the DWPF project.

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

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

17 As such things go, the DWPF is a fairly mature
18 project. I've been with the program since '75, and I'm fairly
19 mature. Glass was selected, as Bob talked to you about, in
20 1982 as the waste form for the DWPF for the reasons that you
21 see here. I think it's important to establish in your minds
22 the fact that the DWPF, the waste form producers in general
23 are not part of RW. This has its good side; it has its bad.
24 The primary objective of the waste form producer organizations
25 is to get the waste out of the form of a slurry and into a

1 solid form. By law, that solid form has to go to a
2 repository, so our interface is somewhat colored by the fact
3 that not only do we have to answer to the repository program,
4 but we, in fact, have other drivers upon us.

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

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

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

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

10 (Laughter.)

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

21 A very brief overview on the process. I wish it was
22 all as simple as this says it is, but basically we have some
23 34 million gallons high-level waste in our waste tanks. I
24 think the easiest way to think about the waste tanks for
25 purposes of today's discussion is that they're overgrown

1 beakers. They're on the order of about 1.3 million gallons,
2 and we do a lot of chemistry in these beakers to reduce the
3 volume of the waste and also to take the cesium out of the
4 soluble portions of the waste to reduce the volume of the
5 material that we have to solidify. That, in turn, of course,
6 then, reduces the volume of material that the repository
7 program has to accept and put into the ground.

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

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

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

1 1950's. Of course, the ones at Hanford go back even further
2 than that. The point I'm trying to make is that there's a
3 tremendous amount of variability in what's probably the most
4 important part of our glass product, the waste, and that we
5 have had to have that uppermost in our minds in terms of how
6 we're going to comply with the specifications.

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

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

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

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

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

21 Several parts to it, parts that I want to stress to
22 this group today are that because of the fact that a lot of
23 our design went on before there were even specifications, it's
24 been very important for us to qualify that technology that was
25 developed before there were specifications and show that, in

1 fact, we can meet specifications with that technology. We
2 also have several demonstration tests to demonstrate our
3 ability to control the product and, in fact, the entire
4 program in terms of its cost and schedule is driven by the
5 specification on radionuclide release.

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

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

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

1 DR. LANGMUIR: Is that an ambient temperature?

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

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

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

16 The MCC-1 test actually fixes everything except for
17 glass composition, so as a result, our job--quite simply put--
18 is that we have to control our composition in order to meet
19 the specification. Now, remember what I said before, though.
20 We have a somewhat difficult problem to deal with there in
21 that we don't have a single composition that we're trying to
22 qualify. Our life would be a lot simpler if we could handle
23 our problem the way West Valley will, and in addition, we have
24 an open system. So we're not quite sure what the waste may
25 look like or what the glass may look like in the future. So

1 it became very important for us to develop a yardstick that
2 would allow us to judge different compositions and determine
3 whether or not they were acceptable.

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

20 We then look at glasses, again, of very different
21 compositions on the MCC-1 test, and I've used as the response
22 here the release of silica. I could have shown release of
23 sodium or a host of other elements, but I used silica because
24 all the materials that we've tested have silica in them, and
25 you can see, I think, that there's a very strong correlation

1 over a very wide range of free energies of hydration between
2 this calculated parameter--calculated from the composition--
3 and the release on the MCC-1 test.

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

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

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

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

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

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

1 best--line of best fit to the data, this is actually your
2 95/95 criterion fit.

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

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

19 First, we're going to take material very similar to
20 what we start the melter up with and show that, yes, we can
21 control and we just make small changes in the feed to the
22 process. Then we'll make a large step change in the
23 properties of the material going to the melter in one
24 direction, and then going the opposite direction, and then,
25 finally, we'll come back towards the baseline, towards where

1 we expect to begin operation for the first batch of feed.

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

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

23 To give you some idea of what the sample of glass
24 looks like, it's--the best description I can give you is that
25 it's something like a Keebler snack cake. It weighs about 20

1 to 50 grams and it's beautiful black glass, or at least it
2 better be.

3 (Laughter.)

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

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

22 Both tests use deionized water, which is actually a
23 rather aggressive leach, at 90 degrees C. under static
24 conditions. However, the PCT uses grains, where the--as I
25 said, the MCC-1 uses monoliths. The PCT has a much higher

1 surface area to volume ratio, which means that it's much more
2 responsive to the glass than is the MCC-1 test. It requires
3 the use of a standard glass so that you can be sure that you
4 haven't screwed up the test, where the MCC-1 leaves that to
5 the user's judgment. It uses stainless steel vessels versus
6 the Teflon for the MCC-1 test. Teflon--or the MCC-1 does have
7 the option of using like Dicore vessels, I believe it is. We
8 like the stainless steel vessels because they are compatible
9 with the radioactive environment.

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

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

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

9 Yes, sir?

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

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

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

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

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

10 MR. PLODINEC: Yes.

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

13 MR. PLODINEC: That's correct.

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

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

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

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

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

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

15 What we have in the way of waste, compared with
16 Savannah River and Hanford, we have one tank. We've got
17 sludge with supernatant, so we've got peanut butter on the
18 bottom and some liquid on top of that. We're taking the
19 supernatant and putting it through zeolite ion exchange
20 capsules or cartridges to remove the cesium. Then we take
21 that water and make cement out of it. At this point in time,
22 we've made over 9,000 drums of cement. About five of them
23 have been found to be bad from the standpoint that we didn't
24 follow the process quite right, but we've looked at those
25 drums, those five drums, and their product is just fine. So

1 we're very happy with that kind of production, that kind of
2 productivity from this system. Those drums are temporarily
3 stored in a drum cell.

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

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

17 Basically, this is the same kind of flow sheet that
18 John and Bob have showed you earlier. Again, we've got about
19 15,000 gallons of thorex waste that we'll mix with the sludge,
20 supernatant and zeolite, mix it all together and homogenize
21 it. At this point it will be roughly 5 to 10 per cent solid.
22 It'll be piped into a concentrator feed make-up tank. It's
23 called a concentrator because we heat it up and we drive off a
24 little bit of the water, quite a bit of the water. We check
25 the composition here and we add glass formers, silica, boric

1 acid and other raw materials to make the glass composition
2 that we want to make.

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

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

16 (Laughter.)

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

25 Then there's a feed delivery system into the slurry

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

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

1 know that we're going to get operational variations if we pick
2 some target in the middle of it.

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

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

24 What this basically leads up to is our strategy for
25 meeting the radionuclide release spec. We've established a

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

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

19 How do we know this is going to work? We've done
20 quite a bit of durability testing. We've worked all along
21 with the Materials Characterization Center and with John down
22 at Savannah River on both the MCC-1 and PCT test. We're
23 prepared to do either, whichever way the specification finally
24 reads. We're also following the work that's being done on
25 glass modeling. You'll hear a little bit more about that this

1 afternoon from the folks at Livermore. We've also been doing
2 some of our own work, especially in empirical models, Ian Pegg
3 and Pete Macedo's laboratory at the Vitreous State Lab at
4 Catholic University, and we've also been doing experimental
5 confirmation of these models as we go along.

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

11 DR. LANGMUIR: Question.

12 DR. PALMER: Sure.

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

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

24 DR. LANGMUIR: So they are tied in?

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

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

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

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

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

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

1 again when we build the new one.

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

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

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

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

1 (No audible response.)

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

4 (Whereupon, a brief recess was taken.)

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

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

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

20 The purpose of the glass task in the Yucca Mountain
21 Project is to develop the data and models that are needed to
22 predict the behavior of the glass waste forms, the high-level
23 glass waste forms, in a repository at Yucca Mountain over the
24 period of regulatory concern, and we need this information in
25 order to use it in performance assessments to calculate the

1 release of radionuclides from breached glass waste containers
2 over time.

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

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

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

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

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

21 We then take those data, compare the model
22 predictions with other long-term site-relevant tests and
23 natural analogues, if we can find applicable natural
24 analogues, identify missing data or model deficiencies if
25 these predictions don't agree with what we actually observed,

1 go back to the beginning and re-think our models, reexamine or
2 conduct new site-relevant tests to see what we're missing, and
3 continue that process until you come to some closure.

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

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

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

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

11 The model of which I've been speaking is a kinetic
12 model for the degradation of the glass. It basically tells
13 you how fast elements are released from the glass, titrated
14 from the glass into a solution. Once the elements are into
15 solution, we use another code called EQ3/6, which you'll hear
16 more about this afternoon and again tomorrow when we talk
17 about fuel. EQ3/6 calculates or looks at the solution
18 composition and determines if mineral phases, solid phases are
19 super-saturated. If they're super-saturated, it precipitates
20 those phases, takes the elements that are present in solution
21 out of solution and sequesters them in those phases,
22 recalculates the solution composition and goes back and this
23 rate model, this kinetic model is a function of the solution
24 composition, as well as other variables like temperature.
25 Using this modified solution composition, you then calculate

1 the next increment of dissolution of the glass and you go
2 through this until you run out of glass or you go on as long
3 as you wish to in time.

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

13 I mentioned we're doing model-specific experiments.
14 The second talk following mine will be given by Kevin Knauss.
15 He'll talk in detail on these experiments, the types of
16 experiments we've been conducting. The purpose of these
17 experiments is to determine, really, not what the parameters
18 are, but the numerical values of key parameters that are
19 needed by the mathematical models. These tests are not
20 repository simulations by any means. They're designed to
21 isolate specific processes so they can be studied in the
22 absence of other parallel effects or other compounding effects
23 that go on at the same time. For instance, you might want to
24 look at the dissolution rate of a glass as a function of pH,
25 so you have to design the experiment that will control the

1 temperature, the solution chemistry and the pH as the glass
2 continues to dissolve because the process of dissolving the
3 glass will affect the pH. So you must design an experiment
4 that is controlled by the solution rather than by the glass.

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

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

19 These experiments are not adequate as a basis for
20 long-term predictions. In most cases, or in many cases,
21 they're simply too complicated to interpret simply. There are
22 too many processes going on at the same time. What we do use
23 these experiments for are to provide simulations of the
24 relevant processes and, as I said, provide the phenomenology
25 of the glass alteration process; what secondary phases form,

1 how much of them, what are their compositions, what are the
2 compositions and textures of the alteration layers that form
3 on the glass, what sorts of interactions occur between, for
4 instance, the stainless steel pour canister and the glass,
5 chemical interactions, and these do provide an overall release
6 rate of elements to solution when you take into account all
7 these different processes occurring at the same time.

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

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

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

19 DR. SHAW: Go ahead.

20 DR. LANGMUIR: Ron Palmer pointed out that his concerns
21 in terms of formulating glasses for processing glasses was
22 that they be durable, that they have certain operational
23 properties that are useful to him. Can you feed back--let's
24 say you find a glass, or the following speakers discuss
25 glasses that appear to be more soluble, more degradable than

1 they might wish, is there any way to feed back that
2 information into the processing and manufacture of the
3 glasses, or are you--or is the glass that comes from the plant
4 a given? Do you have any kind of feedback that can allow you
5 to suggest different formulations of glass?

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

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

24 DR. LANGMUIR: So you don't expect to come back with
25 suggestions as to how to optimize performance at all from the

1 chemical tests that are done on the leachability, for example?
2 You're just going to have some information that allows you to
3 predict what it would be?

4 DR. SHAW: Right. That's correct.

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

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

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

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

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

24 In order to do this, we need data to support the
25 model from simple experiments designed to isolate individual

1 glass dissolution mechanisms. Once we have figured out what's
2 happening as glass dissolves, we need to go and do some simple
3 experiments to quantify each of these mechanisms, and by doing
4 that, we're in a position that we can take this variety of
5 mechanisms and figure out what is controlling the rate in the
6 long-term of glass dissolution.

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

12 Getting kind of specific now with things, glass
13 compositions, what is a typical radioactive waste glass? Here
14 I've got the composition in cation mole per cent of Savannah
15 River Lab-165 glass, and if you're familiar with geology, the
16 composition of this glass is a lot like a basalt. It's
17 silica content, aluminum and iron contents are pretty close to
18 that of basalt, but of course, it's full of boron and a lot of
19 alkalies as compared to basalt. But what we find is that
20 natural basalted glasses and many of the waste glasses
21 dissolve at about the same rate. So this is one of the
22 glasses I'm going to show you results of tests from. We also
23 have here a simple glass. In some of the tests we've made up
24 an analogue of SRL-165 glass that's simpler in composition,
25 makes it easy to interpret the test results, and also, does

1 not have any redox sensitive species in it, so we don't have
2 to control the redox data to excess. This is a glass we've
3 used in some tests to get some fundamental parameters that at
4 some point in the experimental program we'll go back and do
5 those tests with SRL-165.

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

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

24 So in this diagram, fresh glass is essentially, as
25 the reaction proceeds, forms these alteration layers and they

1 can be sort of divided up into two zones based on ion probe or
2 sends profiles through the glass. We have a diffusion layer
3 where there are a concentration of gradients in such elements
4 as calcium, sodium and hydrogen. You can see from hydrogen
5 that this is water diffusing into the glass. This is sodium
6 diffusing out, and this is an enrichment of calcium relative
7 to the insoluble component in the gel layer.

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

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

20 So with that in mind, the kinetic model that we
21 incorporated in EQ3/6 takes account of these observations. To
22 give some of the assumptions in the model, as the glass starts
23 to dissolve--though it doesn't show up on this view graph at
24 all, this is the two layers, the diffusion and gel layer
25 forming on the glass surface. As this process happens,

1 basically you have two coupled competing processes. You have
2 what they call etching, or simply a dissolution of the glass
3 surface layer at the surface of the gel layer, where the SiO
4 and boron oxygen and iron oxygen bonds are broken down. These
5 components are released in solution. And you also have,
6 further into the glass layer, the alteration layers, the zone
7 where the alkalis are diffusing out of the glass.

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

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

1 layer and this dissolution affinity as the overall control of
2 the reaction rate, the dissolution of the glass.

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

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

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

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

9 DR. LANGMUIR: What's the pH?

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

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

1 material, aside from fresh glass, is. It's in the secondary
2 phases.

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

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

16 Also, to confirm one other assumption that we made
17 in the modeling, which is that you have a steady state
18 condition where these alteration layers achieve some thickness
19 and maintain approximately constant thickness with time.
20 These are results from some tests John Bates performed where
21 we look at the thickness in microns of these alteration layers
22 versus time. Again, it's a test on SRL-165 glass at 90
23 degrees C, this time in EJ-13 water, which is a water that's
24 been reactive with the tuff for about a month at 90 degrees C.
25 You can see that the total amount of glass that's been

1 dissolved is relatively large compared with the thicknesses of
2 the diffusion and gel layers. This is based on Simms analysis
3 of the alteration layers, so that essentially much of the
4 glass has been dissolved. These residual layers are about,
5 you know, developed in the first couple weeks and then
6 maintain an approximately constant thickness after that. So
7 we can confirm a couple other assumptions that we have in the
8 model.

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

1 incorporated in our current kinetic model, is to allow the
2 secondary phases to precipitate and control those
3 concentrations of elements.

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

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

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

1 DR. LANGMUIR: Bill?

2 DR. BOURCIER: Yes.

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

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

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

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

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

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

14 A rate constant, which is a function of pH, and this
15 is the topic of the next talk, essentially how you get that
16 rate constant as a function of pH independently of everything
17 else going on during glass dissolution, and then what's called
18 the affinity term, and this has to do with as components build
19 up in solution, the rate of dissolution slows down because the
20 affinity term becomes closer--gets smaller and smaller. The
21 affinity term is, in fact, the concentration quotient of
22 activities of ions in solution for the dissolution reaction
23 of, in this case, the gel layer, divided by the thermodynamic
24 equilibrium constant. So as species build up in solution,
25 this value gets bigger and bigger and this term gets closer

1 and closer to zero, where at equilibrium, this term would be
2 zero and the rate of dissolution would stop. We don't see
3 that in glass dissolution because glass is intrinsically
4 unstable, so you never approach where that term becomes zero.
5 But, obviously, it's very critical to know how that term
6 varies with time in order to calculate how fast the glass is
7 being dissolved over long time periods.

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

19 So when we apply this to glass dissolution, in the
20 simulations that you'll see in a second, what I include is the
21 glass and fluid composition and the rate constant for
22 dissolution. What the code then generates is essentially the
23 glass dissolution rate, the concentrations of components in
24 solutions as a function of time, which you also measure in the
25 tests and compare with, and the types and amounts of secondary

1 phases so that you have a way--you make these predictions and
2 you go back to your experiment and see how close you are, how
3 far off you are in a particular model and do what you need to
4 do to be able to fit as wide a variety in as many, as most
5 accurately as possible for the experimental results.

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

14 Also, we look at essentially the driving force of
15 the reaction, the affinity for gel dissolution, which we're
16 assuming is the rate controlling mechanism here. It starts
17 out very high when solution is very sparse and the
18 concentrations of all the components in the gel. As the glass
19 dissolves, things build up in solution. The affinity gets
20 smaller and smaller and at some point it approximately levels
21 out. So as things build up in solution, it slows the rate of
22 reaction and it's very critical, of course, to know how low it
23 gets and, more importantly, what happens as you go longer and
24 longer in time periods. What controls the concentrations of
25 components in solution? Because that, in fact, controls the

1 overall rate of lasting solutions, so it's really critical to
2 know, especially what secondary phase is precipitated, because
3 secondary phases are going to control what's in solution.
4 What precipitates out of secondary phases will be removed from
5 solution. What builds up in solution and doesn't precipitate
6 won't, and it's the balance between glass dissolving and
7 secondary phases forming that ultimately tells you what the
8 affinity is.

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

16 I'll have to add that these simulations were done by
17 using the rate constant as a fitting parameter, so the
18 equation you saw a couple view graphs ago, we have assumed
19 that that rate constant has dependence on pH or something we
20 used to best fit experimental data. What we're doing now, or
21 have recently done--and Kevin will report on the next talk--is
22 some tests to determine the rate constant independently, the
23 rate constant and its pH dependence so we can plug back in and
24 that way apply this model without the use of fitting
25 parameters. And, as Kevin will show you, the rate constant we

1 got by regressing this data and the one he measured
2 independently in flow-through tests are very close, so we're
3 very happy with those results. It lends credibility to the
4 approach.

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

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

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

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

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

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

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

24 DR. BOURCIER: Try to minimize them? I haven't thought
25 about that. So far we've done isothermal experiments in

1 modeling, and I mean, conceivably, you can put in a function
2 to give the temperature variation of the reaction path. You
3 can do that in EQ6 now, but that's something we need to
4 address at a later point.

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

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

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

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

1 I think it's there.

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

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

22 Okay. In summary, then, we've incorporated this
23 network hydrolysis model, EQ3/6, and shown that we can predict
24 model results in closed system tests. We have started up
25 experiments to isolate and quantify glass dissolution.

1 processes, and we need those for further model development.
2 Right at this point we really need to do a whole batch of
3 these tests to do the sort of the next phase of geochemical
4 modeling of this process, and then improvements are needed in
5 order to better account for the dependence of the dissolution
6 rate on glass composition and glass surface chemistry, two of
7 the things that we really haven't addressed yet in the
8 modeling.

9 That's it for me. Questions?

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

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

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

24 Kevin?

25 DR. KNAUSS: As Bill mentioned, I'm going to be

1 describing some simple experiments that we've been doing to
2 try and assist in the model development effort that Bill was
3 just talking about, and to provide some of the parameters that
4 are required to use Bill's model.

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

18 I'm going to be proceeding in this talk in the
19 following way: What I'd like to do is start out by describing
20 very simply the experimental design that we've come up with
21 for a number of experiments to provide information useful in
22 developing models and in providing the parameters that are
23 needed to use those models, and then I'd like to just step
24 back and very quickly describe why it is that we might need to
25 do experimental work at all; I mean, there is a very large

1 body of data that's been generated in the nuclear waste
2 industry and other industries concerning glass dissolution.

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

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

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

21 During Bill's presentation, he described a rate
22 equation that's been incorporated in the reaction progress
23 model, EQ3/6, and in that equation there are a number of
24 parameters that have to be measured, and these include the
25 rate constant, this pH dependency, and then, of course, we

1 have to account for the chemical affinity for dissolution as
2 the reaction proceeds.

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

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

1 the pH in these experiments.

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

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

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

23 If I can just back up for a second, I'd like to try
24 and justify why it is we felt we had to do some experiments
25 using a simple glass as opposed to trying to back out

1 fundamental information about glass dissolutions from the
2 enormous amount of data that's available in the nuclear waste
3 literature.

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

19 In site-specific types of experiments, you not only
20 have the problems I just described, but they are further
21 compounded by the presence of other repository-type materials
22 such as canister materials, rock, and so on. In experiments
23 like that, site-specific experiments, the solution
24 compositions then that one observes are a complicated sum of a
25 number of processes that are taking place, and it's very

1 difficult to unravel the input from just dissolution, for
2 example, if what you're trying to do is develop a glass
3 dissolution model.

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

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

24 I thought I'd also just mention very quickly the
25 types of equipment we're using because they're not MCC-type of

1 tests. The closed-system test that Bill talked about with
2 SRL-165 was done in what's called a Dickson-type autoclave,
3 which contains a flexible gold bag from which you can extract
4 the fluid and quench it through room temperature and pressure
5 conditions in the absence of a solid, and this prevents a lot
6 of the problems that were described by Means and Spinoza, for
7 example, in MCC-type tests at any significant temperature.
8 The reaction, of course, can be sampled as reaction proceeds.
9 You can take multiple samples from a vessel of this type.

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

1 Now, what we've done are a number of experiments,
2 essentially at unit pH interval and at three temperatures, 25,
3 50 and 70 degrees C, where we've reacted this simple glass
4 with the buffer solutions that I described earlier, and I'm
5 going to just show two typical plots which really describe two
6 general types of behavior that we see in experiments of this
7 nature.

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

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

24 The other thing that one can see using a normalized
25 plot like this is when, in fact, one is forming a gel layer on

1 the surface of the glass. If, in fact, all the elements are
2 released in their stoichiometric proportions, all those lines
3 are coincident and, in fact, they are in this particular case
4 for all the glass components with the exception of silica, so
5 obviously, an experiment like this, we're developing a gel
6 layer through the entire run.

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

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

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

19 The other type of behavior we see at all the
20 temperatures in mildly alkaline and strongly alkaline solution
21 is typified by this particular dissolution rate plot, and in
22 this case, we have essentially congruent dissolution; that is,
23 a stoichiometric release of all the glass components right
24 from day one. In this type of an apparatus, we're taking a
25 cumulative sample so we can account for the total mass of all

1 the glass components that are released throughout the run, and
2 so our first sample point is after 24 hours, and whatever
3 signal would have been generated in the fluid from the gel
4 formation has obviously just been swamped out by the
5 stoichiometric release that occurs once the gel and diffusion
6 layer that Bill described has achieved some constant
7 thicknesses and is now just progressing into the glass at the
8 rate at which the gel itself is dissolving; that is, at the
9 rate at which network hydrolysis is taking place.

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

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

21 The data at pH 1, you might notice, don't tend to
22 progress along the same trends as the other acid experiments,
23 and the reason for that is that in calculating these rates,
24 I'm assuming a constant surface area, and that is the surface
25 area that I measured at the start of the run. The rate of

1 dissolution is so high at pH 1 that, in fact, significant
2 amounts of the glasses have dissolved in each of these
3 experiments at all three temperatures, so that rate is not
4 legitimate.

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

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

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

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

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

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

1 contained aluminum and silica at more neutral pH's.

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

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

23 And then you have network hydrolysis, which is the
24 final breaking of those silicon oxygen bonds, and then the
25 release of silica and other gel components to the fluid, and

1 it's that network hydrolysis which we're keying on as a rate
2 controlling process, and the rate equation that we're using
3 has a form that's very similar to the one that's used in
4 mineral dissolution kinetics where, in fact, mineral
5 dissolution appears to be a surface reaction control-type of
6 process, and you see evidence for that in things like
7 localized corrosion at etch pits, for example. These happen
8 to be aligned more or less along conchoidal fractures that are
9 created when the glass grains were crushed.

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

22 Now, if you recall, Bill described a fitting
23 exercise in which he took an experiment in which he had
24 dissolved SRL-165 glass in a dilute sodium bicarbonate
25 solution at 150 degrees C. And in that fitting exercise, he

1 was trying to calculate by fitting a rate constant using the
2 rate equation that's been coded into EQ3/6, and he also in
3 that exercise was assuming that there was no pH dependency or,
4 in effect, another way to look at it is to say that he rolled
5 up any pH dependency into the rate constant that he was going
6 to calculate by that fitting process.

7 When he did that, Bill showed the data and the
8 curves that were generated in that fitting exercise, and I
9 don't think he mentioned the rate constant that he calculated,
10 which was about 6×10^{-9} g/cm² second for that glass at that
11 temperature at that pH.

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

1 similar to rates measured using natural basalts.

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

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

23 The glass dissolution process that we're trying to
24 model, again, in alkaline solutions, seems pretty clearly to
25 be a surface reaction-controlled process based on a number of

1 lines of evidence. The activation energies are quite high,
2 similar to those for mineral dissolution, for example. We see
3 release rates that are linear with time, which is something
4 that one would not see in a diffusionally-controlled
5 dissolution process, and we even see--in cases of extreme
6 dissolution, we even see the formation of etch pits,
7 demonstrating a surface reaction.

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

17 In terms of the model-supporting experiments that
18 we're doing, we're in the process of doing two experiments now
19 that are designed to investigate this chemical affinity
20 effect, and I described these very briefly earlier. We're
21 doing dissolution kinetics experiments using the flowing cells
22 in which we intentionally have added known amounts of the
23 glass components, and we're making those dissolution
24 measurements at a number of pH's and at a number of
25 temperatures. And we're also doing closed-system experiments,

1 similar to those that Bill described for SRL-165, using the
2 simple glass under basically the same sort of conditions that
3 Bill had used earlier.

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

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

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

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

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

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

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

24 (Laughter.)

25 DR. BATES: You've heard about the waste producers

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

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

24 Now, in a general sense, the purpose of the tests, I
25 think, were pretty well put by the National Research Council

1 in their recent report where they identified structural
2 uncertainty and parametric uncertainty. Structural
3 uncertainty answers the question of do we understand the
4 system well enough to model it? Parametric uncertainty is:
5 Have we chosen the right variables to describe the system, and
6 do we have the correct measurement techniques? Or to
7 paraphrase that, do we have any idea what we're doing, and if
8 we do, do we know how to do it? So I think starting off, that
9 addresses some of the most simple questions that we want to
10 ask.

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

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

1 I'm trying to describe.

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

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

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

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

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

23 The important point is, that we've gotten out of our
24 testing, is that the small amount of water really has a
25 dramatic effect on the way the glass reacts. Now, this is a

1 hard point to come up with a priori, but after you see the
2 results, it's pretty clear based on the test results and then
3 based on how Bill's going about modeling the reaction
4 processes.

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

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

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

23 Let's take a look now at the three examples. Start
24 off with the first example, which is what I call vapor
25 hydration leach. What's going to happen in the repository is

1 the glass is, first of all, going to be in contact with humid
2 air. So if we're doing our modeling or our leach testing
3 based on fresh glass--which most of our testing has been done
4 on--and yet the actual glass in the repository is going to be
5 somehow changed by aging process, which is a vapor hydration
6 process, what we have to demonstrate is whether this vapor
7 hydration process affects the glass such that all the work
8 we've been doing on fresh glass is relevant or not.

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

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

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

1 It'll allow the--

2 DR. LANGMUIR: It's hygroscopic.

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

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

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

20 What the test looks like is as follows: It's got
21 two parts. First is the hydration aging part. We accelerate
22 the aging process in the test because we don't have enough
23 time to duplicate aging that would occur in the repository, so
24 we use saturated water vapor and we use temperatures up to 200
25 degrees C to accelerate the reaction process. And what we've

1 got is a closed bomb. We have a very small amount of water in
2 the bottom of the vessel. We have pieces of glass hanging
3 from a support stand, and we perform the vapor hydration aging
4 experiment for a certain amount of time to impart a certain
5 amount of aging to the glass.

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

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

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

10 Okay, we then do the leach test, and here's what
11 those same three pieces of glass look like after leaching for
12 28 days at 90 degrees C. You can see the top one--well, if
13 you could see the top one, you would see that it doesn't
14 really look very much different than it did before we did the
15 leach test. The 150-degree aged one--now, all these tests are
16 all leached at 90 degrees, but this glass was vapor-phased,
17 aged at 150 degrees. You can see there's a slight cracking in
18 the reacted layer and some of these secondary phases are being
19 dissolved. But the real thing that happens is for the glass
20 that has undergone the greatest degree of aging, the hydrated
21 layer is now falling off the glass and the white secondary
22 phases, which are calcium silicates, are beginning to actually
23 dissolve.

24 What are the results and conclusions from this type
25 of testing? And remember, these are just preliminary tests to

1 see whether this is a process we want to look at in more
2 detail. Looking at the actinide release patterns, we find if
3 you compare the leaching from the vapor phase aged glass to
4 that from fresh glass, that the americium and plutonium
5 releases from the glass increase up to 2,000 times when you
6 leach the aged glass compared to when you leach the fresh
7 glass, and that's because, as I showed on the previous view
8 graph, the layer is simply falling off the glass. It's
9 undergone X number of years equivalent reaction. That layer
10 is not adhering to the glass. It spalls off the glass when
11 it's contacted by liquid water.

12 Perhaps the more important point, though, is that
13 the actinide release under these scenarios is not solubility
14 limited. It's limited by--or, in other words, dissolved in
15 solution, but it's associated with particulate material which
16 is suspended in solution. So now when you go to do
17 performance assessment, you have to take a completely
18 different process into account from how actinides are going to
19 be transported away from the waste package. If we had
20 continued the leach test for longer than 28 days, what would
21 have happened is the hydrated layer would have spalled
22 completely off the glass and instead of having a value of
23 2,000 up here, we would have had a value of about 4,000. But
24 you can fix this number however you want to depending on how
25 much you age the glass.

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

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

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

20 The second example I want to look at is static
21 leaching tests combined with surface analytical studies. This
22 is an example of testing done to measure radionuclide release
23 and to provide mechanistic interpretation for Bill's model.
24 The tests I'm describing here are very simple tests because
25 the first type of thing you want to apply your model to is the

1 most simple type of experimental results that you can get, so
2 that's why we're starting off here. So the goal is to perform
3 simple tests to measure reaction processes, measure
4 radionuclide distributions, and the present tests addresses
5 bounding conditions for the amount of water. Again, these
6 tests essentially simulate a flooded borehole, a lot more
7 water than we'd expect, and we're looking at the expected
8 range of glass compositions.

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

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

25 Okay. What we've done is a detailed analysis of the

1 layer, and that's required to establish the reaction mechanism
2 and the secondary phases that are forming during the reaction
3 process. We're using analytical electron microscopy, which is
4 a foundation of transmission electron microscopy, together
5 with energy-dispersive spectroscopy, and electron diffraction,
6 scanning electron microscopy and secondary ion mass
7 spectroscopy to look at the way the glass is reacting.

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

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

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

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

23 We kept saying, yes, we've got things that look like
24 they precipitated out of solution. Those would be phases that
25 Bill would be interested in. And then we've got all kinds of

1 interesting structures here that looks as though it can tell
2 us something about how the glass is reacting, but from the SEM
3 we don't have a clue. We can get the composition of these,
4 but without knowing whether these are multi-phase or single
5 phase or homogenous, the composition really doesn't do us any
6 good.

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

14 So now if you look in detail at Layers 1, 2 and 3
15 that I identified over here, you'll see that we now get a very
16 nice structure as to what those layers are. If we do high
17 resolution lattice imaging, we can actually see that we do
18 have crystalline phases here. We can identify these as
19 manganese oxides. We can identify Layer 2 as a clay. You
20 can't even see Layer 2 on the--from the SEM. We can identify
21 an iron-rich stain covering the surface and to answer your
22 question, Don, the iron-rich stain is not acting as a barrier
23 to transport. You can see there are diffusion--well, I won't-
24 -not diffusion pathways, but transport pathways breaking
25 through the iron layer in many places. You can't tell it at

1 all from the SEM. From the SEM you would have been tempted to
2 say, based on the solution results because things are slowing
3 down, oh, the iron layer is going to form a protective
4 barrier. You look at it in more detail and you'll find that,
5 indeed, that's not at all the case. It's the affinity for
6 reaction which is slowing down the process.

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

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

1 barrier. It's tying up the uranium as a uranium-titanium
2 phase.

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

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

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

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

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

23 Okay, at 56 days we see what is essentially a--well,
24 it's close to a homogeneous, but it's certainly not
25 crystalline--gel layer. If you compare this layer to 131

1 glass reacted at 40 degrees for four years, the layers look
2 exactly the same. So you would say to yourself, based on your
3 knowledge of 131 glass that I showed on the previous slide,
4 oh, the 165 glass is going to react by the same process.
5 We're going to get a layered structure. We know exactly
6 what's happening. Wrong.

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

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

25 Let's take a look now with 165 glass as to what

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

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

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

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

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

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

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

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

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

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

23 The water contacts the top surface of the glass,
24 flows around the side surfaces of the glass, collects on the
25 bottom surface here and then eventually drips into the bottom

1 of the vessel. We can terminate this test after a year or
2 two, analyze the glass, analyze the solution in the bottom of
3 the vessel to get a mass balance between what's happening in
4 the glass and what's happening in the solution, or we can
5 continue this test by taking the waste package, putting it in
6 another vessel, starting the test--or continuing the test and
7 analyzing the solution in the bottom of the vessel, and so we
8 get a continuous trend as to what's happening with respect to
9 how the glass is reacting and how the radionuclides are being
10 released.

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

21 We see an intermediate release--now, this is
22 compared to our standard conditions of one drop every three
23 and a half days with no sensitized stainless steel. If we
24 sensitive the stainless steel, we see an increase of about
25 twofold due to the fact that the stainless steel and the glass

1 are interacting to form iron silicate phases, which accelerate
2 the reaction of both the stainless steel and the glass.

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

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

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

1 compositions.

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

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

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

18 DR. BATES: Not at all. My tests simply demonstrated
19 that in humid air, glass reacts. We then give that
20 information over to Les and the people who are doing
21 performance assessment and say, okay, either design a robust
22 container or a robust engineered barrier system, or, as I was
23 talking about the clay phases, what I would expect would
24 happen would be they could plug up the container, and once
25 they plugged up the container, nothing else could get out of

1 the container. So I'm not going to address in my tests what's
2 happening. I'm simply trying to identify things as to whether
3 they're important or not, or processes as to whether they're
4 important or not and then go ahead and, if they are, evaluate
5 them further.

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

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

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

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

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

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

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

16 DR. PARRY: Container materials?

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

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

25 Hopefully, what we'll do is when we identify what

1 that material is, go ahead and see how it behaves.

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

5 DR. BATES: Oh, yes.

6 DR. LANGMUIR: At the end of the test.

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

12 DR. LANGMUIR: What's it like?

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

20 DR. LANGMUIR: What's the pH?

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

1 DR. VERINK: Thank you.

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

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

12 So thanks very much. See you tomorrow.

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

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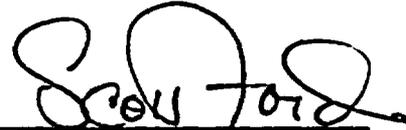
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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD

In the Matter of: ENGINEERED BARRIER SYSTEM PANEL MEETING

Location: PLEASANTON, CALIFORNIA Date: AUGUST 28, 1990

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2 UNITED STATES
3 NUCLEAR WASTE TECHNICAL REVIEW BOARD
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5 ENGINEERED BARRIER SYSTEM PANEL MEETING
6

7 Pleasanton Hilton Hotel
8 Gold Room
9 Pleasanton, California
10

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12 August 29, 1990
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15 BOARD MEMBERS PRESENT

16 Dr. Don U. Deere - Chairman, NWTRB
17 Dr. Ellis Verink, Chairman, EBS Panel

18 Dr. D. Warner North, Member
19 Dr. Dennis Price, Member
20 Dr. Donald Langmuir, Member

21 Russell K. McFarland, Sr. Professional Staff
22 Dr. Sidney J.S. Parry, Sr. Professional Staff
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P R O C E E D I N G S

8:05 a.m.

1
2
3 DR. ELLIS VERINK: Good morning. We're ready to
4 reconvene the activities today and we'll be starting with
5 spent fuel characterization overview. Ted's going to start
6 off. Okay.

7 MR. TED PETRIE: I'm Ted Petrie, again. I just wanted
8 to point out where we are. We've gone through the waste
9 package strategy and implementation plan, the waste
10 acceptance process, high level waste glass, and we're about
11 to talk about spent fuel and then go into the waste data base
12 development.

13 Again, as in yesterday, there will be quite a few
14 speakers coming through here to talk with us today. Ray
15 Stout is the first one and then he will introduce the next
16 one and the next speaker will introduce the next one as we go
17 along trying to keep it a little bit organized here.

18 So, again without further ado, here's Ray.

19 MR. RAY STOUT: Good morning, my name is Ray Stout.
20 This talk is on spent fuel. It's an overview. I have broken
21 it down into three parts. There's about five or six
22 viewgraphs on an introduction. I'll talk about the
23 distributional aspects of properties of spent fuel. Primary
24 variables which we're looking at to select spent fuel and to
25 correlate initially is burnup and fission gas release on the

1 fuel pellet. I'll spend some time talking about conceptual
2 models that are under development. These models are in a
3 preliminary state. We are using them to plan tests and
4 eventually we'll use them to describe the response of the
5 spent fuel for performance assessment and waste package
6 assessment.

7 Why perform spent fuel characterization? This is
8 the objectives of the activities which we have in our
9 technical area. We want to provide data, testing, and models
10 that describe the degradation and radioactive release
11 responses of the spent fuel. This information is used for
12 waste package and system performance assessments for the
13 Yucca Mountain Project.

14 What does this mean in a practical sense? You'll
15 see this viewgraph several times this morning. What I wanted
16 to indicate is that in the event that a container does fail,
17 there is then a potential event sequence in time which you
18 can expect to see for the spent fuel in a container. First
19 off, there will be cladding exposed to the environment. From
20 that cladding, there will be gaseous release response which
21 is the carbon-14 release. If we're going to provide data, we
22 will need to know the initial inventory of that cladding.
23 We'd like to know where it comes from. We think it comes
24 from the oxide film, the early release. Testing will provide
25 that kind of information.

1 Model development will tell you how to extrapolate
2 in time once you have some testing information for other
3 pieces of spent fuel and which you haven't tested. The next
4 event that will follow will be degradation; in fact, this is
5 going on at all times. The primary driving force is the gas
6 pressure inside or one other driving force is inside the
7 cladding. Gas pressure is due to initial gas that's put into
8 fuel pins when they're manufactured and it's also augmented
9 by fission gas released which occurs during reactor
10 operation. We'll spend more time on this topic later.

11 If the cladding fails, then there will be spent
12 fuel exposed. The amount of spent fuel exposed depends on
13 the amount of cladding that's failed. So, we would like to
14 understand this better. This would give you a feel for how
15 much inventory will be subjected to oxidation. The oxidation
16 response of spent fuel occurs in the higher temperature,
17 higher oxidation rate. The oxidation response is important
18 because it influences the dissolution response of spent fuel.
19 It turns out that the oxidation of UO_2 goes up to different
20 states, U_4O_9 , U_3O_7 , U_3O_8 . We need to study each of these
21 states and see the dissolution response. Once water contacts
22 spent fuel, there will be radionuclides in the water. This
23 will bring in the geochemistry part of the problem and we
24 will have a talk on geochemistry modeling.

25 We have a milestone. We hope to bring all this

1 information in its preliminary state together in a charac-
2 teristics report. That report is due in March of '91.
3 Briefly, the contents of that report will have the physical
4 property data of both existing and projected inventories.
5 We'll talk about the radionuclide data for these inventories
6 and what models and test data that are available will go into
7 that report at that time.

8 I thought I'd like to give you a feel of what spent
9 fuel is like. This is a viewgraph courtesy of PNL. This is
10 the size of your hand, a fuel pellet in your hand, or about a
11 half a centimeter by a centimeter or a couple centimeters
12 long. The 200 or 300 of these are stacked in a fuel pin. A
13 fuel pin is about 160 or 170 inches long. Fuel pins are put
14 together in assembly. This is a typical BWR assembly, that's
15 a boiling water reactor assembly. They come out usually in a
16 7 by 7 array in the assembly for BWR. The typical PWR is
17 very similar. These are usually now 17 by 17 arrays of rods
18 so the assemblies go into a core. This is a typical core.
19 The point here is that across a core, the radial direction,
20 you will have a distributional, or a non-uniformity, and the
21 axial direction will be non-uniformity. So, even if you had
22 all the same cores and all the same operating conditions for
23 all the reactors, all your spent fuel would still not be
24 absolutely uniform.

25 DR. PARRY: Excuse me, the fuel is moved throughout the

1 operation of the reactor and there is every attempt to
2 homogenize the fuel, but you're quite right, there is a flux
3 distribution across the core.

4 MR. STOUT: Yes. Flux heat gradient, yes. And, that
5 fuel management cycle is for economic reasons, as well.
6 Thank you.

7 This brings us into talking about the properties of
8 spent fuel, the distributional aspects which is the second
9 topic. This is important to us because when you start
10 looking at what's out there, you find it perhaps not
11 described in a way that you typically do experiments or
12 modeling. Typically, we look at what's going to be the
13 response of a rod, and when you look at the data, it's
14 assemblies, tons, things like this. So, one of the things
15 that we're looking at is how do we get back to rod
16 information. I'll show you how we're going to do that.

17 As I mentioned, there is a large distributional
18 aspect. Part of it comes about because there are many
19 classes of reactors, many classes of assemblies. This is a
20 typical -- this has more information I'm going to cover, but
21 I just want to show that BWR is clumped together. This is
22 the GE rods. This is Westinghouse reactor fuel here. This
23 is metric ton of heavy metal. What we know is for each
24 assembly the number of rods in assembly. If we take that, we
25 go to a viewgraph which you've seen before which is burnup

1 per 1000 metric tons. We can get a relationship between the
2 coordinates of this graph and put these two distributions
3 together; in other words, add the history and the projection
4 and come out with information which gives us information like
5 this which is the number of rods per unit burnup and plotted
6 against burnup. This is like a distribution function, it's
7 not a probability density because we're probably not going to
8 normalize it to one, but from this then, for any increment of
9 burnup, we can tell you the number of rods that have that
10 burnup.

11 Now, why is this important? We're going to be
12 getting into more detail when we do analysis. One of the
13 things that I mentioned already is oxide film. Its thickness
14 is an important attribute. Here, it shows, a courtesy of MCC
15 -- that's the Material Characterization Center at PNL --
16 burnup versus oxide film thickness. We can get an upper
17 bound line. If you have an upper bound line, you have a
18 linear or perhaps a transformation function which you can go
19 from previous viewgraphs. You can now talk about rods per
20 unit oxide film thickness versus oxide film thickness. This
21 is a way of getting to rod data with its associated
22 attribute.

23 We can do that for a variety of, what I call,
24 attributes. These are just the characteristics of the spent
25 fuel. For example, rods per unit carbon-14, this is

1 something we'll need to know. Rods per unit hydrogen, this
2 gets into the hydriding problem in cladding. Rods per unit
3 heat decay, we will need to know that for thermal analysis.
4 Rods per unit activity species, this is a release kind of
5 problem where you need to know the inventory in the spent
6 fuel to study release.

7 The other variable besides burnup, a primary
8 variable -- there are secondary variables -- is percent
9 fission gas release. This is an important variable and we
10 are looking for data which we can get the rods per unit
11 fission gas release versus percent fission gas release. The
12 reason it's important, the fission gas release augments the
13 initial gas pressure in the rod and this has been, as I've
14 mentioned before, a force driving degradation or failure of
15 fuel pins.

16 Fission gas release also tells us something about
17 redistribution of inventory in the spent fuel. This was
18 mentioned, I believe, briefly by Mike yesterday. It turns
19 out that fuel pins with high fission gas release redistribute
20 what's called the volatiles. These are cesium, iodine,
21 technetium, strontium. These also are highly soluble
22 species. If they get out in the gap, rapidly when water is
23 contacted, it contacts the spent fuel. So, where they are is
24 very important for that initial rapid pulse of release.

25 We see here that fission gas release can be

1 correlated with the percent inventory that's out there. We
2 can use that information, again make a linear transformation,
3 get a plot which says the number of rods per unit inventoried
4 in the gap and grain boundaries. What we see is that like
5 fission gas release, we don't expect a large number of rods
6 to have high gap inventory or high pressures; however, those
7 that do have those high pressure will probably be the first
8 to fail. These will also be the ones with the highest
9 inventory and so we can keep track of these in terms of a
10 correlation between those two attributes. That's all I
11 wanted to say about the characteristics.

12 This part of the talk will be the conceptual models
13 that, as I mentioned, are under development. These are not
14 in any final state. We are using them to plan tests. It's
15 an energy process where you look at test data and you look at
16 what you're doing in your model, you refine both. And, as I
17 said, we will eventually use these then to describe response
18 of spent fuel.

19 Now, in going through these, the subsequent talks
20 will amplify on these topics. The gas release response,
21 that's work being done at PNL and Harry Smith will talk about
22 that. Cladding degradation response, again Harry Smith will
23 talk about that. UO_2 oxidation response, that's Robert
24 Einziger from PNL at Pacific Northwest. Water contact with
25 spent fuel and the dissolution response, really we only talk

1 about dissolution response, this is Charles Wilson of PNL and
2 Herman Leider. They will talk about modeling and work that's
3 being planned at Livermore. And, finally, Carol Bruton will
4 talk about a geochemistry solution response and that's the
5 model EQ 3/6 and solubility of a species. So, this will be
6 quite rapid.

7 Gaseous release, this was found to come out quite
8 quickly from cladding. What we're doing is performing tests
9 on it. What we're looking at is a diffusion model. We think
10 that the rapid release resides in the oxide film primarily
11 and Harry will talk about this more in detail.

12 Zircaloy cladding degradation, we're looking at
13 three modes of degradation. What we now feel is the one
14 analysis path is to consider the oxide film failure. Oxide
15 film forms on zircaloy in reactor. The film forms with a
16 significant volume increase. That means the film itself will
17 be in a compressive state of stress. As long as it remains
18 in a compressive state of stress, you can't drive a crack
19 across it and this will be a failure/no failure kind of
20 criteria. We're looking at modeling a deformation then due
21 to the gas pressure during the rods' history and a repository
22 considering elastic, plastic kind of creep response, thermal,
23 and any strains due to hydride precipitation. So, that's a
24 preliminary model.

25 I mentioned hydrides. Hydrides, hydrogen goes into

1 the cladding during reactor operation. It is in solution of
2 high temperatures. When temperature comes down, the hydrides
3 precipitate out as platelets. The platelets shown here, I
4 call circumferential. In this alignment, they would not
5 degradate the cladding and you would expect no failure.
6 However, if the stress is high, they do have a tendency to
7 reorientate. That's a hoop stress in the cladding. If they
8 reorientate, then you can have a crack path across the
9 cladding. These would be the radial hydrides, and in that
10 case, you would predict a high probability of failure.

11 The third topic or mechanism we're looking at is
12 fluoride attack on the zircaloy. Fluoride, ions are known to
13 corrode zircaloy. This appears as a pitting corrosion mode.
14 We're worried about pin hole pathways through the cladding.
15 This was an electro-chemical corrosion response. The
16 degradation of cladding will be discussed by Harry Smith, as
17 I mentioned earlier.

18 If cladding fails, then you can expect oxygen. In
19 the event that the containers also fail to contact the spent
20 fuel fragments, the fragments occur because when you go up in
21 the power cycle, thermal strains crack up the fuel pellets.
22 This exposes more area. So, oxidation response is higher in
23 this case than it would be if you had whole pellets. What
24 we're seeing is that there is a propogation of oxidation
25 front into a fragment. You have U_4O_9 crystalline structure

1 behind the oxidation front. So, this is a phase change. You
2 have UO_2 in the center. We're looking at modeling which we
3 can talk about representing these fragments and following the
4 propagation of this boundary into the grain or into the
5 fragment. That way, we can develop a model which certainly
6 is related back to test data to describe oxidation.

7 The results indicate that we have to worry then
8 about fragment distribution sizes. We have to worry about
9 different temperatures. What's happening is that the grain
10 boundaries oxidize first. They open up and then expose
11 individual grains. And, this problem will be discussed
12 further by Bob Einziger when he talks.

13 This brings us to spent fuel radionuclide release
14 which right now we're considering aqueous release. In other
15 words, fuel is exposed to water. We have to worry about
16 what's in the gap. This is rapid release. We have to worry
17 about grain boundary response because the grain boundaries
18 load up if you have high fission gas release. They also load
19 up with the soluble species just normally because there's
20 migrations out of the grain. And, finally, there's the
21 grains itself which contain most of the actinides. The
22 dependence is quite complicated. We do not have at this
23 moment what I would call a detailed working model. We're
24 still looking at experimental data/approaches trying to
25 isolate various effects. And, what we're looking at is major

1 solubilities of the soluble species, ways to get release
2 rates, and also study the release of the solubility limited
3 species. These turn out to be the actinides. This will be
4 talked about by Chuck Wilson who has done hot cell work and
5 Herman Leider from Livermore.

6 Okay. Well, I guess I had one more viewgraph on
7 this. The two kinds of experiments which we are going to
8 study radionuclide release are flowrate control experiments
9 and semi-static experiments. The semi-static experiments are
10 those of Chuck Wilson in the hot cell and he's also done some
11 flowrate on UO_2 . This data, so far, provides us input and
12 ideas to initiate modeling and, of course, to couple to the
13 EQ 3/6 geochemical simulation code that is at Livermore. The
14 simulation work will be discussed by Carol Bruton.

15 This is sort of a summary viewgraph, the philosophy
16 which we have in terms of testing. Because of the long
17 times, we are looking at what is called mechanistic model
18 development. You have to do this based on short term tests
19 so we look closely at what goes on at a microscopic domain a
20 lot of times. We always try to perform testing over a range
21 of experimental variables which exceeds what we call
22 repository conditions. This is not always possible,
23 particularly because at low temperatures, nothing can be
24 measured, the response is so slow. But, if we can do this,
25 this means that we will be able to interpolate rather than

1 extrapolate on function variables and data that we need for
2 model development.

3 As I said, you'll see this viewgraph many times.
4 The first two topics will be talked about by Harry Smith of
5 PNL and the topic will be called the spent fuel cladding
6 degradation.

7 Any questions?

8 DR. DEERE: Yes. In your Viewgraph 21 when you note
9 that the oxide film will generate large compressive stresses
10 as it's being formed.

11 MR. STOUT: Right.

12 DR. DEERE: Can they get to the point where they will
13 actually lead to either a shear failure or a splitting
14 tendency parallel to the maximum principal stress?

15 MR. STOUT: That's never been observed as far as I know
16 in reactor operation. Oxide film does have a porosity and
17 there have been attempts to analyze that porosity as perhaps
18 a buckling or some kind of a failure to a wavelength of
19 buckling around the clad. But, that's never worked out well,
20 either. Work at Bettis indicates, you know, it may have
21 400,000/psi compressive stress in the oxide film. Some work
22 we sponsored doing elastic analysis sets in this same kind of
23 ballpark, 200,000/psi, 400,000.

24 DR. DEERE: How does that compare with the unconfined
25 compressive strengths?

1 MR. STOUT: I have no feel for that. You see, this is
2 like a pre-surface on the film. It's tied down to this
3 boundary. When you say compressive strength, you're talking
4 about confined? I don't know --

5 DR. DEERE: Unconfined. The reality being a biaxial
6 stress state. It probably will fail before it gets up to its
7 maximum shear strength.

8 MR. STOUT: Yeah.

9 DR. DEERE: And, you'll get a premature splitting
10 failure.

11 MR. STOUT: Yes. That hasn't been seen. What seems to
12 have happened is that if you distribute the volume change in
13 all three directions of strain, you would have even higher
14 stress. There is some work out there which says that when
15 this form is on the surface that it is anisotropic and most
16 of the growth grows normal to the surface. And, so that
17 keeps the enormous stresses from building up. Otherwise, you
18 would predict millions of psi compressive stress in the hoop
19 direction. So, it's not a straight forward problem. We hope
20 to do tests to see what the failure strain is in the cladding
21 oxide.

22 DR. PARRY: Ray, on your Slide 9, you list some
23 quantities by various reactor type and fuel type.

24 MR. STOUT: Yes.

25 DR. PARRY: I'm assuming that those quantities are based

1 on a reactor running for 20 years and then shutting down and
2 not having an extension of its operating life by licensing
3 its extension. Is that correct?

4 MR. STOUT: I really don't know. This work, as I didn't
5 mention, I should give credit to the Oakridge people. Karl
6 Notz, who I think is in the audience, could answer that.

7 MR. KARL NOTZ: Well, the answer is yes.

8 MR. STOUT: The answer is yes.

9 DR. PARRY: Thank you.

10 MR. STOUT: Thank you, Karl.

11 Okay. Harry Smith will talk next.

12 MR. HARRY SMITH: I'm Harry Smith. I will discuss with
13 you briefly the work we've done in spent fuel cladding
14 degradation. I'd like to cover these topics. First, the
15 carbon-14 release from zircaloy cladding. Then, we will look
16 at what we've done with C-ring failure testing from scoping
17 studies and then some pressurized tube testing which is
18 planned. It's just really begun, barely. And then, some
19 zircaloy/fluoride corrosion testing which we've done only
20 scoping studies on, but enough to get some indication.

21 Why zircaloy cladding degradation studies? Well,
22 first, we need to get carbon-14 release data so that its
23 release can be properly assessed in post and pre-emplacment
24 conditions. And then for the cladding degradation, it is an
25 initial barrier to release of any gap inventory radionuclides

1 and so forth. And, if you can show what its barrier
2 characteristics or its resistance to degradation is, you can
3 consider it as a barrier and then you will not maybe need
4 another duplicate barrier to perform its duty. But, you have
5 to be able to show what it does do.

6 Just to give you a quick picture again and remind
7 you of what cladding is, I'll show a few spent fuel rods in
8 cross section as they might be in a consolidated container in
9 repository setting. This is just one of the possible
10 geometries. But, the cladding is a metal sheath around the
11 spent fuel. It has an oxide film over the top. Crud can
12 deposit on top of that, and then in the various repository
13 type scenarios, you may have water that does contact the
14 surface of the film even before a container breaches because
15 of water-logged rods loaded into the container, or after
16 container breach, water that comes in from a repository
17 setting.

18 The zircaloy cladding, the oxide film, and even the
19 crud contained in carbon-14 that I will discuss this morning;
20 water, like J-13 does contain some fluoride, corrosion models
21 could be some kind of a uniform corrosion -- unlikely because
22 of the oxide film -- but pitting, crevice corrosion perhaps
23 could occur and then the cladding itself can degrade also by
24 cracking like in stress corrosion or delayed hydrogen
25 cracking mechanism.

1 Just for your information, the experimental
2 material we are using for experimental work, essentially work
3 we're reporting on this morning comes from PWR reactors, H.B.
4 Robinson and Turkey Point. They're a medium or a slightly
5 low, I guess, burnup material. And, we've looked at thick
6 oxides which we interpret to be 12 to 20 microns thick film
7 of oxide or thin, the dark, 3 to 6 microns thick oxide film.

8 Discussing first the thermal release of carbon-14
9 from the cladding, we've developed and demonstrated, I
10 believe, a technique that will quantitatively measure the
11 release and we will apply or would like to apply this
12 technique to spent fuel, entire population or good samples
13 from the entire population, and reactor hardware.

14 Our apparatus shown schematically consists of a
15 furnace with a homogeneous temperature zone, a gas flow path
16 that brings its own atmosphere across the cladding surface as
17 it resides in the temperature zone, brings it out to a series
18 of traps which allows us to trap tritium that's released and
19 carbon-14, to separate those two. And then, by taking it
20 through a copper oxide furnace, determine what proportions of
21 the release may be in some less oxidized state that weren't
22 caught in the caustic trap or initial tritiated water trap.
23 This is then brought back into the hot cell.

24 Modeling for release, two really simple and really
25 almost the same models are the semi-infinite plane or semi-

1 infinite fitness plane, simply a plane for which the
2 diffusional release from that plane does not see the back
3 surface. So, it looks semi-infinite. Or if it does see, if
4 the source is thin enough so that the diffusional release
5 profile sees the back wall of the reservoir, then you get a
6 finite thickness plane model. And, what happens is at some
7 particular point, depending on the geometry and release rates
8 and so forth, you would see a divergence between these two,
9 something such as I've shown here.

10 First, I'd like to point out from an initial
11 carbon-14 concentration profile we made through the upper
12 surface of a piece cladding shown here, I would like to point
13 out that there is a slight scaling error. So, you should
14 make that correction in your viewgraph. So, if you have a
15 question about it, that's the reason it looks strange. The
16 oxide film depth on this piece of cladding was about 10
17 microns. It looks like there's a higher concentration of
18 carbon-14 present in that oxide film and then drops off to
19 some lower uniform value in the middle. Though we did not
20 penetrate those usually, those were -- it's a very arduous,
21 tedious experimental measurement to make because to get the
22 good uniform stripping, we had to etch at a slow, very low
23 temperature, very slow in the system, and each of the points
24 on there represented several hours of etching time with also
25 the trafficking of the released carbon-14. So, it was a

1 rather delicate measurement to make.

2 Okay, back to the model. Here, we did show some
3 data plotted in the same way of cumulative release against
4 the square root of time. We see for a high temperature, the
5 scale on the left, versus low temperature, the scale on the
6 right, we can see that for the highest temperature, we seem
7 to see a falling off such as you might expect from a finite
8 plane diffusion model release. The others seem to be pretty
9 straight like an infinite (sic), semi-infinite plane, simply
10 indicating they have not seen the back of the reservoir yet.

11 A summary of our data to date is shown in this
12 plot, plotted a little differently than the first one, but
13 shows two things. One, there's quite a temperature
14 dependence on the carbon-14 release from the cladding, all
15 the way, almost four orders of magnitude there over a
16 temperature range of 100 to 350 C. And then, there is a
17 significant atmosphere effect. All the rest of these were
18 done in air. Three Argon tests shown here at 350 are
19 considerably below similar tests done in air.

20 Okay. A summary then of our work and some
21 conclusions, we have developed a system that will allow us to
22 look at the temperature, atmosphere, and other environmental
23 factors as release as a function of those things. And then,
24 our initial data indicates that -- now, I'm saying that 10%
25 of the carbon-14 cladding inventory. This is in no way

1 different than what Ray said earlier. It's just related to
2 the cladding -- specifically and this is at eight hours, 350
3 in air. We notice that argon gives about an order of
4 magnitude or more lower release than in air for the same time
5 period and that the carbon-14 appears to follow some kind of
6 a finite plane source model suggesting that the carbon-14
7 might be there in more than one species or there's more than
8 one reservoir; maybe the oxide film, as Ray suggested
9 earlier, and the cladding itself, the metal, the carbon in
10 maybe solution in the zircaloy and other reservoirs.

11 Moving on to the cladding degradation work, looking
12 at tracking of zircaloy-4, we've done some C-ring experiments
13 that were done to determine whether or not we'd see cracking
14 at all. Just really to tell us if this was something to
15 expect and then to see if we could determine some kind of
16 relationship between time to failure and the stress that we
17 placed the zircaloy under.

18 And then, the pressurized tube testing, the design
19 is a followup to the C-ring experiments to look at what kind
20 of strain is necessary to actually rupture the oxide film to
21 potentially initiate cracking, and then to try to also take
22 those measurements to lower stress levels by some other
23 experimental tricks, in a sense, of maybe mechanically
24 defecting the cladding and so forth and certain ways to get
25 cracks initiated and then watch them actually move rather

1 than just an all or none as it was for the C-ring experiment.
2 And then, to look at the question of hydride reorientation.
3 This is a possibility for some repository type temperature
4 profiles, and if it does occur, it can degrade the mechanical
5 properties of the zircaloy.

6 Okay. Looking at the C-ring cracking experimental
7 apparatus we used, we took an actual piece of cladding, made
8 a C-ring out of it simply by cutting off an arced segment,
9 placing it under compression between two anvils. The
10 relationships here, if this is one, this is five, and this
11 side here to the LVDT engagement screw is a factor of two.
12 So, you can scale all these things and measure a deflection
13 of the C-ring as a function of time under an environment that
14 you establish in this little pan. And, you can either put
15 water in here or, as we did in some cases, also put air, run
16 it with air by cranking up the oil bath a little bit. The
17 thermocouple is in place to tell you that indeed you've
18 achieved the right temperature. We ran these experiments at
19 90 degrees.

20 Just to give you an idea of what you see when you
21 get in this high strained area of the cladding C-ring, when
22 those drain, you see some porosity here in this rather thick
23 oxide film, but you don't see radial cracks. In the high
24 strain area, you can clearly see a set of radial cracks
25 develop that penetrates the oxide film.

1 Some results look like this. They all look like
2 this with various lengths of time to failure. Basically, you
3 had initial relaxation time, a probably creep in the zircaloy
4 because these are all done at quite high stresses compared to
5 the actual yield stress of the material tied to some large
6 percentages of the yield stress. You saw then a slow
7 deformation. In some experiments, it was almost impercep-
8 tible. A period of increasing deflection and then you would
9 go into a period of consistently increasing deflection until
10 you actually approach a failure such as you see here. When
11 we observed failure in one when it was unexpected, we usually
12 had it break on us, shocking the whole system, and we
13 deflected then the neighboring specimens. And, this is the
14 specimen shown here that was a neighbor to this. We saw this
15 deflection, interesting enough. The recovery appeared to go
16 back out to what you might have expected to have been the
17 original failure profile suggesting that it was an
18 environmental effect maybe at the cracked pit, something
19 going on there such as the gathering of hydrogen to lower
20 maybe the crack, or it may be a fresh corrosion phenomena
21 going on. Something going on at the crack that needed to be
22 re-established when you saw failure at the original rate.

23 If we take the data for all of the C-rings run in
24 water and plot the percentage of yield stress -- and this
25 could have just been stress, but I chose to use percent of

1 yield stress because we also determined that that is an
2 initial step in doing our experiment -- you see this kind of
3 a relationship between log of time to failure and that
4 stress, a logarithmic relationship.

5 DR. PARRY: Is that the stress of the irradiated
6 zircaloy?

7 MR. SMITH: That's correct. This is the calculated
8 stress for the outer fiber of the C-ring.

9 DR. VERINK: As installed?

10 MR. SMITH: As installed, yes. Now, we did preliminary
11 experiments to determine how accurate we had to be on where
12 you installed it and so forth. And, we can be quite
13 accurate, it looks like.

14 DR. VERINK: But, with time, you're changing the
15 thickness of the film and so on, aren't you?

16 MR. SMITH: You don't see any hint of that, though you
17 don't have before and after obviously. But, I had done other
18 experiments in which I had just immersed zircaloy cladding
19 material in J-13 for up to periods of like a year and could
20 detect absolutely no change. Now, there's a lot of
21 discussion on how accurate I could do that and it certainly
22 wasn't that fine. But, I would say that the change in
23 thickness of the film during these experiments was negligible
24 because of the fact -- another thing, because I had both
25 thick and thin film specimens represented here and I haven't

1 thick and thin film specimens represented here and I haven't
2 distinguished them for you. There may be a difference
3 between them, there may not.

4 DR. LANGMUIR: Harry, to what extent does it matter
5 which kind of water you've got there, J-13 or something else,
6 since the unsaturated zone water is about three times the
7 salinity and you also might have condensation water which
8 would be distilled?

9 MR. SMITH: I would say good question and that's
10 something we would address, you know, if we use one kind of
11 water, J-13, for the test or just plain hot cell air for the
12 air test that we run.

13 DR. DEERE: What is the approximate yield stress?

14 MR. SMITH: Well, the yield stress that I measured based
15 on looking for a proportional limit -- I mean, waiting until
16 I got a deflection from the proportional limit -- were
17 numbers like 150,000 psi which is high for irradiated
18 cladding. But, you have to remember that in this outer film
19 area, we've got an oxide film there. We have got an oxygen
20 saturated zircaloy, an irradiated zircaloy right beneath it.
21 Now, a typical number, you might have expected 120 maybe or
22 even 130 maybe. So, these seem to be high, but I've also
23 done the experiment using an HT-9 stainless steel for which
24 we had all the properties and I was able to predict those
25 from my measurements to get similar values that were measured

1 by other methods, such as the yield stress, doing the same
2 kind of experiment.

3 DR. DEERE: Is it fairly brittle material or does it
4 have a yield before you get to ultimate?

5 MR. SMITH: It yields. Now, there's some discussion on
6 this. Other people told me it was going to be very yielding.
7 I expected it to be like glass with what some people have
8 told me. Though we did on a couple of experiments drop the
9 weight, as you saw, crushed it and it didn't break. If you
10 take a look at the surface oxide film at the failure time,
11 you will see areas where you get very sharp crack that has
12 penetrated down and is propagating down through the cladding.
13 And, the surface of that crack looks like a transgranular
14 fracture. If then you also look at areas that failed in this
15 catastrophic failure where it broke, you see surfaces that
16 are dimpled, but look kind of like a ductile yield. And, you
17 find places on the surface where the oxide film has been
18 cracked and separated and you get just a sharp, you know,
19 rather V-notch crack. So, it will look like under a rapid
20 deformation, it was acting at least partially ductal, but
21 these things did break in a rather catastrophic manner.

22 DR. VERINK: What is the ratio between the specific
23 volume of the oxide that's there and the metal from which it
24 was formed?

25 MR. SMITH: You're asking me how much volume increase

1 there was in forming the oxide film?

2 DR. VERINK: Yes. So, it's only a very small one?

3 MR. SMITH: Yes, it's a small amount. For me, we have
4 not made measurements. We know what the oxide film thickness
5 was and predict from other measurements --

6 REPORTER: I can't hear you.

7 MR. SMITH: Ten to fifteen percent.

8 DR. VERINK: So, it's not a question of over-straining
9 the adhesion of the oxide versus the cohesion of the oxide?

10 MR. SMITH: I think that's true. The fracture that
11 propagated into the cladding showed absolutely no deflection
12 at magnifications as high as 20,000x on the SEM. I've never
13 seen such a tight adhering film. The porosity does sometimes
14 project pretty close down to the boundary and they -- porous
15 film and that's where I've concluded that a lot of the excess
16 stress was being taken up.

17 DR. VERINK: Um-hum. Well, it sounds like there's
18 greater adhesion to the substrata than there is cohesion
19 within the oxide?

20 MR. SMITH: Oh, yes. Another observation to support
21 that is that these fractures, we took a number out before we
22 failed so we could see the fracture patterns that formed on
23 the surface. We had inactual on cracks. The shear zones
24 between those cracks that formed, you would see the top
25 surface of the oxide film fall off, but there was still an

1 below, but it was still adhering.

2 DR. VERINK: That would only be on very thick films or
3 would it be?

4 MR. SMITH: Well, it was on all the films.

5 In summary, we've kind of discussed some of this.
6 We would just propose that perhaps delayed hydrogen cracking
7 is maybe the principal mechanism involved here. Based on the
8 kinds of fracture patterns we have observed and in comparison
9 with other experimental work, we've observed that the time to
10 failure, log time to failure, was proportionate to yield
11 stress. And, we observed that time to failure under air was
12 about twice as long as it was in the water when we used J-
13 13. And, just for your information, if you extrapolated that
14 stress to maybe some conservative upper limits for the
15 repository situation, you would expect failure to occur in
16 hundreds to thousands of years. We're not claiming that
17 that's a good extrapolation or at all accurate, but that's
18 what you have.

19 Okay, planned pressurized tube testing. First, we
20 were going to determine the strain to produce cracks through
21 the oxide film. We'd like to then extend firm results from
22 C-ring testing. Then, we'd like to look at the question of
23 hydride reorientation under possible repository conditions
24 and then determine the impact of any reorientation we might
25 see on the mechanical properties of that cladding.

1 see on the mechanical properties of that cladding.

2 To get an idea of the level at which the oxide film
3 cracked, our stress level, we've started performing experi-
4 ments such as the one you see here shown schematically. We
5 put pressure fittings on a piece of cladding, attached a
6 strain gauge, and actually even considered acoustic emission.
7 This is passivated except for the oxide area of the cladding
8 section and we've simply measured the resistance through
9 conductive water which could be J-13 to another electrode
10 using a short duration pulse resistance meter.

11 There's also such measurements shown in this next
12 figure. What you see is that at a strain of about 23%,
13 resistance begins to drop very rapidly to a rather low value,
14 a relatively low value, out at about .56% stress. During
15 that same test, the acoustic emissions began at less than .1%
16 strain. Of course, that can be due to any kind of fracture
17 in the cracking, anything going on in the oxide film or the
18 oxide film and substrate. And, we see a relatively uniform
19 increase of the number of events with increasing strength.
20 Though we have not analyzed that in great detail, it appears
21 that the resistance method is probably the best technique to
22 use for determining when we're getting through the oxide film
23 cracking.

24 DR. VERINK: Will there be complimentary experiments in
25 the presence of irradiation?

1 ated cladding just to get the method down and then we would
2 go in the hot cell for the irradiated cycle. We have
3 actually got some potential --

4 DR. VERINK: Okay.

5 MR. SMITH: Now, just the whole general test setup for
6 pressurized tube testing looks like this. Basically, we have
7 a pressurization system in which we have some data readout to
8 follow the actual pressure that's maintained in the cladding
9 section itself shown schematically here. It will be filled
10 with some kind of inert material if we take out the spent
11 fuel. If we leave it in, we'll let the spent fuel take up
12 the volume. And then, this piece of cladding can be put in
13 some kind of an environmental chamber here, small stainless
14 steel pressure vessel of some kind that we can then put water
15 or various concentrations or various chemical concentrations
16 in. We can put different atmospheres in there. This item
17 then fits in an isothermal block, say like aluminum, that we
18 can then impose various -- on the system and we imagine that
19 maybe the test will be done like this. You see, this is the
20 part of the system that sits in the hot cell, the rest of it
21 is outside the hot cell.

22 Now, we've talked about this hydride reorientation.
23 Hydride reorientation may occur because when you put the
24 spent fuel in a repository, the temperature raises for a
25 period of time. This would cause hydrogen that was evolved

1 as hydrides to re-dissolve into the zircaloy and then during
2 the slow cool-down can re-precipitate. Now, when this
3 happens, the hydride may reorient due to that tensile stress
4 that is in the cladding itself due to the internal gas
5 pressure, both because of initial fill pressure and fission
6 gas release.

7 DR. VERINK: There doesn't seem to be any orientational
8 thing that I can tell with cracks through the oxide though,
9 correct?

10 MR. SMITH: No. In this particular picture, I wasn't
11 trying to illustrate anything like that. What we would
12 expect to do is first to see if we can reorient the hydrides,
13 at all. If we can't reorient them, there's nothing to worry
14 about. If we can reorient them, then we have to see what
15 happens to the mechanical property and then it becomes
16 another type of specimen we put into our standard pressurized
17 tube testing maybe with some modifications that become
18 obvious at the time. That's what we plan to do.

19 Just some data that suggests that we need to
20 consider this, in a normal reactor shutdown, you come down
21 from a temperature like 350 and you have a fairly rapid cool-
22 down rate shown here and they observed no radial hydrides.
23 And, if you do the same thing with a similar rod, but not in
24 the reactor, but without any internal pressure, you see at a
25 slow cool-down rate, you see no reorientation of the

1 hydrides. Now, this pressure shown here is equivalent to
2 something you might expect at one, it may be slightly
3 extreme, but not unreasonable for some of the spent fuel
4 rods. You take it for 323, cool it at 5 degrees an hour and
5 they do see radial hydride reorientation. And, that would be
6 enough for significant degradation of the mechanical
7 properties. So, this needs to be checked out.

8 Just to show you what we mean by reorientation,
9 this is normally the way that hydride looked in a piece of
10 spent fuel cladding that you get out of the reactor that, in
11 essence, stayed that way.

12 DR. VERINK: Now, that's internal pressure in the tube
13 or --

14 MR. SMITH: Yes.

15 DR. VERINK: All right.

16 MR. SMITH: Okay. When it cools down in a reactor,
17 they've pressurized the cladding to keep it from collapsing
18 because of the reactor pressure, itself. So, they kind of
19 balance off. So, there's not a big stress gradient in the
20 cladding itself at that time. But, when you get outside, the
21 external pressure is now removed and you have additional
22 fission gas release. Now, you have the potential for a
23 significant pressure inside that can cause the hydrides to
24 reorient when it cools down at the repository rate, whatever
25 that is. Okay. So, this is what they look like in a

1 reoriented state.

2 Now, I'd like to switch to the zircaloy/fluoride
3 corrosion testing. It has been recognized for many years
4 that the fluoride is very detrimental to zircaloy and great
5 efforts are made to make sure that you don't have it when
6 you're completing your fuel rods. Fluoride is present in the
7 groundwater, such as J-13 at 2.2ppm. And, we really have no
8 quantitative studies that exist under the conditions of
9 interest. Now, it should be pointed out also that the fact
10 you have fluoride in the groundwater is important, too,
11 because it could be concentrated by refluxing and so forth
12 during the repository lifetime. So, you may be considering
13 something up to even 100ppm or greater in the reactor water
14 or at least that's what I am told. And, so we have done
15 studies down into that range.

16 Now, what we tried to do in the zircaloy/fluoride
17 interaction study was first to develop and demonstrate the
18 techniques that would allow us to look at corrosion rates at
19 the kind of levels you might see in a repository situation.
20 Then, we applied this technique to a series of zircaloy-4
21 specimens and then we would like to apply, eventually, this
22 to irradiated spent fuel cladding to determine if our
23 unirradiated cladding results are the same as you would get
24 with irradiated cladding.

25 Okay. What we found with the zircaloy/fluoride

1 interaction studies was that a pH stat system was a good way
2 of making measurements and we believe we could do it very
3 nicely on irradiated fuel samples. The pH stat either was a
4 pH stat or a fluoride stat technique that you use for high pH
5 areas. Zircaloy-4 corrosion rate is a function of pH and
6 fluoride content and temperature very clearly. And, we did
7 see pitting all over the place. However, the way we were
8 doing the experiment, you could not demonstrate exactly what
9 condition, which condition was the cause primarily because we
10 were using a particular specimen at a number of different
11 pH's and we would then at the end examination observe this
12 pitting that had taken place.

13 DR. VERINK: What you're doing is controlling the pH.
14 That's what you're doing, right?

15 MR. SMITH: Well, yes. What happens is that as the
16 corrosion reaction occurs hydrogen ion is consumed in the
17 reaction. And so what you do is by statting it, you're
18 adding a little hydrogen ion and maintaining a constant pH.
19 And, from that information, you deduce a corrosion rate.

20 DR. VERINK: Um-hum. And, you're assuming that the pH,
21 wherever you're sensing it, is where the action is. Is that
22 right?

23 MR. SMITH: Yes, you do assume that. However, we use a
24 small reaction vessel and we do vigorous stirring while the
25 test is going on. So that you can judge how accurate that

1 is, but that's what we're trying to do. We do see consistent
2 results, I can tell you that. We do see hystoresis results
3 which does indicate some interesting mechanisms going on and
4 so forth, but we do see consistency.

5 Some more conclusions, we do see a scale-forming
6 reaction which appears to be the standard reaction for
7 zircaloy reacting with a water producing its trassivating
8 film. The film that's going reactive seems to be probably
9 fluoride complexing with the zirconium oxide film and
10 producing a soluble species. That's the second slide, I
11 think. And, these seem to be consistent with other
12 literature work done on this using other methods for
13 measuring corrosion. Now, we need to do this on an
14 irradiated cladding. We have not done that and that does
15 need to be done to confirm that it will work.

16 Summarizing my work, first with carbon-14, we've
17 got a functional apparatus to do the work and we have seen
18 that the release rates are a function of both temperature and
19 atmosphere. And, the zircaloy cladding cracking studies,
20 we've got evidence of cracking at high stress levels. If you
21 extrapolate that to repository levels, you'd expect failures
22 in hundreds to thousands of years. Pressurized tube results
23 will extend this hopefully to lower pressures and look at the
24 potential for hydride reorientation and the impact that it
25 will make.

1 The fluoride/zircaloy corrosion is observed.
2 Corrosion down at 100ppm, measurable for 100ppm fluoride, and
3 it's strongly dependent on pH fluoride, as well as I say,
4 fluoride concentrations.

5 DR. VERINK: And, that was pitting, is that right?

6 MR. SMITH: Well, it's pitting, but you know, if you do
7 some calculations, and we also do weight loss studies to kind
8 of give a separate confirmation of our measurements, it's not
9 clear whether the calculated weight loss implied pitting.
10 Pitting may be another mechanism that's active, but not the
11 total mechanism.

12 DR. VERINK: So, there's also a surface film?

13 MR. SMITH: Yes, a reaction type of thing going on,
14 right. Pitting was definitely there, though.

15 DR. LANGMUIR: Will you extend the work you've done in
16 the aqueous phase with respect to the cladding cracking and
17 fluoride induced corrosion to steam and high temperature
18 effects which is what's really going to be going on for a
19 long time?

20 MR. SMITH: Well, this is the reason for the little
21 environmental chambers that we were going to produce. As I
22 said, we can go into high temperature water, 170 degrees, for
23 instance, and have actually water in there or steam or go to
24 a higher temperature and do the same thing in those chambers.
25 That pressure is not significant enough to really modify the

1 pressure we put in the tubing. It would be a much higher
2 stress level. And, all those things could be done, I
3 believe, with the system. That is the plan.

4 DR. VERINK: Have you had a chance or is it part of your
5 normal scheme to see whether there's any knowledge to be
6 gained from checking these kinds of results with the
7 appropriate Pourbaix diagram for these?

8 MR. SMITH: We have looked -- it seems to parallel the
9 species predicted by Pourbaix and levels -- we really haven't
10 looked at it a lot because we've been worrying about actually
11 getting good numbers first. I felt that we needed good
12 numbers before we worried about comparing those others.

13 DR. VERINK: Um-hum.

14 DR. DEERE: Yes. Could you go back, please, to Slides
15 24 and 25? These are the hydride reorientations.

16 MR. SMITH: Sure.

17 DR. DEERE: I guess really it's the diagram 25.

18 MR. SMITH: 25.

19 DR. DEERE: Now, under normal, do you have this orienta-
20 tion of the hydrides before you begin to cool down? I mean,
21 during the operational phase?

22 MR. SMITH: Well, this is in the normal phase you would
23 expect to see from cladding that has been removed from a
24 reactor, after it comes out of the reactor. This is what you
25 would see. This is what I see all the time.

1 DR. DEERE: Yes.

2 MR. SMITH: Exactly like this.

3 DR. DEERE: Do you think this also looks like this when
4 it's in the reactor?

5 MR. SMITH: Well, in the reactor, you're at a
6 considerably higher temperature. I would guess a lot of
7 these have come out perhaps during cool-down. Of course, you
8 realize that manufacturers of cladding are very particular
9 about getting a proper structure in the cladding itself so
10 that the hydride will form in this orientation in reactor
11 service. Now, there's some hydrogen probably as hydrides,
12 but most of it is in solution at 350. As you come down, a
13 lot of the thing barges those hydrides.

14 DR. DEERE: I would think this orientation is the one
15 that might want to exist during operation because you have
16 the high compressive stress or circumferential stress in the
17 cladding.

18 MR. SMITH: Um-hum.

19 DR. DEERE: And, free surface for expansion is out into
20 the container. So, you would have a tendency for anything
21 that's going to form or any reorientation to have exactly
22 that. But, when you come over here in the reoriented
23 specimen, even though you state that this is in a compressive
24 field because the container is pressurized --

25 MR. SMITH: Well, it's more neutral. Let's put it this

1 way, it's more of a neutral. It's not a high stress state at
2 that time. It's more neutral. The cladding has simply been
3 fabricated so that the hydrides will tend to come out and
4 this is the manufacturers' knowledge that goes into producing
5 cladding in this form. So, this will have it because they
6 realize degradation from mechanical properties if you've got
7 radial hydrides. And, so what happens in the repository or
8 what could happen -- this is what we would want to look at
9 -- is that in that situation now you have no constraining
10 outer pressure. As the temperature goes up, these hydrides
11 then redissolve into the matrix. Then, as you'd reach peak
12 temperature, and start back down again, they start coming
13 out. But, now the pressure field stress they feel they see
14 in the cladding is not a low stress field. It's a much
15 higher stress field and it's tensile.

16 DR. DEERE: That's what I was going to say. That's what
17 it looks to me like, that you might have external pressure,
18 but if you're cooling down, you're developing tensile strains
19 or extension strains or tension in that and you get the new
20 reorientation.

21 MR. SMITH: Yes.

22 DR. VERINK: Are those distributions, say, so-called
23 normal and basically intergranular?

24 MR. SMITH: Yes.

25 DR. VERINK: Are they sometimes transgranular? Well,

1 I'm intrigued by the distribution to the other orientation.
2 It seems like it would be easier to do that intergranularly
3 than it would be transgranularly.

4 MR. SMITH: The other orientation usually is on the
5 grain surfaces when you reorient.

6 DR. VERINK: Yeah.

7 MR. SMITH: And, it's a stress driving --

8 DR. VERINK: Yes, but you'd think that faster diffusion
9 pass would be intergranular rather than through the bulk of
10 the grain.

11 MR. SMITH: Yes.

12 DR. VERINK: It's interesting.

13 DR. DEERE: Another way I'd like to look at this, our
14 cracks did form in the orientation that I thought it might,
15 but they immediately became filled with the oxide in here.
16 The cracks that formed in the other direction and then were
17 -- well, they had to be filled because it moved from one
18 position to the other. I don't know what was the mechanism
19 of the transfer.

20 MR. SMITH: Now, I'd like to introduce to you Robert
21 Einziger who will talk about spent fuel oxidation.

22 MR. ROBERT EINZIGER: The only thing anybody remembers
23 from my hydride experiment is the mistake I made. I'm Bob
24 Einziger. I'm with the Pacific Northwest Laboratory. I'm
25 going to spend a few minutes talking about spent fuel

1 oxidation.

2 I'd like to briefly review the information we know
3 about spent fuel oxidation response, then go into two of the
4 sets of experiments that we've been doing. One is the
5 thermogravimetric analysis and the other is dry bath testing.

6 Somewhere in the neighborhood of approximately less
7 than .1% of the rods are going to enter the repository in a
8 breached condition and you can define breach any way you
9 want. But, the cladding will have been compromised. And, at
10 the time the canister is compromised, oxygen will be
11 available to the pellets for oxidation to take place. In
12 addition, while in the repository, additional rods may breach
13 due to the corrosion that Harry just talked about. If you
14 looked at the phase diagram for oxygen uranium, you'll find
15 out below 150 degrees C that UO_3 , not UO_2 , is the stable
16 oxidation state.

17 Now, if you get oxidation, a number of things are
18 going to happen. First, you're going to change the phase of
19 the fuel. You can have UO_2 , U_4O_9 , U_3O_7 , U_3O_8 . You will open
20 additional internal fuel surface so that if a leachant
21 contacts the fuel, there will be additional surface area to
22 release radionuclides. You'll release some of the trapped
23 fission gas both from the surface of the grains and also
24 internally to the grains as oxidation proceeds. And, if you
25 have sufficient oxidation, eventually you'll split the

1 cladding and change the path that the leachant has to take.

2 The bottom underlying question is what is the
3 change of O to M as a function of time? If it's very slow,
4 oxidation may be taking place, but it doesn't take place in a
5 time frame that we're interested in. If it's rapid, then we
6 may see any or all of these effects.

7 This is some pictures of what happens as the
8 oxidation process takes place. This was from an experiment
9 where we took a rod segment and we drove a small hole in it.
10 We oxidized it for a fairly short time. In this case, it was
11 only for about 10 hours and it was 360 degrees C. And,
12 you'll notice that we split the cladding open. It was about
13 7% deformation of the cladding. The split was quite long.
14 In this case, it went pretty much straight up and down the
15 cladding. We've seen it go around the cladding. We've seen
16 less deformation in cases. We've seen it happen at lower
17 temperatures, but the bottom line is if you get sufficient
18 oxidation, you'll split the cladding open.

19 If you look at individual fragments, this is a
20 picture of fragments of fuel as they've been taken out of a
21 fuel rod. As you oxidize to U_4O_9 , you'll see a reflective
22 area around the grain boundaries. These reflective areas are
23 the U_4O_9 that's forming on the grain boundaries. As you go
24 through the U_3O_7 state on to the U_3O_8 state, you have a
25 reduction in density which expands the fuel and eventually it

1 will tear the fuel apart. So, this fuel becomes this fuel.
2 If you continue further into the UO_3 state and even further
3 beyond that into the hydrated UO_3 state, you'll start to tear
4 the grains themselves apart. This experiment was done at a
5 fairly high temperature, approximately 360 degrees C, but the
6 same effect has been seen at lower temperatures to a lesser
7 degree.

8 Looking at the information that was available on
9 oxidation before we started this experiment and continued to
10 develop in other experiments as we were going on, we formed
11 some basis for establishing the oxidation work. I think it's
12 very important to realize that the oxidation behavior of
13 irradiated fuel could not be inferred from the behavior of
14 unirradiated fuel. There was a significant amount of work
15 that was done on unirradiated fuel. None of it agreed with
16 what we're finding with irradiated fuel. Although UO_2 is the
17 basis for spent fuel, it's not the thing that seems to be
18 governing it.

19 We also know from the literature that temperature
20 is a very important variable. One of the surprises that was
21 obtained early in other programs, the oxidation rate tended
22 to be lower with increasing burnup. Now, as we get to higher
23 burnups into the 30 and beyond range, we're finding not much
24 of a burnup effect, but we oxidized UO_2 on rating UO_2 much
25 faster than we oxidized spent fuel. You look at the

1 literature, the effect of moisture was unknown. There were
2 studies that said that the moisture in the atmosphere
3 significantly increased the rate of oxidation. There was
4 other studies that indicated that it significantly decreased
5 the rate of oxidation.

6 DR. PARRY: Well, you do have one important data point.
7 You have failed fuel in the reactor and you don't get
8 oxidation --

9 MR. EINZIGER: Well, you're dealing with a different
10 situation in the reactor and the water state, the same as one
11 of the mistakes that people tend to make is using very high
12 temperature steam data to infer what happens with the
13 oxidation of a fuel. So, we try to stay away from using that
14 data. But, in a reactor, there is not any extensive
15 oxidation.

16 Another thing that was apparent from the literature
17 is that the low temperature oxidation data was not available.
18 There were a few tests done on unirradiated fuel under
19 conditions that really weren't applicable to the tests we
20 were looking for.

21 What were the purposes of the spent fuel oxidation
22 program? First was to determine the mechanisms and rate of
23 oxidation. We wanted to find the effects of temperature,
24 burnup, and moisture on this rate of oxidation. In addition,
25 we wanted to get input for modeling of the oxidation and

1 lastly provide samples for further leach testing.

2 We did three types of things in the program. One
3 was the thermogravimetric analysis testing. This was done on
4 single samples. It was used to provide mechanistic data.
5 There were short-term tests, approximately 3,000 hours or
6 less and basically what they did was continuously weigh the
7 sample as it oxidized. Concurrent with that, we did dry bath
8 testing. These were for longer terms, usually two years or
9 greater. There were many samples so that we could determine
10 repeatability of data. We provided extrapolation data so
11 that we could take what we found in the short-term TGA
12 testing and fit it to some lower temperature information. We
13 went down to lower temperatures and it was done by interim
14 weighings. Approximately every six weeks, we weighed the
15 sample. Additionally, some samples were removed from both of
16 these tests for examination; ceramography, transmission
17 electron microscopy, x-ray diffraction, ion microprobe in
18 some cases, and fission gas analysis.

19 Let's look for a moment at the TGA tests. We've
20 used two types of fuel, PWR fuel at about 27 GWD/MTU. This
21 was the Turkey Point fuel and we've also done some work with
22 the ATM-101 which is H.B. Robinson fuel. These should be
23 sister fuels. The only difference is the grain size,
24 approximately 25 microns in the Turkey Point fuel and about 5
25 microns in the ATM-101. We've also studied some BWR fuel,

1 about 32 GWD/MTU. This was Cooper fuel, ATM-105, and for the
2 information of the committee what the ATM's refer to are the
3 fuel designations of the approved test material provided by
4 the Materials Characterization Center.

5 The TGA tests ran temperatures between 140 and 225
6 degrees C. At 140, insufficient oxidation occurred for us to
7 measure it in a significant time period. At 225 degrees C,
8 the reaction went too fast for us to also measure it in the
9 TGA system.

10 We used dew points mainly of 14.5 degrees C,
11 although some tests were done at -70 degrees C. Just to give
12 you an indication, -70 degrees C has about 5ppm or less
13 moisture in the atmosphere, and at 14.5 degrees C, it's
14 orders of magnitude higher. These tests ran anywhere from
15 approximately 300 hours to 2600 hours. In the course of the
16 experiments, we obtained final O/M's ranging from 2.02 to
17 about 2.4.

18 We tried to analyze some of this data and basically
19 we used a model which assumed that the grains were spherical;
20 not true, they're not spherical. That the grains oxidized
21 independently; not true, they don't oxidize independently.
22 That there was a planar oxidation front; well, for a short
23 time, that's true. And, if you use those assumptions, you
24 come up with a description that predicts the O/M as a
25 function of time and gives you a rate constant. So, if you

1 plot this side of the equation versus $t^{1/2}$, you should come up
2 to determine a rate constant.

3 In fact, this is what we obtained. We have a
4 period where we're increasing and this is what we think is
5 basically due to the fact that the grains are not
6 independent. That we don't satisfy the assumption that
7 they're all independently oxidizing. We think at this point
8 that the oxygen is migrating down the grain boundary very
9 rapidly. Eventually, we have a time when the assumptions are
10 pretty well satisfied. The grains are independent. We
11 haven't had sufficient oxidations of the grain themselves.
12 So, we're still having a planar front. If you continue the
13 data longer than this, then eventually it turns up and you
14 don't have the linearity anymore.

15 DR. PARRY: You mean off the scale or off the --

16 MR. EINZIGER: Excuse me?

17 DR. PARRY: You mean off this -- out past 28 hours?

18 MR. EINZIGER: Well, eventually, what will happen is
19 that you will get sufficient oxidation. So, you go above .33
20 and the model blows up.

21 Basically, the model that gets put together is that
22 there's oxidation in the drain boundaries and this is a
23 similar picture that you saw before. The individual grains
24 have oxygen around them. There's been a rapid transport path
25 of the oxygen to the grains. That gives them their

1 individuality. And, the oxygen starts to penetrate into the
2 grains. Here's a grain boundary and this is a TEM photograph
3 and here you see a layer of U_4O_9 , and here is the boundary.
4 It's a very sharp boundary between the U_4O_9 and the UO_2 . If
5 we had changed the lighting a little bit, you would have seen
6 the same thing on the other side of the photograph.

7 There are complicating factors though. This is a
8 fragment of sample that was oxidized in the TGA. From the
9 curvature of the surface we can tell that that was an outer
10 surface of the pellet as it was originally fabricated and
11 these are cracked surfaces that happened in reactor.

12 DR. VERINK: We're looking down on the outer surface?

13 MR. EINZIGER: You're looking down at a cross section.

14 DR. VERINK: This is a cross section?

15 MR. EINZIGER: That's right. You'll notice that the
16 oxidation front is significantly further into the pellet as
17 it comes in from the outer surface than it does from a
18 fractured surface. We think this may deduce some rim
19 effects. We haven't explored it in sufficient detail to find
20 out what's going on there. It does create a complicating
21 factor in analyzing the data, though.

22 You can summarize the TGA data by saying that spent
23 fuel oxidation is a two step process. It occurs by oxygen
24 penetrating the grain boundaries and followed by oxidation of
25 both grains. We also know that there's a strong temperature

1 dependence and it does affect essentially an arrhenius type
2 dependence. The activation energy though seems a little bit
3 strange in that it's independent in this stage of the
4 oxidation process. The tests did not give us any indication
5 of strong moisture effects and still essentially left the
6 question up in the air. We know that oxidation occurs more
7 rapidly at the pellet surface. The majority of the
8 information in these tests does not come from the weight gain
9 data. Mechanistic data comes from the microstructural
10 examination of the oxidized fuel. There are two TGA
11 apparatus at PNL, currently both of them are idle and
12 examination of the samples and data to determine the effects
13 of grain size, fuel type, and gas release to date have been
14 deferred.

15 Let's move on for a second to the dry bath tests.
16 As I mentioned before, the lowest temperature that we could
17 get in the TGA tests was about 140 degrees C. So, we're
18 obtaining some high temperature data. A thousand years into
19 the repository lifetime, temperature is not going to be 140
20 degrees C, it's going to be somewhere down around 95 degrees
21 C. So, we'd like to know that if we extrapolate the high
22 temperature data obtained from the TGA down into temperatures
23 that might occur in a repository that we're still sitting
24 with the same mechanisms and our projections are correct.

25 DR. VERINK: What do you mean by shortest measurable

1 oxidation rate?

2 MR. EINZIGER: Actually that should mean for the TGA we
3 could obtain data in a certain amount of time. We ran for
4 about 3,000 hours, and if we ran at a lower temperature for
5 that amount of time, we would not find anything there. It
6 would just --

7 DR. VERINK: Immeasurable?

8 MR. EINZIGER: Immeasurable.

9 DR. VERINK: Um-hum.

10 MR. EINZIGER: The TGA is a one sample device. We can
11 put one sample in and run it and we opted for about four
12 samples a year so we could get just more than one data point.
13 And, based on that, we're talking about 3,000 hours. There's
14 nothing in the experimental setup that precludes us from
15 putting a sample in at a lower temperature and running it for
16 a year, 10 years. Beyond that, we have institutional
17 problems.

18 The dry bath test used initially Turkey Point PWR
19 fuel, 27 GWD/MTU, and we used 50 samples. We followed that
20 up with Cooper BWR fuel, approximately 30 samples.
21 Currently, we're putting in Calvert Cliff fuel of two
22 different types. Both of them are high burnup fuel. One has
23 a low fission gas release, less than a percent, and the other
24 one is a high fission gas release of 18%. We're running at
25 three temperatures, 175 degrees C, so that we can overlap

1 with the TGA data, and down as low as 110 degrees C. Once
2 again, a temperature that for any substantial length of time,
3 if we went lower, we couldn't get good data.

4 There's two different dew points, -55 degrees C and
5 +80 degrees C. Once again, -55 degrees C, you're down in
6 about the 10ppm moisture range. At 80 degrees C, you're up
7 at about 200,000ppm.

8 Current duration of the tests, some of them have
9 run as high as 25,000 hours and are continuing. The highest
10 O/M we've gotten is 2.38 and, by the way, that sample has
11 been removed and it's being examined at the current time.

12 A quick view of the setup in the dry bath test,
13 basically we have a dry bath with just a heating mantle. In
14 it are three aluminum plates, anodized (phonetic) aluminum,
15 with holes drilled in them. Inside each hole is a nickel
16 chromium crucible with about 10 grams of spent fuel. They're
17 covered with a protector of nichrome so that in case we drop
18 one of these samples -- you have to realize each of these are
19 being done in a hot cell with two fingers. Imagine all the
20 tests, take two fingers, and do it. So, that's one of our
21 limitations. Each of the baths has a blank crucible in it so
22 we can tell what weight gain is occurring from the crucible
23 itself and generally it doesn't vary by more than +/- .3mg.
24 Each of the blocks also has a thermocouple.

25 To date, we've run these tests for up to 25,000

1 hours, the O/M essentially change as high as .4.
2 Interestingly enough, the oxidation is reproducible to about
3 10%. That means that if we take a series of samples and
4 oxidize them under the same conditions and spread in the
5 observation data, it's about 10%. We feel it's pretty good.

6 There is reasonable agreement between the rate
7 constants obtained in the short-term TGA tests and in these
8 dry bath tests. As we're getting to the lower temperatures,
9 we find that the predictions from the TGA tests tend to form
10 an upper bound, that we're getting slightly lower oxidation
11 rate constants from the dry beds.

12 The finer grain BWR fuel tends to oxidize faster
13 than the PWR fuel under all temperature and atmospheric
14 moisture conditions. It appears, though, that this isn't a
15 matter of PWR versus BWR, but a matter of grain size effect.

16 To date, we're still not sure on the affect of
17 atmospheric moisture. We're starting to see a slight effect
18 of moisture, but it is slight. It's barely coming out of the
19 data after 25,000 hours.

20 Current experiments in fuel, we are using tailored
21 samples, using only exterior fuel fragments or interior fuel
22 fragments in order to accommodate modeling needs. Currently,
23 only the long-term dry bath tests are being conducted with
24 some limited sample examination and analysis being done.

25 DR. VERINK: Is it reasonable to conjecture that the

1 temperature dependency on your uranium spots corresponds to
2 something like diffusion of oxygen in uranium or --

3 MR. EINZIGER: Within the error in the data in -- you
4 have to be careful when looking at diffusion of oxygen in
5 UO_2 . It can range over six orders of magnitude because it
6 has a strong O/M effect in it. But, in general, when you
7 look at -- it's more believable that it's in the right range,
8 yeah. It's got about the right activation energy.

9 DR. VERINK: That's fairly consistent between the
10 oxides, though?

11 MR. EINZIGER: Yeah.

12 DR. LANGMUIR: The oxidation rate is not a function of
13 P_{H_2O} , apparently. Would you think that's --

14 MR. EINZIGER: Excuse me?

15 DR. LANGMUIR: The rate is not a function of the
16 availability of moisture, as you say. Might that suggest
17 that the rate is -- moisture availability is perfectly
18 adequate at all the levels you looked at; it's not limiting?
19 That's the inference I would have.

20 MR. EINZIGER: Yes.

21 DR. VERINK: We're due for a break now and this is just
22 about right on time. So, let's take a break until 10 minutes
23 of 10:00.

24 (Whereupon, a brief recess was taken.)

25 DR. CHARLES WILSON: I'm Chuck Wilson and I'm with PNL

1 and I do spent fuel dissolution studies on actual fuel
2 specimens in the hot cell. I'm going to talk about some of
3 the properties that influence the radionuclide release
4 behavior from spent fuel and Ray already this morning gave a
5 little background on that -- and briefly describe a couple of
6 methods we used in the laboratory to do spent fuel
7 dissolution tests and then go into some highlights of results
8 from the tests that we've conducted to date.

9 Relative to release, the radionuclides in the spent
10 fuel fall under two general categories; those that are very
11 low solubility and the more soluble radionuclides. The
12 soluble radionuclides can be in either true solution or can
13 be low solubility species or adsorbed onto particulate matter
14 that are in suspension. Carol later will talk about
15 modeling. You can with thermodynamic models calculate
16 solubilities. Colloids are a little more difficult to deal
17 with with models.

18 One of the properties of the low solubility
19 nuclides which are mainly the actinides is that these reach
20 their maximum steady states and concentration in the
21 solutions fairly rapidly in the tests which would indicate
22 that the release will not be particularly dependent on the
23 characteristics of the spent fuel waste form itself. Now,
24 the more soluble species, it's a different story. In fact,
25 the tests we've conducted to date would indicate that to meet

1 the regulations you can't depend on the durability of the
2 waste form itself. You're going to have to look at other
3 waste package factors and environmental factors such as time
4 distribution of cladding container failures and low
5 probability water contact scenarios and other site-specific
6 criteria.

7 We'll go on to talking a little more about soluble
8 radionuclides in general. The spent fuel, as mentioned in
9 Ray's talk, is a non-homogeneous material. When water would
10 first contact the fuel, we'd have radionuclides that may be
11 present in the gap, fuel cladding gap, on surfaces that have
12 migrated out of the fuel during radiation and the soluble
13 species and particularly iodine and cesium dissolve almost
14 immediately on contact. So, this gap release occurs like in
15 a matter of days from first contact. After that, we'll have
16 a preferential component where we're preferentially leaching
17 soluble radionuclides from areas like grain boundaries or
18 other secondary phases of the fuel where they may concentrate
19 during irradiation. With time, assuming that the fuel
20 doesn't become substantially degraded by some environmental
21 process such as oxidation before water contact, the current
22 contention is that the dissolution rate of the UO_2 matrix
23 where most radionuclides reside will be the rate controlling
24 factor.

25 Okay. Our first tests were conducted in a recent

1 Okay. Our first tests were conducted in a recent
2 procedure we developed back in the 1983-84 time period and we
3 called them semi-static tests. And, here, we submerged the
4 specimens in the water and take periodic solution samples
5 until we reach some kind of steady state condition. Say,
6 after six months, we'll change the water and restart the
7 specimens for a second test and subsequent test cycles.
8 These tests give data on the steady state concentrations you
9 reach with the actinides and you can find secondary phases
10 forming and so it provides information on what secondary
11 phases may be controlling actinide concentrations. Also, we
12 can measure the rate of dissolution, both the instantaneous
13 gap dissolution component and the preferential and continuous
14 release components for the soluble radionuclide dissolution
15 rates.

16 One thing we can't measure in the static test
17 because uranium and the actinides saturate in solution, and
18 don't remain in solution, are the matrix dissolution rates.
19 We've completed three series of tests in the program using
20 ATM and Turkey Point spent fuels. More recently, we've been
21 working on developing flow-through techniques so we can try
22 to measure the matrix dissolution component of the fuel
23 dissolution and that, so far, is concentrated mostly on the
24 technique developments using UO_2 , although the UO_2 reviews
25 have been on actual production pre-irradiated fuel pellets.

1 one of the semi-static test systems look like. This happens
2 to be the system we used for what was called the Series 3
3 tests and these tests were conducted with two types of
4 configurations. One was the bare fuel configuration where we
5 split the cladding open and let the fuel just fall into the
6 bottom of the basket that contains, you know, the fuel where
7 everything is submerged in the groundwater. These tests used
8 J-13 water. And, another configuration where we would put
9 water-tight end fittings on clad segments and artificially
10 introduce a defect. Some of the defects were like a 200
11 micron diameter laser drilled holes or slits and then we
12 would periodically sample the solutions until we reached a
13 steady state and then terminate and go on to sequential
14 cycles with the same fuel specimen.

15 DR. PARRY: Excuse me, your J-13 water, is that
16 synthetic?

17 DR. WILSON: No, on these tests we used the water that
18 came from the actual J-13 well, you know, and we have --
19 Barrel G was how we, you know -- and then we have a Barrel F
20 and we characterized this water. Every time we use it, we
21 analyze it to kind of follow its chemistry.

22 In the flow-through apparatus we're developing --
23 and we want this to be fairly simple if we're going to apply
24 it to hot cell. Imagine the hot cell wall being right here,
25 we have a feed water container and this could be a sealed

1 vessel with a known cover gas to control the chemistry of the
2 water and we have a control flow pump and in the hot cell we
3 have a specimen column pumping this solution through and
4 collecting samples. The objective here is to measure the
5 dissolution rate for uranium and soluble radionuclides in a
6 test where all the uranium remains in solution so that we
7 know that we're measuring matrix to solution. And, it turns
8 out not to be a real easy thing to do because the uranium
9 solubility is below or fairly low -- in fact, the
10 concentrations which you get played out in adsorption effects
11 are even much below the solubility as we measure in a static
12 test. So, we have to have flow rates that are sufficiently
13 high that the uranium isn't played out, but when we raise the
14 flow rates the concentrations of water may be only in contact
15 with the fuel for a few minutes and those dissolution rates
16 to the concentrations of the soluble rate you do apply are
17 often too low to measure chemically.

18 DR. LANGMUIR: Chuck, how do you control the oxidation
19 state of the system which is --

20 DR. WILSON: Of the system?

21 DR. LANGMUIR: Which is so critical in terms of release.

22 DR. WILSON: Okay. In tests we've done on the bench,
23 this will be a sealed vessel or bubble. We'll equilibrate it
24 with a gas and then we'll have an oxygen probe that will go
25 down into the water to measure the -- the probe reads out in

1 like ppm or actually it reads out in an EMF and you use a
2 chart, a conversion chart, to convert to dissolved oxygen.
3 That's where we're at now in the developmental tests. We
4 haven't really done controlled oxygen potential tests in the
5 hot cell with real fuel yet.

6 DR. LANGMUIR: But, you're not scrubbing oxygen out of
7 the system then?

8 DR. WILSON: By scrubbing it, we're doing gas purging.
9 I'm --

10 DR. LANGMUIR: But, you're going to have finite amounts
11 of oxygen within your hot cell during the reaction?

12 DR. WILSON: Oh, yes, but this is a closed -- all this
13 tubing here is a closed system until you get to here, but we
14 run this for months. You know, we're measuring
15 concentrations over a long period of time with a controlled
16 oxygen potential solution going through there and it takes a
17 period of time to reach some steady state conditions.

18 DR. LANGMUIR: Yes, but with any oxygen at all, you're
19 oxidizing the U(IV) to U(VI) so you're going to have higher
20 solubilities?

21 DR. WILSON: Yes, this isn't an equilibrium type of
22 measurement. So, I don't think we get down to the oxygen
23 concentrations that would keep the system reducing to UO_2 ,
24 but we measure kinetic factors.

25 I'm going to just review some of the data from

1 tests and this is just a key to understand, I'm talking about
2 five air/fuel test specimens here, H.B. Robinson Series 2,
3 Series 3 at 25 degrees and 85 degrees C. I'm going to just
4 summarize some results on the actinides from these tests.
5 The result suggests that the actinide release will be
6 solubility limited and that's because we reached steady state
7 concentrations relatively rapidly in the system. However, we
8 haven't really completely assessed the affects of colloids
9 and, you know, actinides may adsorb onto suspended particles
10 in the system, whatever it be, in the repository or in the
11 tests.

12 Sample filtration results indicate that the
13 majority of the actinides, particularly americium and curium
14 measured in samples and particularly in lower temperature
15 tests were removed by filtration around suspended particles.
16 As we raised the temperature, the kinetic factors appear to
17 favor precipitation of stable secondary phases over the
18 colloid formation and the filtration effects tend to be
19 reduced. If you look at the effects of temperature and
20 filtration of a function of the actinide, we saw the greatest
21 effects with the americium and curium and next the plutonium,
22 uranium and neptunium are fairly similar, although uranium
23 had a little more temperature effect than plutonium on the
24 results.

25 Just really two points I want to make with this

1 chart. First, that the steady state concentrations are
2 reached relatively rapidly. In the first cycle, we have some
3 super saturation effects when the water first contacts fuel
4 that's been in the air for some time and the concentrations
5 decrease and then we relatively rapidly reach steady state
6 conditions in the tests. The second thing is that these
7 three tests here, the upper tests, are the 25 degrees C test
8 and we see significantly lower, like two orders of magnitude
9 lower in this case, plutonium activities in solution when we
10 raise the temperature to 85 degrees C. This is a .4
11 micronfilter. If we filter these samples, the activity drops
12 down not quite to the 85 degree C level, but it does drop
13 because of the colloid content.

14 Looking at filtration effects, this happens to be a
15 test where we're looking at americium in a 25 degree C test.
16 We see that the unfiltered and the 0.4 micronfilter data,
17 there's little difference, but there's about a two order of a
18 magnitude drop in the measured activity. In the membrane are
19 two nanometer filtered sample activities and we see as we go
20 off on to Cycle 2 that a two order of magnitude drop
21 persists. At the higher temperature, we see the recycle,
22 one, that we're rapidly decreasing in concentration or
23 activity with time and that the effect of the membrane
24 filtration at the higher temperature is much less indicating
25 that the colloids are probably less of a factor at the higher

1 temperature.

2 DR. PARRY: I think we're missing Page 11 in some of
3 these handouts. We would appreciate getting a copy.

4 DR. WILSON: Which one is Page 11?

5 DR. VERINK: The one you just used.

6 DR. WILSON: This one is not in the handout? Okay.

7 If we look at the 25 degree C results from these
8 tests which would be the more conservative results in .4
9 micronfilter samples which should include both colloidal and
10 true collusion fractions and we look at the steady state
11 concentrations that we measured and assume we have a flow
12 rate of 20 liters per year per waste package, we can
13 calculate some release rates assuming that quantity of water
14 saturates at these actinide concentrations and using those
15 parameters we calculate release rates on the order of 10^{-9} of
16 the inventory of each actinide per year which is much below
17 the 10^{-5} 10 CFR 60 limit.

18 DR. LANGMUIR: Isn't this also a strong function of
19 whatever oxygen content you had in your solution since it's
20 incongruent dissolution?

21 DR. WILSON: Yeah, if this was a -- well, I don't think
22 it has much to do with congruent dissolution. It has to do
23 --

24 DR. LANGMUIR: Well, no, it isn't. But, the rate of
25 dissolution of the UO_2 which is the key to all of this is

1 function of the oxygen.

2 DR. WILSON: I don't think the rate of dissolution of
3 the UO_2 has much to do with what these concentrations are.
4 Carol will be talking about this more later. This is
5 determined really by chemistry in the repository.

6 DR. LANGMUIR: I don't see how. I mean, if you're
7 talking about -- you're putting water through the system.

8 DR. WILSON: This isn't a flow-through. This is static
9 test.

10 DR. LANGMUIR: That's static, but the release rate will
11 be a function of a reaction which involves oxygen and UO_2 .

12 DR. WILSON: Well, the release rate is a function of how
13 much water is becoming saturated at these concentrations and
14 it has nothing to do with the dissolution rate of the fuel.

15 DR. LANGMUIR: But, your product is a U(VI) product.

16 DR. WILSON: Right.

17 DR. LANGMUIR: You're taking it from U(IV) to U(VI)
18 which is an oxidation process.

19 DR. WILSON: Yeah, I'm assuming that there's oxygen in
20 the repository and at that rate the oxidation and dissolution
21 of the uranium and the actinides into the solution occurs
22 rapidly compared to the time that it takes to transport the
23 water. I can talk --

24 DR. LANGMUIR: We can talk about it later.

25 DR. WILSON: Okay. We're going to talk about it later

1 because I'm running out of time. This figure just shows a
2 particle out of -- this is a fuel particle that's been in
3 tests in J-13 water for about a year and a half and we can
4 see the grains of the fuel and grain boundary grooving and
5 dissolution along here and then we see all these cycular
6 crystal phases which turn out to be uranophane which is a
7 calcium/uranium silicate that's forming on the surface of the
8 fuel. As the fuel dissolves, the uranium isn't going very
9 far and it's these crystals that are determining at the
10 uranium concentration, presumably some other phase will be
11 determining plutonium and americium concentrations. And, so
12 it's not really dependent on how fast this fuel is
13 dissolving. It's really more related to these other phases.

14 DR. LANGMUIR: Well, where does the silica come from?

15 DR. WILSON: The silica is in the J-13 water and so is
16 the calcium. And, the rock in the repository has a lot of
17 silica in it. So, we presume it's going to be in the water.

18 Okay. This is kind of a summary of some of the
19 soluble radionuclide release data. Technetium, cesium,
20 strontium, and iodine in terms of inventory fraction per year
21 released in these tests were on the order of like 10^{-4} per
22 year at 25 degrees C and went up by a factor of about 600% in
23 the 85 degrees C experiments in the range close to like 10^{-3}
24 per year or slightly less or in the range shown, 3 times 10^{-4}
25 to 1.2 times 10^{-3} were measured.

1 Carbon-14 tended to be preferentially released even
2 farther into the test than just a gap inventory measurement
3 and, in fact, 1% of the specimen inventory in the test
4 conducted in sealed vessels were measured as being released
5 in the first year of the test. And, this release was
6 primarily from gap and grain boundaries, but not much of it
7 appeared to be from cladding exterior. And, it wasn't from
8 fission gas either. This was dissolved out of the fuel, this
9 carbon-14, and if we conducted the tests in unsealed vessels,
10 we really didn't measure it because it was lost as CO₂.

11 This figure kind of shows the relative activities
12 of all the different radionuclides we measured in solutions
13 during the test. You can see it spanned a range on this plot
14 of 11 orders of magnitude. The most active radioactive
15 species in the young fuel, of course, are the shorter half-
16 life cesium-137, strontium-90, which in a couple hundred
17 years have decayed out, but the longer half life soluble
18 species like carbon-14, technetium-99, cesium-137, iodine-
19 129, you know, these all have half lives on the order of
20 thousands of years or greater. In Cycle 3, I've shown the
21 solubility limited activities of plutonium and americium
22 isotopes that we also measured in solution just for a
23 comparison.

24 If we look at this data in terms of fraction of
25 inventory released over given periods of time -- and here I'm

1 plotting inventory fraction measured in solution versus time
2 -- we see the gap inventory release of cesium-137, a fairly
3 strong preferential release of Cycle 1 of carbon-14 and
4 iodine-129. The cesium and technetium and iodine are much
5 lower in the sequential cycles, but the carbon-14 is still
6 being released at a substantial preferential component of
7 release.

8 DR. PARRY: When you speak of inventory, you mean
9 inventory within the --

10 DR. WILSON: In the fuel. This is inventory in the fuel
11 plus the cladding in the case of carbon-14, but it's the
12 inventory that was in the sample that was in the test.

13 DR. PARRY: How did you measure that inventory? By
14 burnup?

15 DR. WILSON: Well, carbon-14 was measured radio-
16 chemically in the same lab we did the measurements on the
17 leach solution samples. And, the cesium and iodine and other
18 radionuclide activities, we used ORIGEN code output for the
19 fuel that we used.

20 This is pretty much just a repeat of the previous
21 slide. It happens to be a different test, but it just
22 magnified the scale of Cycle 2 and 3 that show that these
23 soluble radionuclides are being continuously released with
24 time. And, in this slide, it looks like it's close to a
25 congruent release.

1 Here, I want to show the effects of temperature and
2 oxidation to key variables in the release. We've got four
3 identical Turkey Point fuels except for two of them were
4 oxidized to both O/M's of 2.21 and 2.33. We've got one of
5 the unoxidized samples, at 25 degrees C test and one at an 85
6 degree C test, and the two oxidized samples, both at 25
7 degrees C, and we can see that the oxidation caused
8 substantial increase in the false release or gap release
9 component of technetium. And, the temperature effect again
10 was about a factor of six and that preferential release as a
11 result of oxidation for technetium carried on into the second
12 test cycle and these tests are still going. We're at about,
13 oh, 1300 days on these two tests now.

14 DR. LANGMUIR: Chuck, the O/M ratio is the --

15 DR. WILSON: Oxygen to metal ratio.

16 REPORTER: Could you repeat the question? I couldn't
17 hear you?

18 DR. WILSON: The O/M ratio of the fuel is the oxygen to
19 metal ratio, the bulk oxygen to metal ratio in the fuel.

20 DR. LANGMUIR: So, basically, it's UO_2 at the low end
21 and $UO_{2.33}$ at the top end of that?

22 DR. WILSON: Yes. Right. And, that's a bulk, that's
23 not a particular phase.

24 DR. PARRY: Chuck, I'm sorry to trouble you, but would
25 you go back to #16, please?

1 DR. WILSON: Let's see, okay.

2 DR. PARRY: I just want to check the dimensions there on
3 the left hand side. Is that 1% or --

4 DR. WILSON: This is 1% release or close to 1% of the
5 cesium-137 in the tests was released almost immediately or
6 .9%, as soon as the water contacted it in this particular
7 fuel. Another fuel that maybe have a different gas release
8 for the fuel, like the H.B. Robinson fuel -- this is the H.B.
9 Robinson fuel. Turkey Point fuel release a half of 1% of the
10 cesium on initial contact.

11 DR. PARRY: Thank you, I misunderstood you.

12 DR. WILSON: Okay. Every time I try to explain this
13 slide, I get tied up. So, I just want to make a couple
14 points here. This kind of shows some of the effects in a
15 flow-through test that you can measure of water composition
16 and temperature and I'd like to use this for a bit of also an
17 introduction of the next topic by Herman Leider because he's
18 going to talk about doing these types of tests in more
19 detail. But, what we're seeing here is we're starting in J-
20 13 water. We change to a dilute bicarbonate, the same
21 bicarbonate concentration in J-13. We increase by a couple
22 of orders of magnitude and we started putting things back
23 into it like the silicon and the calcium. The dissolution
24 rate drops, just a constant flow. So, this is also a
25 proportional dissolution rate. And then, we see an

1 irreversible effect when we raise temperature which led us to
2 the conclusion that something has to be precipitating out or
3 happening. We may not even be measuring dissolution rate.
4 We started examining after that the surfaces of the
5 particles, the UO_2 particles, first on an electron
6 microscope. We couldn't see anything, but when we started
7 looking at it in the Auger microprobe we were able to detect
8 that we formed very thin, like 50 angstrom layers of a
9 calcium silicate containing layer on the surface that was
10 apparently formed and acted as a kinetic barrier and made
11 these tests irreversible. But, we were able to partially
12 dissolve that layer off by going back to deionized water or
13 more rapidly we dissolved it off by going back to
14 bicarbonate.

15 This is just an example of another test which this
16 data has been run out somewhat further and we've done some
17 different oxygen potentials after this data was taken. But,
18 it just shows that there is an effect of reducing oxygen
19 potential in the solution. This is air-saturated deionized
20 water, about 8ppm dissolved oxygen. We've Argon sparged it
21 and the oxygen potential with time went down to about -- or I
22 shouldn't say potential, concentration when down to about
23 10ppm of dissolved oxygen, a substantial decrease in the rate
24 of dissolution. We went back to the air sparged system. We
25 immediately increased and then we just run the air cover.

1 DR. LANGMUIR: In your previous experiments, did you
2 have well-defined control on this option content? Did you
3 know what it was?

4 DR. WILSON: We didn't measure it, per se, like we did
5 with the probe here. It just was air equilibrated solutions.

6 DR. LANGMUIR: In all cases it was air?

7 DR. WILSON: In all the semi-static tests, it was pretty
8 much air equilibrated solutions, air cover in the
9 experiments.

10 Okay. It looks like I'm about out of time here,
11 but kind of in summary, the actinides in the tests appear to
12 reach solubility of limited concentrations fairly rapidly.
13 So that would indicate the release should be solubility
14 limited. Soluble nuclides, though, will be somewhat more
15 complicated to model because the fuel is a non-homogeneous
16 material. We have the gap and grain boundary, matrix release
17 components, plus the fuel is likely to change with time as a
18 result of oxidation or degradation of the fuel in the
19 repository and oxidations, grain boundary dissolution can
20 cause an increased surface area over time. But, for the
21 samples we did run, we found that there are gap releases of
22 cesium and carbon-14 on the order of 1% of the inventory in
23 the first year. And, for other soluble radionuclides in
24 later test cycles, technetium-99, cesium, strontium, and
25 iodine we measured release rates generally in the range of

1 10^{-4} to 10^{-3} of the inventory per year in later test cycles.

2 There's a lot of things that we really haven't
3 figured out yet about what's going on. And, some of the
4 things that would be good additional information needs would
5 be radionuclide distributions in the spent fuel. This is
6 something that has been done through MCC and currently there
7 isn't a lot of activity there, but in particular, it would be
8 nice to know a little more about the carbon-14 distribution
9 in the fuel itself. The dissolution behavior of oxidized
10 fuel and other fuel types such as high gas release fuels, we
11 really haven't done that yet. The effects of colloids, the
12 actinides that sorb out onto colloids are already in the
13 groundwaters and how do colloids come about and what are they
14 and what are their effects? That will particularly have an
15 effect on this conclusion up here. The effects of water
16 conditions on matrix dissolution rates. Herman is going to
17 talk about this a little more in the next paper, but it's
18 something that we've just scratched the surface on.

19 In the models that are available to date for
20 modeling spent fuel radionuclide dissolution behavior are
21 similar to the types used on glass where you have a known
22 surface area and you don't have that in spent fuel. It's
23 going to change with time and it's difficult to measure, and
24 to use these types of models, we really need some kind of
25 time dependent model for the surface area of the exposed

1 surface area of the fuel on how it evolves with time.

2 Everything I've presented has actually been
3 published in different documents and I gave Helen a copy of
4 four references which describe most of this data in more
5 detail and she'll make those available to the panel members.

6 The next talk, Herman Leider will be talking about
7 dissolution experiments on UO_2 and experiments to make some
8 of the measurements I was talking about in the last
9 conclusion.

10 DR. HERMAN LEIDER: I'm going to describe to you how
11 good it's going to be. These are experiments we're about to
12 begin at Lawrence Livermore; in fact, they're imminent. They
13 may even have begun today, but I'm not quite sure. This will
14 be on undersaturated flowing dynamic dissolution tests on
15 uranium dioxide.

16 In anticipation of possibly your first question,
17 why study UO_2 ? Basically this is a study in chase of a
18 mechanistic model for dissolution of spent fuel and what we
19 have to do is be able to describe the basic maker's
20 dissolution first. Irradiated fuel is a rather complicated
21 chemical mixture and so we feel it is essential to be able to
22 describe the dissolution of uranium dioxide, per se, at least
23 uranium dioxide in contact with a number of chemical
24 conditions. Once we do this, we can make a direct comparison
25 with spent fuel and, in principle, learn a lot of things

1 about the effect of the presence fission products in the
2 matrix which are to several percent usually in an irradiated
3 fuel. We can examine the suspected, at least postulated,
4 chemical effects of the irradiation field in changing the
5 chemistry of the water because of the high activity near the
6 fuel and we can possibly have a good deal to say about the
7 contribution of grain boundary to solution since they are a
8 source of the some of the fission products which are exolved
9 from the irradiated fuel.

10 Your second question would be my second question,
11 too. Do we need any more experiments? It's a big
12 literature. And, the answer is yes because there's lot of
13 data and it's not self-consistent nor is it useful for our
14 purposes. I'll show you some of this.

15 For instance, these are published dissolution rates
16 for uranium dioxide, initially uranium dioxide, under various
17 conditions. Some spent fuel is included. It doesn't take
18 too much of a careful look to see there are orders of
19 magnitude differences as a function of pH is the way this is
20 plotted.

21 DR. LANGMUIR: Is it largely because of the oxygen
22 concentrations not being --

23 DR. LEIDER: I believe that's partly because of
24 inadvertent lack of control on important things like oxygen
25 potential. It's also due to deliberate differences which

1 people didn't recognize as important, say, in water
2 composition.

3 DR. LANGMUIR: Complexation.

4 DR. LEIDER: Yes. There's lots of things that were
5 never done carefully and well-defined. That's why we have to
6 do this, I believe.

7 It's not just the rates of the dissolution that are
8 scattered. The solubilities as reported in the literature
9 are pretty bad, especially for tetravalent uranium which is
10 less important for our case because we expect oxidizing
11 conditions. For uranium-6, there's a big scatter, less than
12 in 4, but a big scatter. So, we don't even know very well
13 the equilibrium concentrations of saturated solutions,
14 saturated in the sense of the solute being dissolved. And,
15 to some extent, I'm guilty of this. Some of the old data was
16 mine.

17 DR. LANGMUIR: Do you have the data from Parks & Pohl in
18 here?

19 DR. LEIDER: I do.

20 DR. LANGMUIR: That's after '88, isn't it?

21 DR. LEIDER: That's in there, too. This came from a
22 recent SKB report and I believe that's included. They
23 referenced all their points, but I took it off because it
24 complicated the viewgraph. However, this particular report
25 listed on the bottom does have all the sources for this.

1 Static or semi-static tests do have this
2 limitation. These are the kind of things that Chuck Wilson
3 just reported to you being done on spent fuel and they're
4 essential on spent fuel. It's very hard to do much with
5 extremely hot material. But, the static or semi-static tests
6 can't give you rates except for the very soluble materials
7 which you can see build up in time. They will give you
8 solubility levels at steady state. So, we want to do dynamic
9 tests to be able to determine rates, as well as saturated
10 conditions.

11 Now, in the unsaturated flow tests for many
12 important species in spent fuel, but certainly for your
13 uranium which is what we're going to be studying, per se, you
14 can produce measurable concentrations. So, you can measure
15 what you get out of a product in the flowing system. This is
16 also true for things like cesium and strontium. Some of the
17 others may be below detection limits and they'll have to be
18 looked at in detail. Analytical techniques have limitations.
19 I don't know exactly how many fission products you can
20 accurately determine with this method, but you can certainly
21 do uranium.

22 In the tests we're proposing, we will be far below
23 the saturation level of a solute and we will be using what
24 amounts to simplified water. We will not use J-13 well water
25 which contains many components. We will use certain

1 simplifications so that we don't have the complication of
2 secondary failures precipitating.

3 The philosophy of these measurements is precisely
4 the same really as what you heard described for the glass
5 dissolution. In fact, the apparatus and the techniques are
6 very similar to what Kevin and Bill Bourcier talked about
7 yesterday. We expect in a flow-through test -- and you will
8 know this expectation is right since Chuck showed you a slide
9 already -- that we will plot the inverse flow rate versus
10 concentration you achieve and it will be linear. And, the
11 slope of the plot will give you a dissolution rate and he
12 already showed you that's largely so, at least in the
13 preliminary tests. We can measure solubility directly.
14 Basically, you get to slow enough flow rates and you've got a
15 static condition. And, so if you have this slope which goes
16 up and then bends over, or you plain stop and measure when it
17 gets to be static, you can get solubility in these
18 experiments, as well.

19 The last is a point for people who are interested
20 in a lot of details about dissolution properties. I'm sure
21 it's a case if you see a change in slope while in the
22 unsaturated condition, you're looking at a change in
23 mechanism. We don't anticipate this, but at least we'll be
24 able to see it if it happens. So, surprises can be dealt
25 with in this kind of a measurement. Surprises can be

1 recognized, I cannot say dealt with.

2 Here is something you saw shortly a little time ago
3 by Chuck Wilson. This is his flow-through dynamic tests on
4 UO_2 unirradiated fuel in this case. He did it in deionized
5 water and in synthetic J-13 water. In both cases, you've got
6 a pretty good linear relationship between the reciprocal of
7 the flow rate and the uranium concentration. And, the slope
8 is the rate. So, we know this is going to work pretty well,
9 and once we start, it is going to be wonderful.

10 We will use simplified solutions. We are going to
11 limit the variables in the water to pH, that is hydrogen/ion
12 concentration, to carbonate/bicarbonate concentrations which
13 are the complexing agents that will enhance solubility of
14 uranium, hexavalent uranium, of course, and the oxygen
15 activity or concentration, if you like, because the oxygen
16 will be crucial here in getting to that hexavalent state
17 which is the soluble or much more soluble version. And, in
18 principle, you can see it, but the limiting material we'll be
19 looking at is something like schoepite which is uranium
20 trioxide all the way up.

21 Under repository-like conditions, you know, the
22 other constituents of the water you expect, such as the J-13
23 water, which has silica and calcium will definitely produce a
24 lot of insoluble secondary phases which will be solubility
25 limiting. Interpretation of this complex system is probably

1 beyond our means and so that's why we're simplifying it.
2 And, in any event, these will produce lower levels of
3 concentrations than it will without them. So, we're looking
4 at the worst case which is what you want to do for modeling
5 purposes. Because if you don't look at the worst case,
6 you're not predicting safely.

7 Now, if you'll look at irradiated fuel, you're
8 going to have radionuclides that are not uranium from three
9 sources. These have been alluded to a number of times. I'm
10 not going to bore you with this. The gap which is volatiles
11 released external to the fuel and is immediately available
12 for dissolution. Stuff that's gone out of the grain because
13 of insolubilities into the grain boundaries to form other
14 phases which are going to behave differently kinetically
15 because they're more accessible in principle than in the
16 stuff that dissolved in the matrix. And, the matrix itself,
17 the flow-through tests are going to attack mainly an
18 exploration of the bottom one. We hope to be able to, by
19 inference, say something about the others.

20 A schematic of this, it's somewhat different than
21 ones you've seen before, but I like it. I just like it.
22 But, it simply shows the total release rate, not release, and
23 it's plotted on a log/log. Seal (phonetic) as a function of
24 time with the total being the upper envelope that covers
25 everything. We have a constant contribution presumably from

1 matrix dissolution. You have a very fast and quickly
2 decaying contribution from the gap, the stuff that's free
3 immediately. It goes in and then it's gone. And, the grain
4 boundaries are faster than the matrix in principle and will
5 -- you can see stuff nearer the surface in the grain boundary
6 will go pretty fast. And, if the water has to penetrate
7 deeper and deeper, it will slow down. Eventually, everything
8 will asymptotically approach the matrix given enough time,
9 whatever that happens to be. We hope to say something about
10 that with our experiments.

11 Now, this is not to say people don't understand
12 anything about dissolution, they certainly do. Going back to
13 a very elementary text, you say, hey, people have decent
14 models that describe dissolution. This is back in the early
15 parts of this century. An equation like this which describes
16 the rate of dissolution of a non-dissociating material. It's
17 a function of how quickly the solution becomes concentrated
18 in the solute. This describes lots of things very well.
19 However, we're dealing with ionic materials. So, even
20 starting with such a simple model -- and this isn't so awful
21 as you might think because it's so easy to look at --
22 complicates things because once you start getting ions you
23 start complicating the chemistry of it.

24 Now, this is a very overly simple equation for
25 dissolution of UO_2 and it's just a pedantic tool here. So,

1 disregard the formation of +4 ion which people in solution
2 chemistry know is not something you're going to find. But,
3 in this case, it's simply illustrative that when you dissolve
4 an ionic material, you make ions. Other things strongly
5 influence your dissolution properties. For instance, in this
6 case, you can see that it's very strongly dependent on the
7 4th power, in fact, of the hydroxyl ion concentration and
8 thus on the pH, the 4th power of pH which is -- water
9 constant related directly. And, so already we've come to our
10 first complication.

11 Now, a schematic of what happens when you immerse
12 UO_2 or spent fuel into water of some sort and we'll say
13 whatever repository water is, this water is going to have
14 some oxygen dissolved in it. There's going to be some
15 oxidation potential. It's going to oxidize to a certain
16 degree, the surface of the UO_2 . What's more, the water is
17 going to be contain things other than water. The L written
18 in this equation are some undefined cation. In our case, we
19 could say that's bicarbonate. These things will form a
20 stable complex with uranyl ion, for instance, which dissolves
21 from the oxidized fuel and make it more soluble than it would
22 otherwise be. All this has got to be considered. As I say,
23 this is in simply for schematic purposes.

24 When we look at what happens in the UO_2 , there's a
25 lot of things that may determine the rate of dissolution. We

1 know it's going to oxidize. We don't know for sure how it's
2 going to oxidize, whether it's going to be molecular oxygen
3 dissolved in the water making the uranium oxide go to a
4 higher state or whether the oxygen is going to have to adsorb
5 on the surface of the solid and dissociate into ions or
6 whether it has to dissolve in the solid. All these things
7 are possible.

8 The point I'm making here is, for instance, the
9 dependence on external parameters for these processes are
10 understood. We don't know which ones are important, but we
11 can describe them sort of in first principles. And, once you
12 make it oxidized and you have it in the water, especially in
13 our case when we're talking about carbonate/bicarbonate, you
14 have all these processes that go on in solution as part of
15 the dissolution process. These aren't exhaustive, but it's
16 simply an exposition that there are a lot of things we
17 understand might happen, probably do happen, and we can
18 describe their dependencies on basic properties of the system
19 accurately. We just don't know which ones are important yet
20 without doing the tests, but we know which ones are probably
21 involved. Some of these are going to be involved and
22 unimportant. You can throw them out in the model.

23 We decided because of the variables even in the
24 simplified solutions that the only sensible way to deal with
25 this in an economical fashion, and I mean economical in the

1 real sense, is to do a statistical approach. We have
2 designed an experimental matrix using a commercially
3 available program, for instance, a well-defined mathematical
4 technique for doing statistics on an array of variables in
5 experiment which will allow us in a set of reasonable tests,
6 which may be done simultaneously in part, to determine the
7 interaction between these various parameters, say, the
8 bicarbonate, the temperature, the oxygen, et cetera, and
9 determine the relationships between them in a quadratic
10 fashion. That is take an equation and give it to you in
11 terms of a polynomial, $a + bx + cx^2$. Now, these aren't first
12 principle relationships, but we do know the first principle
13 format of a relationship and can decide which ones fit a
14 quadratic or a linear one, at best. This will not only give
15 us an actual empirical relationship for the conditions we
16 look at, but will allow us to decide which of the theoretical
17 forms fit it best. Anyway, this allows us to get a lot of
18 information that one by one variation of parameters will take
19 years to do. Hopefully, this will not take years.

20 Here's an example, a little bit hokey in terms of
21 the top scale, but this is what we're going to do is describe
22 the matrix of 19 experiments which include replication in the
23 alkaline region, that is, you can see the pH in this case is
24 going to range from 8 to 10. At least, that's written down.
25 We're going to look at temperature between 25 and 75 or it

1 could be any range we chose, you know, zero and 100. We're
2 going to look at the activity of -- in this case it should be
3 the carbonate/bicarbonate concentrations. In the acid case,
4 it will be the gaseous activity which determines the
5 solubility of CO_2 and the oxygen activity. This matrix is
6 easily achieved. It's not too horrible in these flow-through
7 tests to do. That's only 19 tests. We may be running six at
8 a time. And, we can get a lot of information out of it and
9 I'm convinced that the only way to look at a system this
10 complicated is from a statistical point of view.

11 Now, if we look at what we're going to do with
12 spent fuel, we will do the same thing ideally. I don't know
13 if Chuck is smiling or groaning back there, but at least
14 within the limitations of what you can do in hot cells, we're
15 going to try and repeat as many of the elements in that
16 matrix or in such a matrix as we can with spent fuel so we
17 have a direct comparison. And, this will, in principle,
18 allow us to extract the differences in behavior due to the
19 differences in composition because of the fissioning that
20 went on or the irradiation that went on.

21 We're also looking at some interesting, new, and
22 novel techniques that are very sensitive for looking at the
23 process, one of which has been explored a bit for us by Rick
24 Russo at LBL in Berkeley and this is a technique which is
25 called spectro-electrochemistry. But, basically, let me just

1 tell you what it is. They do the electrochemistry using a
2 uranium oxide probe and they establish an oxidation potential
3 electrically and they use a parallel beam of a laser which is
4 deflected and it's deflected because of gradients in the
5 refractive index due to both concentrations of chemical
6 species or thermal gradients that are produced during the
7 reaction. And, in principle, can also do spectroscopy
8 simultaneously because if you use a laser and you're watching
9 it deflect, you can also tune it on a transition you want and
10 see something come in or go away.

11 The other thing which is a little easier for me to
12 visualize is using scanning atomic scale microscopy. This is
13 new stuff. This includes scanning tunneling microscopy and
14 atomic force microscopy. This is stuff that's available at
15 the laboratory right now at our laboratory. Siekhaus and
16 Balooch are operating these now. Both of them are available
17 and will operate under water. They'll operate under real
18 conditions and you have in principle the capability of seeing
19 on a given flat surface, pretty flat surface, an atomic layer
20 disappearing and the rate at which it disappears. This is a
21 direct measurement of rate without having to fool around with
22 anything else. You just watch it go away. This has been
23 done. They've done it recently on oxidation of pyrolytic
24 graphite. This is not a related thing. But, they've watched
25 it oxidize layer by layer and they can measure how far, atom

1 by atom, how fast it goes away. You're seeing things that
2 under conventional techniques are 12 orders of magnitude too
3 slow to measure. That's nice. We hope this will pan out for
4 us. That's a very good check, by the way, on any model we
5 have because if you don't fit that observation, you're in
6 trouble.

7 So, in summary, we think we have found a way to do
8 tests in a satisfactory fashion which are statistically
9 satisfying. We have an environmental system capable of the
10 fine control necessary to eliminate the variables that cause
11 -- scatter in data. We're about to start and it's going to
12 be great.

13 Thank you.

14 DR. VERINK: At this stage, if there are no questions, I
15 will introduce someone who probably knows more and is
16 prettier than I am. Carol Bruton will come up and tell you
17 all about the geochemical implications of all this and the
18 value of EQ 3/6 code.

19 MS. CAROL BRUTON: What I'd like to do today, is to
20 discuss some geochemical modeling work we've been doing. The
21 modeling of dissolution of spent fuel. So, the planned
22 outline for today is to first give you an idea of what
23 geochemical modeling is, what the tools we are using are, and
24 then to give you a conceptual idea of how the models work.
25 And then I'm going to show you some sample simulation results

1 and compare the simulation results to the results that Chuck
2 Wilson has got in his hot cell test. Then we want to
3 investigate implication of changing water chemistry on our
4 simulation results. And, in conclusion to give you an
5 indication of what important variables that we must consider
6 in trying to predict radionuclide concentrations in solution.

7 Why do we use geochemical modeling? Because, we are
8 being asked to evaluate nuclear waste repository performances
9 over time periods as great as ten thousand years in response
10 to a wide number of variables, such as temperature, fluid flow
11 and other conditions. Now the traditional approach to this
12 type of problem is to set up an experimental program which we
13 have done. But obviously in any experimental program, there
14 are a number of limitations, such as we are restricted to a
15 laboratory time scale of a number of years, or if we have to
16 make predictions, we are up to ten thousand years.

17 In addition, for a given experiment, you can only
18 set a given number of variables in their combination. So when
19 we are asked to evaluate performance under a different set of
20 conditions, it can be difficult. And that leaves the last
21 one, it's very difficult to extrapolate the results of one
22 experiment to multiple repository scenarios.

23 That's why we are suggesting that the most powerful
24 combination to attack these problems is to combine the
25 experiments with geochemical modeling. The combination of

1 them is more powerful than experiments alone or geochemical
2 modeling alone. By using this combination, we hope to develop
3 quantitative process oriented models of repository response.
4 And yesterday you heard one of the best examples of that in
5 Kevin Knauss and Bill Bourcier's work in their developing a
6 kinetic model for glass waste form dissolution.

7 Once we have these process oriented models, we can
8 simulate complex interplay among the proxies that control
9 rates of waste form degradation. And ultimately to predict
10 the changes in the chemical environment that will occur
11 throughout the post-closure period.

12 The geochemical tools that I am using for the
13 simulations you'll see is the EQ3/6 software package. Now
14 it's composed of two codes. EQ3 which is an aqueous species
15 distribution code and EQ6 which is the more interesting one,
16 because that actually carries out the dynamic simulation of
17 interaction among host rocks, repository components and the
18 fluids. Now both of these codes are based on fundamental
19 thermodynamic principles. And thus, they both call upon
20 common thermodynamic data bases with data for almost 2,000
21 solids, gases, and both inorganic and organic aqueous species.

22 Now since the simulation was made using EQ6, what
23 I'd like to give you now is a conceptual overview of how EQ6
24 works and then you'll have a better understanding of how I got
25 the results.

1 What I've got now is a series of three color
2 overlays which are compressed into one black and white one in
3 your handout. Okay, how does EQ6 work? How do I model in the
4 interaction of a solid phase in the presence of a fluid? Well
5 the first thing you do is you give it the composition of your
6 starting phase whether that be a spent fuel pellet or glass as
7 Phil was doing yesterday. And then you specify the rate at
8 which the components of this spent fuel pellet in this case
9 are released into the solution. Now if you have a rate
10 equation such as you have for glass, then use that absolute
11 rate equation. If you have no rate equation, you can assume
12 the dissolution is congruent. Or for spent fuel, we may want
13 to assume that the grain and gap boundary components are at
14 least a little bit faster.

15 Now since this simulation was done for spent fuel
16 before we had a kinetic rate equation, I assume that the
17 components of the spent fuel were released congruently into
18 the adjacent solution. And by congruently, I mean that they
19 were released in proportion to their quantity in the initial
20 spent fuel pellet.

21 Well the next step in the code is to calculate the
22 species distribution of these elements released in solution.
23 Carbon gets released in solution and it speciates as a
24 carbonate and a bicarbonate species. You'll see that when
25 uranium goes into solution it forms a uranyl ion. And then

1 the uranyl ion sees this carbonate in the solution and
2 combines to form a uranyl carbonate. That's a function of
3 EQ3.

4 Now the powers of geochemical modeling approach is
5 in the next step. When you look at the composition of the
6 solution and check to see whether you are saturated or super-
7 saturated with respect to any solid phases, for example, this
8 spent fuel, are we saturated with respect to the calcium
9 uranium silicate haiweeite. If the code finds for super-
10 saturated with respect to any solids, it will simulate the
11 precipitation of these phases until we produce a secondary
12 phase assemblage. And you see, for each thing it precipitates
13 it has to revise the fluid chemistry. So once the solution
14 has come back down to equilibrium for the secondary set of
15 phases, you go right back to the beginning, dissolve a little
16 bit more of the spent fuel, change the solution composition,
17 check for precipitates and so on. So through the simulation,
18 you can see we will predict the sequence and the identity of
19 the solid precipitates that form as we dissolve the spent
20 fuel, and also how the fluid chemistry changes as it
21 dissolves.

22 Okay, now we'll look at some simulation results.
23 What I did was to take a representative PWR spent fuel
24 composition, which included both fuel and non-fuel components,
25 that is sub-components from the zircaloy cladding and hardware

1 and I dissolve it in J-13 water at 25 degrees centigrade.
2 What I predicted was the solid base that precipitated and the
3 changing composition aqueous phase concentrating on the
4 radionuclide concentrations in and solution.

5 Okay, this is the set of solid that precipitated as
6 I dissolved that spent fuel. The horizontal bars here refer
7 to the stability ranges of each solid phase. And for your
8 information, on the next page of your handout, I won't show
9 it, it's got the names of these minerals and their
10 compositions in case you are curious.

11 So you will notice that I've expressed the sequence
12 of solid phases in terms of the amount of spent fuel that got
13 dissolved. The log of the grams of dissolved spent fuel per
14 kilogram water. This axis is our proxy for time. When we get
15 a kinetic rate equation, you will see on this axis time, but,
16 for the time being now, we're just calculating the extent of
17 reactions in terms of the grams of spent fuel dissolution.

18 Now there are about 25 components in this spent
19 fuel. And you see we get a wide range of solid precipitates.
20 Those in the beginning ranging to those that are more
21 representative of J-13 water and those at the end more
22 representative of the components in spent fuel. But rather
23 than going through this whole thing, what I'd like to do is
24 concentrate on the results for three radionuclides, uranium,
25 neptunium and plutonium, look at the solid phases and then see

1 how the solid phases control the composition of the
2 radionuclides in solution.

3 Okay, let's look at the results for uranium first.
4 On the top part of the diagram, what I've done is to excerpt
5 from that paragenesis plot the stability phase of minerals;
6 the three phases that precipitated to sequester uranium.
7 Haiweeite, which is a calcium uranium silicate, soddyite a
8 uranium silicate and schoepite which is a hydrated uranium
9 oxide.

10 Now look at how the precipitation of these phases
11 were affected by the composition of the solution. On the
12 bottom part of the diagram here, I plotted the elemental
13 concentrations in milligrams per kilogram of silica and
14 uranium. Again as a function of the amount of spent fuel
15 dissolution. As long as the silica in solution was high and
16 it is high in J-13 water, uranium concentrations were
17 maintained at the .03 milligram per kilogram level. But as
18 soon as I depleted the solution in silica, uranium increased
19 in the concentration to over 10ppm.

20 This suggests that as long as we have sufficient
21 quantities of silica in J-13 water to support the
22 precipitation of uranium silicates we'll keep uranium low in
23 solution. Now I should mention here Chuck Wilson did observe
24 the precipitation of haiweeite and soddyite in his
25 experiments. He also observed precipitation of uranophane,

1 which is another calcium uranium silicate. But unfortunately
2 the data in the data base for uranophane was actually
3 estimated by Don Langmuir and is not precipitating in the
4 runs. I think we have to do more calorimetric studies on
5 uranophane.

6 DR. LANGMUIR: Just an estimate.

7 MS. BRUTON: Okay, let's compare it with the results of
8 Chuck Wilson and his studies of Series 3 at 25 degrees
9 centigrade with H. B. Robinson fuel. This is the
10 concentration of uranium he measured, about .3 milligrams per
11 kilogram in solution. A little bit higher than our predicted
12 .03, but we'll see a little bit later there are other probable
13 explanations for that.

14 But it does suggest there are sufficient silica in
15 Wilson's water to maintain relatively low concentrations of
16 uranium in solution.

17 Let's turn to neptunium. Look at the same diagram
18 here. These are simulation results at 25 degrees centigrade.
19 Now neptunium is a little bit different. There was only one
20 phase that precipitated to sequester neptunium. That was
21 neptunium oxide. And I made the initial simulations assuming
22 atmospheric conditions, a fergacity (phonetic) of oxygen in
23 equilibrium with the atmosphere.

24 And my neptunium precipitated late in the sequence.
25 When I look at the log of my neptunium concentration in

1 molality it increased in solution until I started
2 precipitating neptunium oxide. When you look at the results
3 of Wilson, and he measured neptunium concentrations not at 10^6
4 ⁶, but 10^9 . But we know that the neptunium concentration in
5 solution is very dependent on the redox potential. And so
6 when I artificially went in and made another simulation
7 assuming that the fergacity of oxygen of 10^{-12} , we obtained a
8 much better match to Wilson's experimental results.

9 Now Chuck has just mentioned that he did not control
10 or he did not measure the redox state in his vessel. And he
11 did have air cap in it. These results may suggest that we
12 would have to consider gradations in the redox potential in
13 these reaction vessels.

14 The next diagram we see, actually I tried to
15 explicitly show the dependence of neptunium solubilities on Eh
16 and pH. This is called a Pourbaix or Eh and pH diagram and
17 I've tried to simplify it a bit. On the Y axis, the Eh in
18 volts, on the X axis, the pH. And what I have contoured here
19 are the molalities of neptunium in equilibrium and neptunium
20 oxide as a function of Eh and pH. And what you can see is
21 that we started our run at about a pH of 8 and under very
22 oxidizing conditions you can see how a very small change in Eh
23 can drastically change neptunium concentrations in solution.
24 That suggests in a repository scenario that we are going to
25 have to have some idea of what controls the redox state to be

1 able to predict what neptunium concentration would be in
2 solution.

3 Now for plutonium, is that also dependent on Eh or
4 pH or on something else? When we take the same type of
5 diagram, Eh and pH, and these contours are now for the allowed
6 molality of plutonium in equilibrium of PuO_2 . And again you
7 can see that under pH of about 8, as in many of these
8 experiments, that the concentration plutonium is highly
9 dependent on the Eh. There's another factor that we have to
10 consider in plutonium. And that is it's not only dependent on
11 Eh and pH, but it is also dependent on the nature of the phase
12 of the solid precipitate that first forms from solution.

13 Here I have superimposed a set of different lines on
14 this diagram, so let's go through them. While my initial
15 simulation--if you remember that first diagram under oxidizing
16 conditions, I precipitated a plutonium oxide. Now that
17 plutonium oxide constrained plutonium concentrations in
18 solution to about 10^{-16} , depending on the fergacity of oxygen.
19 A very low level. But the experiments of Rai and Ryan, et al,
20 suggests that the first plutonium precipitate may not be this
21 crystalline form, but a more amorphous hydroxide phase. So
22 when we go make the simulation constraining the precipitate
23 form to be plutonium hydroxide, we get much higher
24 concentrations of plutonium in solution, about 10^{-4} and 10^{-6}
25 versus 10^{-12} and 10^{-16} .

1 So looking at the results for uranium, neptunium and
2 plutonium, we can see that while uranium concentration was
3 dependent on the overall chemistry of J-13 water, neptunium
4 was mainly dependent on the Eh of the solution. But,
5 plutonium tells us that not only do we have to consider those
6 variables, but you also have to consider what phase would be
7 the most likely one to precipitate kinetically.

8 All right, there's always a question that comes up
9 in any estimates of radionuclide concentrations in water--
10 I've been using these simulations assuming it's J-13 water.
11 There's a question, is J-13 water representative of the
12 composition of water at the proposed repositories sites? In
13 fact, is J-13 water sampled from the saturated zone
14 representative of water from the unsaturated zone? And
15 finally, what if the composition of this water varies areally
16 over the site. How will that affect our predictions of
17 radionuclide concentrations?

18 The next diagram you have is just a table showing
19 you what ranges and compositions have been measured for J-13
20 water. And things in small concentration 10ppb, but we can
21 get up to a few milligrams per kilogram change in solution of
22 radionuclides. In fact when you look at the compositions of
23 extracted pore waters which come from a non-welded unit of
24 unsaturated paintbrush tuff, we see higher concentrations of
25 these elements in solutions. How will these changes in

1 solution composition affect our predictions of radionuclide
2 concentrations in solution?

3 An additional thing we have to consider is the water
4 that compacts the waste package will probably not be the
5 composition of the water that's out on the site now, because
6 it's going to undergo a lot of interactions on its way into
7 the package and also on the way out. For example, would it be
8 heating up the host rock. What happens when we heat up the
9 water and it interacts with the host rock? We are going to
10 have metal corrosion going on. It may interact with cement or
11 any organics that are left in the bore hole; interactions with
12 any manmade components and you have a radiation field. All of
13 these parameters can have an affect on the pH and Eh of the
14 solution and also an affect on the major and minor components
15 of the water, through processes such as precipitation of
16 phases, sorption and in the case of organics, complexation.
17 All these things may have to be taken into account. I did
18 some sample calculations to show that yes, you do have to
19 take them into account because they can affect the
20 radionuclide concentration.

21 On this diagram what I've plotted is the uranium
22 concentration in milligrams per kilogram as a function of pH.
23 And these are minimum solubility envelopes for uranium and,
24 for the solid line, for J-13 water. That is at a given pH the
25 uranium concentration can increase but it reaches a maximum

1 when these labeled phases tend to precipitate. So this gives
2 you an idea of what the concentrations in uranium in solution
3 are as a function of pH.

4 Now if we do this calculation assuming standard J-
5 13 water, we get the solid curve here. Now my question is,
6 what if the calcium content dropped by order of magnitude from
7 12.5 milligrams per kilogram to 1.25 milligrams per kilogram?
8 That is shown by this dash line here. Note that the
9 concentrations in uranium in solution can just about double.

10 Now if we take it one step further, let's not only
11 decrease the calcium by an order of magnitude, but let's
12 change the silica to an order of magnitude dropping it from
13 cristobalite saturation to quartz saturation. Look at the
14 drastic effect it has here. Bring it up to about three orders
15 of magnitude change of potential uranium concentrations in
16 solution because we've changed the major element chemistry of
17 J-13 water. So I think we do have to take these interactions
18 with all the components of the repository into account before
19 we can reliably predict radionuclide concentration in
20 solution.

21 DR. LANGMUIR: Carol, is it going to be a single number
22 anyway when you get to a near field situation of the thermal
23 gradient and all these variations probably will occur in a few
24 inches, plus a few more.

25 MS. BRUTON: We hope to get ranges. We hope to make

1 conservative estimates. But we have to make the simulations
2 under the different conditions to see what our ranges are, and
3 then to compare all of the different ranges so that you can
4 get a coherent range that will take into account all possible
5 scenarios. That's how we are looking at it now.

6 So to summarize, I think we found, which is no
7 surprise that we would be able to confirm it is that actinide
8 concentrations in solution can vary significantly with changes
9 in Eh, pH, solution composition, and the nature of the
10 actinide-bearing precipitate. And here I show you a little
11 chart that sort of summarizes the results from this talk and
12 from some other things I didn't include.

13 But what I'd like to emphasize is that they have an
14 impact, but the solution chemistry must change by orders of
15 magnitude to impact actinide behavior.

16 And if you remember the chart I showed earlier of
17 compositions of J-13 water, it doesn't appear that the
18 observed variations in the chemistry of J-13 water and the
19 extracted pore waters from the unsaturated zone do not seem
20 large enough to affect actinide concentrations.

21 And this is what I want to emphasize, it's the
22 interactions among the waste form, the repository components
23 and the host rock that can result in such order-of-magnitude
24 changes in solution chemistry. And that we much consider
25 these interactions in order to reliably predict radionuclide

1 concentrations through time.

2 Thank you.

3 Questions?

4 DR. LANGMUIR: I know EQ3/6 has a kinetic subroutine
5 which you haven't used here and I suspect there simply isn't
6 data for the uranium minerals at this point to put that
7 subroutine into action.

8 MS. BRUTON: Right. You mean for spent fuel dissolution?

9 DR. LANGMUIR: Well for example you are suggesting that
10 uranium is limited by some secondary uranyl phases, but you're
11 just strictly using thermodynamic arguments to determine what
12 the levels might be and to compare those to some experiments
13 in which rates presumably were involved.

14 MS. BRUTON: That was really curious because that is one
15 of the reasons for making the comparison. Okay, we're making
16 the comparison, there are simulation based on purely
17 equilibrium considerations. When comparing it to Chuck's
18 experiments which have both equilibrium and kinetics, how well
19 are we doing?

20 And the other thing was I didn't mention, but
21 looking for results in like neptunium and plutonium, now Chuck
22 measured these concentrations to reach steady state levels,
23 but he didn't observe any solid precipitates that sequester
24 these phases. So one of the things was, okay, can we use the
25 modeling to give us an idea of what phases might be

1 precipitating in his experiments because we'll never be able
2 to see them. They are just going to occur in such small
3 quantities.

4 DR. LANGMUIR: So you really can't validate what you've
5 got at this point. It's inferential.

6 MS. BRUTON: We don't want to--yeah, we weren't doing
7 this to say, okay, we want to. Our results should match
8 Chuck's. It was basically, okay, can we use the results to
9 give Chuck a better indication of what might be happening in
10 the system and take it a step further. How sensitive are
11 Chuck's results to changing different parameters like solution
12 chemistry or something else.

13 DR. VERINK: You'll note by the schedule that we are
14 right on schedule again. Because of the change in the general
15 thrust of the activities in the next section, it seems
16 appropriate to take lunch now and try to be back here so we
17 can kick it off at 12:10.

18 (Whereupon, a lunch recess was taken off the
19 record.)

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

1
2 DR. VERINK: Let's reconvene.

3 I call your attention to the fact that at the close
4 of the formal program, there will be time for some questions
5 from the audience as well as from the panel.

6 MR. PETRIE: We are about to start the final session.
7 This afternoon we are going to talk a little bit more about
8 spent fuel and the characteristics and the data base. Your
9 first speaker this afternoon will be Alan Brownstein from the
10 Department of Energy. I'll turn it over to him.

11 MR. ALAN BROWNSTEIN: Thank you.

12 This is going to be a little bit of change of pace
13 from discussions, technical discussions that we have heard in
14 the last day and a half. You've heard mentioned reference to
15 data bases, characteristics data base and spent fuel data
16 base. What we want to do today is to show you what it is we
17 collect, how we collect it and where we collect it and what we
18 do with it, what stage we are in in the process of putting
19 together what I would call a reference set of information that
20 the researchers, the participants that you've heard from, use
21 as a base of information and where we are going to go from
22 here. That's the objective.

23 The data bases, there is really two data bases that
24 the OCRWM program uses. I've listed up here three. The
25 integrated data base is really executive or summary level data

1 that represents a waste from a broader scale low level waste
2 we'll get into from the lead sites. But it's really a
3 document for the public. It's not the detailed data bases
4 that are contained in the reactor-specific spent fuel data
5 base and characteristics data base.

6 In the presentation today, we are going to have Rick
7 Walling from PNL talk about the reactor-specific spent fuel
8 data base and Karl Notz on the characteristics data base.

9 The spent fuel data base, it comes from the
10 utilities, the owners and generators of the waste. And what
11 we get from them is the inventories and projected spent fuel
12 discharges. They provide us quite a wealth of information,
13 the key fuel definition operational parameters, the type of
14 fuel, burn-up, enrichment and items like that that Rick will
15 get into in detail. And we get from them their projections
16 which we dovetail with EIA projections so that both the
17 utilities and we in projecting out the end of life all are
18 singing off the same song sheet. Both the spent fuel data
19 base and the characteristic data base are used by all the
20 OCRWM and extended family of participants in the program.

21 Now the characteristics data base, what that does is
22 really go the next step from the spent fuel data base. It
23 provides the technical details of the waste that either will
24 or may require geologic disposal. And that includes more than
25 just the spent fuel. It includes the high level waste and

1 miscellaneous waste. The data--and I'll show you a flow chart
2 later, is compiled principally for the spent fuel from the
3 spent fuel data base, but they compile information from fuel
4 vendors, NRC, waste generators and lead sites. And they get
5 into a great deal of detail as Karl Notz will describe of the
6 physical descriptions, chemical compositions, radiological
7 properties. Again these are the two data bases that form the
8 reference set for the OCRWM family.

9 For completeness there is another data base that is
10 widely used for the public. This is summary or executive
11 level data from the integrated data base. And again,
12 principally it's from the CDB, the characteristics data base,
13 and the 859, but they, too, get some information, some summary
14 level data from the lead sites. It serves a very important
15 purpose. It makes sure and gives the opportunity for the DOE
16 family including EM and NE to make sure that we are all
17 talking about the same thing and to use for a planning base
18 that we all know what each other is dealing with.

19 Unlike the characteristics data base and the spent
20 fuel data base this is not OCRWM's alone. We are supported in
21 this roughly half and half with EM. And there is a little
22 piece of NE another part of DOE in there. So this is not our
23 data base. It's something that we work with, we contribute to
24 and it's again more for providing baseline summary data to
25 Congress and the public when they ask questions as opposed to

1 the details.

2 In terms of what we use the data for, all the
3 program elements used the characteristics data base and the
4 spent fuel data base for their planning decisions. And
5 obviously in the waste acceptance process, both from the waste
6 acceptance process you've heard for the last day and a half,
7 the waste acceptance process, described standards at close of
8 contract that we have with utilities, transportation, all the
9 elements up to and including our fee adequacy analysis. So we
10 do have this reference system where everybody is integrated
11 and coordinated.

12 This gives you a real quick synopsis of how the data
13 bases are put together. We get the data from the utilities
14 for the spent fuel. This is the commercial spent fuel. We go
15 through, do QA, reconcile information. This is a continuing
16 process. In some of these double lines, there is analysis
17 done at several levels and there is a double feedback to
18 indicate that there are a number of checks and balances so if
19 something looks anomalous they'll come back and understand
20 what's wrong. That whole process Karl and Rick will get into
21 in detail.

22 The input from the CDB, we've talked about the fuel
23 vendors and waste generators, there is some additional,
24 especially from the lead sites of other information from the
25 TRU waste and low level waste that the characteristics data

1 base really pulls from the integrated data base. Since the
2 CDB gets into a little more detail or much more detail than
3 the IDB, they will use that as a starting point and then
4 actually go back to get some additional specific information.

5 In terms of answering questions, in terms of
6 planning, we really use these two in order to answer the
7 questions that come up. It's not a question of taking one or
8 the other. There is a great deal of integration and
9 coordination and communication between these two and really
10 the questions that have come up, in order to answer them, you
11 can't use one alone and we rely heavily on both to answer the
12 questions in there.

13 In terms of where we are and where we are going, the
14 reactor-specific data base is essentially complete for
15 inventories. It's updated annually as new fuel is discharged.
16 History is, it's about in a cooperative way since the mid-
17 70's, but in 1983 after the Nuclear Waste Policy Act was
18 passed we signed, I think you've heard reference before, this
19 standard disposal contract with utilities, and one of the
20 requirements in that contract with the utilities provide us
21 information on something called a RW 859 form.

22 So the project that was started and evolved through
23 a cooperative nature is now mandatory. We have held a number
24 of meetings and continue to hold meetings with the utilities
25 and discuss whether the data is--it started out as quite an

1 imposition on the utilities certainly getting the inventories
2 lined up on all the information we were requiring. We hold
3 regular meetings with them to see if there is data that we
4 don't really need, that we can stop; if there is more data
5 that we need to add. We are in a process now of revising the
6 RW 859 which is the principal input to the reactor-specific
7 data base. We anticipate revising it by May, so, we are
8 beginning to discuss things now to examine, since the last
9 update three years ago, has the program determined that they
10 need more information than is there. The utilities have been
11 very cooperative in discussing this as long as we can make a
12 strong case and understand the rationale, and to make sure
13 that there are no frivolous data demands. And I think that's
14 reasonable on their part and it's worked out pretty well.

15 We know already that at this next update that we are
16 going to be concentrating on getting information on defective
17 fuel and non-fuel components. That's something that we talked
18 about the last time in the last revision. It's difficult to
19 understand how best to put what we need and what questions we
20 should ask in a way that all the utilities can answer them.
21 And we have been working rather intensely for the last three
22 or four months with them in trying to frame those in the best
23 way that we possibly can. Those negotiations if you recall,
24 were going out to our entire family now to ask about new data
25 requirements that the program needs, especially in these areas

1 we will get together with utilities in the next few months and
2 hopefully propose a revision of RW 859 in May. That's a
3 process that has to go through OMB to get the federal data
4 form approved.

5 Now the characteristics data base that began in '83,
6 understanding that we needed more information on the
7 characteristics of the fuel than the utilities can provide us.
8 It uses literature searches, input directly from fuel vendors
9 and utilities. The data base unlike the spent fuel data base
10 is incomplete in certain areas. There is a concern from fuel
11 vendors and certain fuel vendors on proprietary issues. It's
12 a concern that we are trying to get a handle on so we can
13 acquire the information that the program needs. Karl will be
14 talking about that, but it's a hurdle that's out there. And
15 this is updated periodically and I believe there is another
16 update coming very shortly.

17 So now what we do is go back and hear from Rick
18 Walling who is the key person involved in putting together the
19 reactor-specific data base development and then Karl Notz.

20 If there are any questions, I'll be happy to answer
21 them.

22 MR. RICK WALLING: As Alan said, my name is Rick Walling.
23 I work for Pacific Northwest Laboratory, and I've been
24 involved with the reactor spent fuel data base for a number of
25 years.

1 This data base is actually sort of a co-effort
2 between the Energy Information Administration and PNL. They
3 generally do the interface with the utilities and put out the
4 data form to the utilities and do a lot of collecting, and we
5 are involved in reviewing the data after they have gotten in
6 and also help put it to use quite a bit with the various
7 programs.

8 I think actually we've been hearing for the past
9 couple of days why the spent fuel data base is important. It's
10 the reason why we are here. We have this fuel to dispose of
11 and there's a need to know how much of it there is and how
12 much of it there's going to be.

13 The reactor-specific spent fuel data base is waste
14 generator oriented. Primarily the commercial reactors
15 contains inventories projections and associated site
16 information and it's maintained and updated annually for the
17 user base.

18 The primary source of data for the spent fuel data
19 base is the nuclear fuel data form RW-859. This is, as Alan
20 mentioned, a mandatory survey of the utilities conducted by
21 the Energy Information Administration. The data submission is
22 actually a report by exception. The utilities do not have to
23 update the entire data base each year. They are asked to
24 update existing submittals and supply new information. And
25 the data is generally a snapshot in time.

1 As of generally the end of fiscal year--end of
2 calendar year. What is the status, what fuel have you
3 discharged and what have you put in the reactor, et cetera.
4 In some cases it's necessary to get a little bit of data from
5 other sources and alternate data sources include direct
6 contact with the utility. The nuclear fuel data form does not
7 collect every nuance of possibility that we might want to
8 capture, and sometimes it's necessary to contact the utility
9 especially if something they've submitted looks funny. And
10 there's other data that's collected just from other available
11 sources as needed.

12 Alan got into the evolution of the 859 a little bit.
13 Prior to the Nuclear Waste Policy Act and the development of
14 the 859, there were surveys that were done, but these were all
15 voluntary. And most of the utilities were helpful and did
16 respond, but it was not mandatory. Generally the data level
17 requested was simplified to the extent since it was voluntary
18 to keep it simple, and all that was collected was batch level
19 data on the spent fuel, and there was really no cycle history.
20 There were 20 assemblies discharged as of that date, but there
21 was no detail back on how many cycles that had been irradiated
22 beyond the final discharge.

23 DR. PARRY: When you say batch oriented, what do you
24 mean?

25 MR. WALLING: In this case batch was just--I think a

1 batch at that time was defined as a group of fuel that
2 essentially went through and basically achieved the same level
3 of burn-up. I think it was plus or minus say 5,000 megawatt
4 days per metric ton.

5 Currently batches, at least as we have it in the
6 system, as defined by several other parameters being the same
7 fuel type and having the same irradiation history and quite a
8 few other parameters. But at that time, for a given discharge
9 jig you might end up with two or maybe three batches by this
10 burn-up criteria.

11 MR. BROWNSTEIN: Let me add, where we are now, one of the
12 complaints that the utilities were making is that we are
13 asking for quite an amount of information for each specific
14 assembly. And they were saying, why can't we handle similar
15 assemblies that have gone through--you know have the same
16 enrichment and have gone through the same cycle, why can't we
17 just handle them in a batch. So we met and got together and
18 defined those parameters such that every batch has the exact,
19 identical characteristics and they can report once on this
20 batch. The only thing individual you will get is assembly
21 ID's. But they now no longer have to report thirty times for
22 the one discharge. So that's how we have sort of evolved and
23 that's what a batch is now. We'll have specific assembly ID's
24 but they will have the same exact characteristics.

25 MR. WALLING: Okay, come calendar year 1984 the original

1 RW-859 went out and this first 859 was an annual update by all
2 of the utilities. As of the end the calendar year, the
3 utility got the whole data set that they had submitted the
4 previous year back to them and were asked to verify all the
5 data that was there. Again it was set up in a computerized
6 form so they didn't have to re-enter all the data. They could
7 just verify it was there and input new data. But, they were
8 essentially asked to sign off on all of it.

9 They submitted assembly-level detail on the fuel.
10 There was a cumulative burn-up reported at the end of each
11 operating cycle on each assembly of fuel, although this was a
12 non-mandatory request, but probably 90 percent of the reactors
13 did comply with that.

14 Future discharges in this initial 859 were predicted
15 all the way to the end of the reactor life as projected by the
16 utility. And after three years of using this form it was felt
17 that the historical and kind of static information, things
18 like crane capacities and dates of when the reactor started to
19 operate or whatever some of this information didn't have to
20 keep being re-submitted each year and was well-established.

21 So then we got to the current form as it exists
22 today. There is now an option for the utilities to either
23 submit this data as an annual update or a couple of months
24 following their restart after refueling they are to submit the
25 data. Approximately two-thirds of the reactors use the annual

1 update option and the other third submit following the
2 recharge.

3 The information collected on the 859 has now been
4 really reduced down to the set of data that is needed to keep
5 the data base up-to-date. And that is primarily information
6 on new fuel that has gone into the reactor, fuel that is being
7 re-inserted into the reactor and an update on their--they are
8 now projecting their future discharges only for the next five
9 operating cycles so there is an update of that. And there is
10 an update of any fuel discharge from the reactor at that time.

11 The new data submitted is merged with the existing
12 data base by EIA to create a complete data set. And as Alan
13 mentioned we went from early submittal to batch-level data to
14 assembly-by-assembly, very detailed submittals. And now it's
15 gone back to a little more of a batch-level orientation.
16 Although an assembly-level, a data record for each assembly is
17 maintained in the EIA, but it contains kind of a batch average
18 data for the assemblies that that pertains to.

19 Also the burn-up on the fuel is only collected at
20 the time of discharge of the fuel from the reactor. If the
21 fuel is reinserted and comes out a second time we would have a
22 second burn-up point. But, we would not have--if a spent fuel
23 assembly was burned in cycles one, two, three, taken out of
24 the reactor and then reinserted for cycles five, six and
25 seven, we would not have burn-ups for one and two, we would

1 have it for three; we would not have it for six, and we would
2 have it again for seven. But if a similar one burned in cycle
3 one was taken out and only burned in cycle five and then taken
4 out for good, we would have a full burn-up history.

5 Okay, this is a brief overview on what kinds of data
6 we have in the data base. Generally there are four areas;
7 reactor characteristics, some information on spent fuel
8 storage, there's characteristics on the spent fuel and then
9 there are some subsets of data on the operating
10 characteristics of the reactor.

11 On the reactor characteristics, this is fairly--
12 this is kind of some of that static information that I was
13 talking about earlier. Things like the name, kind of an ID
14 that we put on the reactor to keep track of things. What is
15 the reactor type? Who was the reactor vendor? What utility
16 are we talking about? Where is the reactor located? What are
17 the power ratings? Dates related to when the reactor started
18 up, when they entered low power testing. When are they
19 planning on shutting down and retiring? When does their
20 license expire? And, some data regarding fuel handling
21 capabilities such as crane capacities and a few other things.

22 DR. PARRY: Do you also indicate whether access is by
23 water or by train or truck?

24 MR. WALLING: Yes, there is some of that. That is
25 information that was collected with the original 859 and that

1 is not currently being updated via the 859, but there are
2 other studies going on within OCRWM to continue assessing that
3 data and actually add to that data base.

4 On spent fuel storage, in order to kind of have an
5 idea of how much the reactors are getting into trouble with
6 time, as they continue discharging fuel, we need to know pool
7 capacity and things. You know, when they will probably have
8 to start using dry storage if they haven't already. So we
9 need things like pool capacities and pool configuration data.
10 There's a little bit of information on dry storage capacities
11 or what dry storage they are using. And also, the utilities
12 each time they report now do report an accumulated inventory
13 by contributor. There are a few reactors that have
14 transhipped fuel back and forth and we get kind of a baseline
15 number for a reactor for how much fuel it is holding from
16 another site.

17 On spent fuel characteristics, on every assembly
18 that is out there, there is an assembly identification and a
19 batch identification. The cycles irradiated, which cycles the
20 fuel was in the reactor is maintained. There is a fuel vendor
21 and assembly type ID in there. That's a key element because
22 that is a key field to interface with the characteristics data
23 base since it maintains data on the physical characteristics
24 of various fuel assemblies. This is the key to get us in to
25 merge the inventory data with the characteristics data. Also

1 we pick up the initial enrichment and the heavy metal content
2 of the fuel, the initial pre-irradiated heavy metal content
3 and the burn-up.

4 In addition to the data I just said which is in for
5 all assemblies, special characteristics that are picked up as
6 they are reported, the fuel is identified if known by the
7 utility as they report whether it has a defect or not. Any
8 modifications that have been done to the fuel as if it's been
9 reconstituted or reprocessed or something like that. Also if
10 the fuel has been--there's a few assemblies or a few reactors
11 out there that do shuffle fuel around between their reactors,
12 so if the fuel has been irradiated in more than one reactor,
13 then there is a field to pick that up. And also fuel that's
14 been sent to an offsite location, then we also have identified
15 where the fuel is at and when it was shipped and how it got
16 there. And in some cases we know the cask type and how it was
17 shipped.

18 Okay in operating characteristics, this is a fairly
19 small set. We have a cycle ID and the shutdown date for the
20 cycle, and the effective full power days during that operating
21 cycle. The cycle shutdown date is the date that is used to
22 help assign a date of "discharge" to the fuel for purposes of
23 waste acceptance or age of fuel that it is in the repository
24 or whatever.

25 Well, the data that is collected on inventories is

1 good, but to date that represents only about 19,000 metric
2 tons that we anticipate is going to be somewhere around 80,000
3 metric tons or so through the end of all the existing
4 reactors' lives. But as I mentioned before, the RW-859, the
5 utilities only project five cycles out in the future and that
6 only gives us data for the next five to ten years, depending
7 upon what cycle length they are operating under.

8 So there are also some projections that are done.
9 EIA takes the first step and does some aggregate spent fuel
10 projections just on general energy projections and percent of
11 nuclear growth and percent that nuclear is helping generate
12 electricity in the U.S. and such, and this eventually ends up
13 creating a projection for the amount of spent fuel that will
14 be produced in total. That is merged with the utilities
15 projections of what they will do over the next few cycles and
16 also merging that with a few other pieces of information like
17 an assumed capacity factor which is somewhat based upon
18 historical data. We end up with a data base that gives us a
19 data base for reactor by reactor guesstimate of what fuel will
20 be out there in the future.

21 This is not so much important for this group, but it
22 is important for the people doing systems engineering that
23 like to have a semi-realistic data base for predicting things
24 like cask fleets and logistics and such.

25 The no new orders case with increased burn-up is

1 used as a planning base, but EIA projects a number of
2 different cases and there are high and low energy growth and
3 burn-up variations that are used to create sensitivity data
4 bases which are also used.

5 These forecasting assumptions are reviewed annually
6 and there are new data bases that are created annually, so we
7 are in constant move.

8 And then this is a list very similar to what Alan
9 showed near the end of his talk. The reactor-specific data is
10 used by a lot of people for a lot of different purposes.
11 We've heard about ATM's that the Material Characterization
12 Center has been providing and collecting. They've done some
13 work with the reactor-specific data to--well they are now
14 looking at whether those ATM's are representative within the
15 population. In the past there's been some looking at items
16 like what is the population of say the stainless steel clad
17 fuel and can we tell if that is a significant enough piece to
18 need to acquire an ATM for that purpose. So there is some use
19 by the people that we've been hearing from here for this data
20 base, but it's also used for a lot of other purposes like
21 systems engineering and such.

22 That's the end. Are there any questions?

23 DR. PRICE: Do you have in your data base on fuel
24 handling, you indicated crane capacities, other limiting
25 features like infrastructure features, clearances, roadbed

1 limitations and these kinds of things in here?

2 MR. WALLING: Not in this data base. But there are
3 other--there have been some programs at Oak Ridge that are
4 more tasked to do that. There are also some ongoing studies
5 to go to each reactor and try to figure out what capabilities
6 they have or may be able to have if they or somebody else, if
7 they were somehow upgraded. Say, how far are they away from
8 being able to accept a rail cask as opposed to having to use a
9 truck cask.

10 MR. BROWNSTEIN: We've gone out and we have something
11 called the FICA study, the Facility Interface Capability
12 Assessment and that is sort of within the fence assessment of
13 not only what is there but with some minor modifications of
14 what could be there. And there is another study that looks
15 at the same type of considerations outside the fence, roads
16 and so forth, clearances to get there, to see how much
17 flexibility we have.

18 DR. PRICE: I think we are aware of both of those
19 studies. But these haven't been integrated into your data
20 base?

21 MR. WALLING: No, not at this time.

22 DR. PARRY: On your last two slides, you did not indicate
23 the possibility of license extension. Have you considered
24 that yet?

25 MR. WALLING: Oh, thank you. The standard--somehow it

1 got missed. I'm sure it was on there once upon a time. The
2 standard assumption that was made with the projection data is
3 that each reactor with few exceptions will operate for forty
4 years from the start of their operating life.

5 The few exceptions are the reactors that have shut
6 down or have indicated very strongly that they will shut down
7 in the near future. Ranch Seco, Ft. Saint Vrain, those are
8 recent candidates.

9 DR. PARRY: Peach Bottom-1.

10 MR. WALLING: Peach Bottom-1. But like I said, the
11 standard assumption is that they will operate forty years.
12 I'm not aware--currently there is an extended life case beyond
13 that point, but there have been in the past. There has been
14 sensitivity cases at some of these points.

15 DR. PARRY: It certainly might have a real impact on the
16 capability of any site to handle all the fuel.

17 MR. WALLING: That's very true. Any other questions?

18 All right I think our final speaker for the day is
19 Karl Notz and he will be talking about the characteristics
20 data base.

21 MR. KARL NOTZ: Good afternoon. My name is Karl Notz.
22 I'm the task manager for the waste characteristics data base.
23 And, I appreciate this chance to tell a little bit about the
24 data base.

25 The physical evidence of the characteristic data

1 base are these eight volumes here which were printed in two
2 printings, six volumes in December of '87 and two volumes in
3 June of '88. These were backed up by five PC data bases.
4 There's a demo disk inside the first volume to give the users
5 an idea of what's in the data bases. Those data are collected
6 on 48 of these 5 1/4 inch floppy disks. There's roughly five
7 million pieces of information in there. And the eight volumes
8 contain maybe two percent of that.

9 In addition we use special studies and technical
10 studies to provide additional backup information and set the
11 stage for improvements and those have been published as ORNL
12 reports.

13 The objectives of the characteristic data base are
14 to provide a single unified source of data for use for the
15 federal waste management system, including all those parts of
16 it that have been mentioned by both Alan and by Rick. And to
17 provide the detailed characteristics of those wastes that
18 will, or may require geologic disposal.

19 The scope is to include those things that may
20 require geologic disposal and that is obviously LWR spent
21 fuel, immobilized high level waste, non-LWR spent fuel and
22 miscellaneous waste which is largely greater than class C low
23 level waste, which is not acceptable for shallow burial.

24 We provide data in these categories, the physical
25 descriptions, the dimensions, the weights, the method of

1 assembly; the chemical compositions both in terms of both
2 total elemental content, and where we have the information the
3 chemical composition of it because those are important in
4 determining the behavior. The radiological properties
5 represent probably 80 percent of the data that we have and
6 that includes of course the thermal power, the gamma, and the
7 neutron radiation. We have it here for the individual
8 nuclides as well as collectively and the integral heats. And
9 of course inventories and projected quantities.

10 Just to give you a rough idea of about how much we
11 are dealing with and what kind of peak load we have, this is
12 of course a very summary type of presentation. It involves a
13 lot of assumptions, but it indicates clearly that you do have
14 largely--and this has been reduced to canister to have
15 something we can count. So this is the largest amount, but
16 the immobilized high level waste is also a significant
17 quantity. The non-LWR and special case fuel, although they
18 are a smaller quantity because of special problems with them,
19 and then the greater than class C waste has a potential to be
20 a large contributor. The LWR spent fuel is going to be the
21 source of most of the heat, but the others are not
22 insignificant. And you'll notice also there's a rather wide
23 range, wider ranges of uncertainties in these heat loads here.

24 Spent fuel of course had a wide range of heat load
25 also depending on the burn-up, but they are going to package

1 those in such a way to help levelize that out. But, that's a
2 separate topic altogether. That's just not our task to deal
3 with that.

4 DR. PARRY: Excuse me, your watts per canister, does that
5 take into account decay?

6 MR. NOTZ: This is--of course decay is an important part
7 of all of this, and this represents a nominal level at the
8 time of implacement so you recognize is it five years old, is
9 it 15 years old? This is kind of a levelized number if you
10 would take everything you have, you would average out to
11 something like that. Some canisters will have more than that
12 and some will have less. And of course, when it decays, that
13 will drop since the bulk of that heat is going to be from your
14 short-lived fission products. After 30 years of age this
15 number will drop down almost in half.

16 DR. PARRY: How about on the immobilized high level
17 waste, does that include the strontium and cesium capsules?

18 MR. NOTZ: Yes and no. I'm not quite sure how they are
19 going to fold those in or what they are going to do with it.
20 If they leave them as a separate entity and create a special
21 package for them, they are going to be limited because those
22 generate so much heat that you cannot fill the canister all
23 the way up with them. You'll have too much heat.

24 There is some consideration that they may open those
25 up, recombine that material with other high level waste at

1 Hanford and put it into the glass wall (sic). The benefit is
2 the glass wall is a little character out of waste form.
3 Whereas the capsules, well we know some of them are leaky
4 right now, we are going to have to invent a special waste
5 package and it may not be economical to do that. It might be
6 cheaper just to recombine them.

7 In summary then, we have extensive properties, the
8 inventories and projected quantities. We have the intensive
9 properties, the physical descriptions, the chemical
10 compositions, the radiological properties, and then we also
11 have what I call exception properties. These of course apply
12 to everything (indicating). These exception properties only
13 apply to some things. And defective fuel is obviously one
14 such category. The most obvious special fuel is TMI rated
15 fuel which doesn't even look like LWR fuel anymore. And then
16 of course, the non-LWR spent fuels are such a wide range and
17 types of fuels out there.

18 For the LWR spent fuel, this is my flow chart of the
19 data flow. We receive data from the EIA and PNL on
20 inventories and on projections. And this also includes the
21 data that we are supplied by the utilities, which we have to
22 have to do our work. We have to have the initial enrichment.
23 We need to know the burn-up. We need to know the heavy metal
24 content. We need to know the assembly type and how many there
25 there are. We also need to have detail data on those

1 assemblies which we have obtained from the vendors with the
2 exception of GE and we do it ourselves in that case. With
3 this information we now can provide physical and chemical
4 descriptions and inventory projections.

5 To get the radiological properties, we take the
6 appropriate data and run it through the ORIGEN2 code which
7 draws upon PWR and BWR models and nuclide libraries, and do
8 that calculation and see that it's available to all those
9 users out there.

10 We printed a thousand copies of this and we are down
11 to 200. It went out on category distribution; it went out to
12 special distributions and we answered requests for it and we
13 probably have 150 copies left right now that we will probably
14 send off to various universities and educational institutions
15 because we are now in the process of doing a revision on this.
16 And I will close my talk by talking about some of the
17 improvements that the revision is going to have in it.

18 When we did the first set we had 78 assembly types
19 out there. That was confusing. As we have continued our work
20 over the years, we are now up to 126 assembly types and there
21 has to be a systematic way of categorizing these descriptions,
22 otherwise, it is too difficult to deal with. So the basis
23 that we chose to simplify all those assembly detailed
24 descriptions was what we call classes, which are based on
25 reactor core configuration.

1 Once the reactor has been built and the core
2 designed, then that fixes the length, cross-section and in the
3 case of BWR, the array size. The BWR's have cruciform so you
4 can use different array sizes. And there are seven BWR
5 classes and 16 PWR classes. In each case we have the
6 generics, in otherwords there are several and in some cases
7 many reactors of a certain type. And then again for both of
8 them we have a number of one-of-a-kind. And these are the
9 early reactors of which there was only one built and then the
10 design was changed.

11 Now within these classes, you can break it down
12 further by the model type, each has it's own design. And for
13 a given vendor they change their design as time goes by. They
14 find ways to minimize defective fuel and improve neutron
15 utilization and things of that sort.

16 This is just one example and you've seen this
17 before. Ray Stout showed you this graph earlier. These are
18 those 23 classes. There is only 22 on here. Pathfinder is
19 not shown. The heavy bar is what we had of December 31, 1987.
20 The open bar is what's projected out to 2020. And Rick gave
21 you what the ground rules were for that. So, these are all
22 BWR's, the bottom part is all PWR's and you can see the
23 generic classes have by far the lion's share of the spent fuel
24 that's out there.

25 We calculate the radiological properties using

1 ORIGEN2, a code that's been around for a long time. And in
2 order to do that for spent fuel, we must know the initial
3 enrichment, the burn-up and the discharge date. And we do
4 that for each batch. Cycle data, we have used generic cycle
5 data for BWR's and generic cycle data for PWR's, but this is
6 based on data supplied by utilities and accumulating and
7 analyzed by EPRI.

8 For immobilized high level waste, we need to know
9 the composition and the canister fill date. We just
10 arbitrarily said we are going to put the high level waste data
11 out on the current projected date of filling the canister,
12 which may or may not be realized, but still of in the future a
13 little bit. But in the case the spent fuel went to discharge,
14 that's the fixed point and we go forward from there.

15 One of the important things that we've learned in
16 the last year is that the enrichment is a very important
17 parameter in doing the ORIGEN2 modeling and it must be handled
18 correctly. So we do have the data available batch-by-batch.
19 We know what the enrichment was. We know what the burn-up
20 was. And this is a graph of those data. The solid circles
21 are 80 or more assemblies in the batch. The open circles were
22 less than 80 assemblies per batch. So you can see it does
23 group. We did the regression analysis and got the
24 relationship. So when we do a calculation--now, we did it at
25 10, 20, 30, 40, 50, and 60 up to 50 for BWR's and up to 60

1 gigawatt days for metric ton for PWR's.

2 We used this statistical relationship between the
3 enrichment and the corresponding burn-up. As you can see
4 though, a lot of fuel isn't on the line exactly. And we
5 determined that by going plus or minus 7/10ths of a percent we
6 included virtually all the fuel. So in our data base we have
7 the calculation not only for the center line, but also for the
8 two extremes and then we have built in an interpolation
9 function which allows you to interpolate on enrichment or also
10 on the burn-up, if you wish, to pick up any point in there.

11 This is a similar curve for PWR's and you can tell
12 that it's not quite the same as the other. It doesn't have
13 as much curvature and doesn't flatten out quite as much.
14 That's one reason why we have to have separate models for
15 PWR's and BWR's.

16 So these radiological properties then include the
17 individual nuclides. The code actually works on the gram-
18 atoms of individual nuclides. That's the basic unit that it
19 works with. And it groups them into fission product,
20 activation produce and actinides. And the data output
21 includes the alpha emissions, the beta-gamma emissions, and
22 these are broken down to 18 energy groups. The neutron
23 emissions, and it breaks it down by spontaneous fission and
24 alpha-N neutrons, and of course the thermal output and the
25 integral heat.

1 Here it gives one example. The amount of
2 radiological detail of course is very extensive, but I know
3 there is interest in C-14 for Yucca mountain, so we pulled
4 together this particular view graph. This is on the basis of
5 a metric ton of fuel whether it's a PWR or BWR. And it shows
6 you that the Carbon-14 is found in the UO_2 fuel. It's found
7 in the cladding. It's found in the assembly hardware that
8 holds the pins together. In the case of BWR it's found in the
9 channel. There is also a little bit in that plenum space and
10 there's a little bit in the crevice on the outside.

11 The important thing in this chart, I think, is the
12 fact that the Carbon-14 doesn't come from the fuel. It comes
13 from the nitrogen impurity, by and large. In the case of the
14 crud, we are assuming it comes from the activation of the
15 oxygen that's in those oxide forms that are on there. But
16 we've had to make some assumptions as to the nitrogen content
17 of the fuel and that's probably a pretty good number. And
18 we've used some pre-existing data here for the nitrogen
19 content of the zircaloy and the inconel and stainless, and
20 these maybe--probably are on the high side. And that's an
21 area where we need to do some more work.

22 Although these numbers here for the plenum and the
23 crud look small, these are very accessible fractions. As soon
24 as you penetrate the container, the crud is on the outside of
25 the container and it's available. Or, as soon as you

1 penetrate the cladding then what is in the plenum space is
2 available.

3 Okay, referring back to our characteristics report,
4 it's a lot of material here, but the first two volumes include
5 a summary plus those four major waste form types that we
6 talked about. Everything else that is in there is to back
7 that up. Some of this is additional detail and some of it is
8 user's guide for the PC data bases. These are all supporting
9 appendices of one form or another.

10 We have five PC data bases for spent fuel and one
11 for high level waste. The ones for spent fuel, one deals with
12 the quantities that have been discharged, and that also
13 includes the projections and it also includes detailed
14 descriptions of the hardware that hold those assemblies
15 together and that go with it.

16 That is just the quantities area and it includes
17 data on defective fuel, for example. It also includes the
18 identifiers that we have used collectively between PNL and EIA
19 and Oak Ridge. We use a common set of identifiers for
20 assemblies. That's identified in here also, so you know not
21 only how much it is and when it got discharged, but what kind
22 of assembly it's in.

23 The assembly data base gives a detailed description
24 of individual assemblies; these 126 types I mentioned
25 including the hardware that hold them together. And this also

1 includes the radiological properties of that hardware.
2 Because, in the hardware you have only a few activation
3 species which appear.

4 The spent fuel however has hundreds of the
5 radioactive species. The radiological data bases for the
6 spent fuel itself is on the basis of metric tons of contained
7 heavy metal.

8 The non-fuel assemblies hardware data base--there's
9 two kinds of hardware out there. It's what we call spent fuel
10 disassembly hardware. If you leave the assembly intact, then
11 the assembly hardware stays right with the assembly. But if
12 you consolidate, then that hardware is separated and that's
13 why we call spent fuel disassembly hardware.

14 On the other hand, the non-fuel assembly hardware
15 which is largely PWR control assemblies and BWR control
16 blades, that is a separate item even if you do not
17 consolidate. So we have a separate data base for this which
18 includes both the quantities and radiologic properties. And
19 we have a new one which is not in these documents but it's in
20 the revision we are now working on and that is the serial
21 numbers.

22 Looking ahead to the day when a accountability is
23 going to be a requirement, the serial number data base will
24 allow you to go by individual assembly serial number and go
25 back to how much it represents, what its properties are, its

1 radiological properties are, so that everything can be tracked
2 back in a unique manner.

3 For a high level waste, we have data on both the
4 interim form because after all that's going to be the parent
5 of those canisters and then on individual canister basis.

6 All of these data bases are menu-driven. They are
7 user-oriented. They have gotten a good reception from the
8 people who have used them. Most people don't even have to
9 refer to the user's guide in order to get them up and running.

10 Here are just a couple of very simplistic type
11 examples of the data that we've extracted on an assembly class
12 basis and I've picked on fuel rod diameter here and to show
13 you some of it. And there's some interesting things to show
14 up here. For example, within a given vendor, as he goes to a
15 later design, the diameter gets smaller. It's happened here
16 with B&W and it's happened here for Western Engineering. It's
17 happened here for Westinghouse within theirs. The newer
18 designs are going to smaller diameters.

19 And the same thing is evident here in the GE fuels.
20 As you go to newer designs you go to smaller diameters. In
21 the case of GE, the same basic fuel design can be used in both
22 of these classes. The primary difference is that Class 4, 5
23 and 6 is about six or eight inches longer than Class 2 and 3.

24 We were unable to acquire details on GE assembly
25 from them. They treat that all as proprietary. So we did a

1 study referenced here at the bottom in which we got NRC docket
2 type information and literature publication to get the
3 descriptions for the GE fuels. One thing we do not have in
4 detail though are their burnable poisons and their enrichment
5 patterns. BWR fuels in particular run through a more complex
6 loading pattern within an assembly than do the PWR's.

7 There was an earlier question about how much
8 variation there is across the core. And it's true within the
9 core they will rotate those assemblies and move them to
10 different positions to balance out the burn-up and to keep
11 them from overheating on the first cycle. But within a given
12 assembly and this is especially true for BWR's, there is a
13 wide range in the BWR where you have the fissile form coming
14 in. You have those four corners which is different from the
15 outside corners. And in this one example, the enrichment can
16 vary for a given assembly between 1.3 and 3.3 percent. As the
17 enrichment varies you also vary the burnable poison content
18 and you will vary the burn-up within those individual rods.

19 The data we have are assembly average burn-ups. We
20 do not have individual rod data. We do have individual
21 assembly data, but not individual rod data. I hope we don't
22 ever need it again.

23 DR. PARRY: Are there variations longitudinally?

24 MR. NOTZ: Oh, of course there are. If you take a look
25 at the burn-up curve, it bellys out and both the top and

1 bottom ends slack off considerably.

2 DR. PARRY: In loading or just in the way it burns?

3 MR. NOTZ: In the way it burns, because the neutrons fall
4 off.

5 DR. PARRY: No. You indicated that you had a variation
6 in enrichment across an assembly. Do they do any adjustments
7 longitudinally?

8 MR. NOTZ: I think the BWR's do. To my knowledge PWR's
9 don't do it yet. But it is probably a future refinement that
10 may be coming, I don't know. But again the burn-ups that we
11 have are assembly averages and the ORIGEN2 code is designed to
12 give you an assembly average. It recognizes that there is a
13 distribution of neutron flux within the core both radially and
14 longitudinally and that's been accounted for in constructing
15 the model.

16 DR. PARRY: Such variations will play hell when it comes
17 time to reprocess if you do.

18 MR. NOTZ: They could.

19 Okay, the hardware is becoming increasingly visible
20 as something to be concerned about. A report on the hardware
21 has been put out by PNL and the concern of course is if you
22 consolidate then you've got all this spent fuel assembly
23 hardware to dispose of. And some of it is going to be greater
24 than class C. And it's not real clear how much of it might
25 be. So he took measurements on three different assemblies and

1 took samples from three different assemblies, measured 12
2 different areas, divided it up into zones and also did ORIGEN2
3 calculations for comparison. And just in summary, we have
4 divided the total assembly into the top end fitting region and
5 the bottom end fitting region and then the glass plenum region
6 which is unfueled and then the core region which is the fueled
7 part. And taking samples from all these areas and looking at
8 a dozen or more different nuclides, the factors if you take
9 the core region as being 100 percent activation, this is on a
10 per gram basis of whatever it is you are looking out, whether
11 it is zirconium or niobium or whatever, then in the plenum
12 region is 20 percent of that and the top end is 10 percent of
13 that and then the bottom end is 20 percent for PWR and 15
14 percent for BWR. It would take a fair amount of experimental
15 work to refine those numbers much better than that.

16 The non-LWR spent fuel is a concern for a number of
17 reasons. And again we have published a report that is
18 referenced here on this. The major contributors here are HTGR
19 reactors, Ft. St. Vrain and Peach Bottom-1, and also a special
20 fuel is a degraded LWR fuel from TMI-2. And you can see that
21 here we have represented most of the contributors. Some of
22 these are unique in the things they--I'll get that in a
23 minute, about your special properties.

24 The other contributors here are the LWBR, the FERMI-
25 2 Blanket (sic), the TRIGA research reactor and then

1 collectively a lot of research and development type reactors.

2 Now these are of interesting concern because they
3 are different from LWR fuel. Their chemical composition is
4 different. They might be carbides or they might be metals.
5 Their cladding is different. There might be silicon carbide
6 or it might include sodium bond. Their physical condition in
7 some cases is quite different.

8 Going back to this chemical composition for those
9 HTGR's, they are embedded in a graphite matrix. Many of them
10 because of their nature are high enrichment and low burn-up.
11 This causes us to be concerned about the criticality. So we
12 did address the criticality issue in this study.

13 And then finally some of them contain thorium and/or
14 U_{233} so you are going to wind up with some U_{232} which has some
15 rather nasty radiation properties of its own.

16 Because the ORIGEN2 code is such an important part
17 of our work and the radiological data are so crucial to all
18 this work, we did a sensitivity study, and we did use a new
19 cross-section set that had been developed and published. We
20 wanted to find out the relative importance of some of the
21 variables that you can deal with in setting up the models. It
22 turned out that enrichment was by far the most important one
23 and so in our re-issue here, we have dealt with enrichment
24 explicitly, as I just pointed out. It had a major affect on
25 the actinides. And the actinides in turn are the source of

1 your neutron emission. They are what contribute to
2 criticality and it also has in fact on some activation
3 products.

4 Things which had a minor impact, fission products
5 are dependent almost entirely just on the burn-up, so they
6 were not affected by enrichment. We tried running at
7 different power levels and that changed the number of days it
8 took to get the burn-up, but it didn't have much affect on the
9 output, particularly when you are looking at fuels of more
10 than five years old.

11 Also the decay time does not influence our
12 interpretation of these results, again when you are looking at
13 fuels over five years old.

14 Okay, we just completed a draft of the first
15 revision of five volumes of our data base. The other three
16 volumes will come out next fiscal year. The major
17 improvements that we have in this revision is that we have
18 improved the classification scheme. I've told you about that.
19 We have additional data on LWR assemblies, especially the GE
20 and I've told you about that. We have revised and improved
21 our radiological data and we've just talked about that. I've
22 mentioned the interpolation functions. The integral heat
23 allows you to pick any starting time and any stopping time and
24 to calculate what the integral heat is over that total time
25 period.

1 We've added the serial number data base. We have
2 these new improved factors for activation of the hardware. We
3 have added to the assembly data base a fuel pin data base
4 which is a sub-set. And if you do consolidate, just allows
5 you to subtract the hardware away from the pin.

6 We have an improved way of doing the neutron source
7 strength for high level waste data. Some of the old numbers
8 were too low. And then in all of the PC data bases, we have
9 taken advantage of comments from users and upgrading of
10 software to improve the interfaces of those data bases for the
11 users.

12 That concludes what I have to say. I'd be happy to
13 donate these eight volumes to anybody who wants to take them
14 back with them or I would be happy to mail them to you if you
15 would rather get them that way.

16 DR. DEERE: No, we'll take them now. We'll have them
17 boxed and we'll ship them back.

18 MR. CLONINGER: For the record, would you note that Mr.
19 Notz gave the board a whole set, volumes 1 through 8 of
20 DOE/RW-01.

21 DR. PETRIE: Thank you. That concludes the prepared
22 presentation. We have time now for some closing questions.
23 If there are any additional comments or questions we can take
24 those now. Or in fact I guess that concludes at this point.

25 DR. VERINK: I think the time would be particularly

1 appropriate for any questions from the panel that might cover
2 any aspect of what we've talked about in the last two days.
3 And when we get through with the panel's questions, we'll open
4 this up for questions from the audience.

5 Does anyone from the panel have any particular point
6 to raise?

7 One question that has kind of come up is considering
8 the budgetary constraints and one thing and another that
9 crunch on everyone in various ways. What priority do you feel
10 is or should be given to the container development kinds of
11 things that have been discussed?

12 DR. PETRIE: Well, I don't believe there is a specific
13 priority given to it. I can just state that it is lower than
14 the site suitability issues.

15 DR. VERINK: Does that mean that it will be worked or
16 does that mean that it probably won't be worked?

17 DR. PETRIE: In the present budget--where we are today
18 with the present budgets, I would say there will be some
19 modest amount of money provided or resource provided for those
20 activities. It will very likely be less than last year.

21 DR. VERINK: Will that option be exercised by your
22 organization or will it come from Washington, or what will
23 that be? Where's the pinch from?

24 DR. PETRIE: The general frame work is laid out by
25 Washington. Within that we'd have some flexibility, but

1 basically I suspect this is a policy decision made at
2 headquarters level.

3 DR. VERINK: So if there were to be any alteration that
4 would be the place to talk to?

5 DR. PETRIE: I would think so, yes.

6 DR. DEERE: This might be a right topic to bring up at
7 the strategy planning meeting in a few weeks to be held in San
8 Francisco.

9 DR. PETRIE: Let me just ask Max, are you familiar with a
10 strategy planning meeting that's coming up?

11 MR. BLANCHARD: No, I have not heard about it.

12 DR. PETRIE: Okay, so I hadn't either so--

13 DR. DEERE: I won't say anything more about that.

14 DR. PETRIE: So, you've probably hit the right place.

15 DR. DEERE: Well, I think one of the reasons that Ellis
16 brought up the question is that we see the workload that you
17 have laid out and particularly in many of the different
18 presentations, but specifically in the first two that we had,
19 where you are doing the flow down and traceability for the
20 source of requirements for the waste package design
21 alternatives. And obviously there has got to be a great deal
22 of work done on that. There hasn't been a lot done to date.
23 At least we haven't seen a lot presented as yet. And we just
24 are wanting to know what the time frame that this kind of
25 assessment is going to be able to be brought forth.

1 DR. PETRIE: Can you give us a minute to caucus?

2 DR. DEERE: Sure.

3 DR. PETRIE: I would like to repeat something which Max
4 said yesterday maybe in response to that to put it in
5 perspective. And I think the numbers that he gave you
6 yesterday were we were planning on getting something like \$275
7 million for the project next year. And our best guess--you
8 didn't say that? I thought you did.

9 MR. BLANCHARD: If I did it was a mistake. To the best
10 of my recollection which may not be all that accurate the most
11 optimum case for FY91 is \$172 million. And the current spend
12 rate for the project is \$194 million. That is not doing any
13 new site characterization work.

14 DR. DEERE: On page three of the transcript--

15 MR. BLANCHARD: That's only doing the monitoring work,
16 like seismic monitoring and meteorological stuff that you've
17 seen when you've been out to the site. So there are no new
18 starts there.

19 So, the expectation was if the permits were lifted
20 or we got clearances and we could start, then we would do
21 everything we could to focus our money in initiating new site
22 characterization work so that we could focus on early
23 identification of potential disqualifying conditions, should
24 they be at the site.

25 DR. PETRIE: The \$275 million I mentioned was what we

1 would expect to have if we were going to maintain a schedule
2 like '92 for start of ACD, which is what we are talking about
3 here. That's my recollection and I'm sure you will quote me,
4 but nonetheless it's only a recollection. It's not a
5 guaranteed number. Our best expectations, most optimistic
6 expectations for next fiscal year are less than what we would
7 hope to get to carry on our program with that--some program.

8 If that helps you at all, and I hope it does, that's
9 about the best I can give you at this point.

10 DR. VERINK: One of the thoughts that's been going
11 through our mind as a panel member, is that--well, we were
12 very pleased and impressed with the kinds of discussions that
13 were made about how to make the canisters or containers more
14 robust and so on in the improving climate with regard to
15 receptiveness to such an idea on the part of some of the
16 regulatory people.

17 And so we were thinking it might be very timely to
18 have a workshop which would deal with the development of the
19 robustness of the container and fleshing out in some more
20 detailed terms how the combination of environmental control
21 and materials could work together to accomplish this. And we
22 were thinking that if we could shoot for something like in the
23 middle to late January time frame, that might be a kind of
24 thing to shoot for, which could keep the momentum going in
25 this very important area. And perhaps focus some plans which

1 could be very helpful.

2 DR. PETRIE: In response to that I would think that we
3 would like to confirm that with you at some later date. I
4 don't think we could commit to that today.

5 DR. VERINK: I understand. But I thought you should know
6 the direction we are thinking and get your reaction to it.

7 DR. PETRIE: Well, let us consider it and get back with
8 you.

9 DR. DEERE: Because we do know that one of your early
10 parts of work on this program is to set up the requirements
11 for these alternative systems, because the requirement for one
12 system might be somewhat different than the requirement for
13 another. And we felt that during a workshop, these are the
14 types of things that could be discussed in an informal sort of
15 way.

16 DR. PETRIE: Oh, yes. I think a workshop would be in
17 order. The question is the timing of it.

18 DR. DEERE: Yes.

19 DR. PETRIE: When would be an appropriate time to do
20 that.

21 DR. DEERE: Yes.

22 DR. NORTH: I'd like to reiterate the question that I
23 raised yesterday about the relative lack of emphasis on
24 performance assessment in the first phase. The phase that you
25 are really in now. This is on your flow diagram which is page

1 12 in I believe it was the first presentation that Les Jardine
2 made.

3 And my reaction from the point of view, the risk and
4 performance analysis panel which I chair is we've heard a lot
5 of very interesting science and engineering in the last two
6 days, but with the exception of Dr. Jardine's second
7 presentation, there was very little attempt to focus and
8 prioritize what it is that you are really going to need for
9 performance assessment. And it seems to me that one can focus
10 that at the level of what is most critical for the design
11 concept that is your reference case right now, but that the
12 same issues apply perhaps with different priorities to the
13 alternative of an extended life canister which many of us on
14 the board are very interested in, seeing further worked out
15 the ideas for the alternative that Les Jardine presented. And
16 it seems to me that a workshop might well take as part of its
17 emphasis, trying to get a first cut at some of these
18 prioritization issues.

19 Now you said in your waste package plan, page 317,
20 that you are going to do it, and you even quoted the language
21 from that paragraph. And I think we'd all be very interested
22 in seeing just how it is you propose to do it, to set the
23 priorities and how you might do this against various levels of
24 your budget that you might have in the coming year.

25 DR. PETRIE: I'm not sure I know how to answer that.

1 DR. NORTH: I didn't expect that you would.

2 DR. PETRIE: I do see Les taking notes galore here.

3 DR. VERINK: Are there any questions from the audience?

4 Would you please come to the microphone and give your name for
5 the record.

6 MR. PHIL NIEDZIELSKI-EICHNER: Good afternoon. My name
7 is Phil Niedzielski-Eichner. I'm here representing Nye
8 County, Nevada. Just a couple of questions. One I'm afraid
9 is a follow-up on the theme that the board members were just
10 asking about. And that's related to process on the
11 alternative design approach for waste package and engineered
12 barrier. The question would be how and when would the
13 programmatic policy requirements be identified and be
14 integrated with the technical requirements. Dr. Jardine made
15 a point of distinguishing between the two and my question is
16 how will those two be integrated and when?

17 The second question related to that is the
18 methodology for the selection of ranking for the acceptable
19 design solutions, how will they be developed. And what is the
20 likelihood that decision ranking methodology will be tool for
21 that purpose?

22 The third question is related to the greater than
23 class C in a waste package plan. I think also on page 317
24 it's indicated that no efforts will be expended in pre-ACD for
25 developing detailed plans for accommodating lower than class C

1 waste. And I'd just like to have some elaboration on the
2 reason for that.

3 Thank you.

4 DR. PETRIE: Did anybody get that? I'm afraid there were
5 a lot of questions there.

6 DR. VERINK: Maybe if we could have them one at a time.

7 MR. NIEDZIELSKI-EICHNER: Okay. I just wanted to get
8 them on the record for you.

9 DR. PETRIE: They will be on the record, I suspect. Is
10 that what you were asking? Would you like to have a response
11 at some later date? Is that what you are looking for?

12 MR. NIEDZIELSKI-EICHNER: Let's just take it one step at
13 a time. In terms of Dr. Jardine's distinction between
14 programmatic policy and technical requirements, there was a
15 lot of discussion on how the technical requirements might come
16 into play, but what is the process for how the programmatic
17 policy requirements will be integrated with the technical
18 requirements.

19 MR. CLONINGER: Well I don't know if I can totally answer
20 your question. Regarding the when, we have addressed that.
21 It's a function of priorities and budget. The non-technical
22 aspects of requirements flow down will have to be addressed
23 through some decisionating methodology yet to be identified
24 for this part of the program.

25 Does that cover your first question and it does

1 cover your second question.

2 MR. NIEDZIELSKI-EICHNER: From a time standpoint. So you
3 are suggesting it's really a budget-driven issue.

4 MR. CLONINGER: Partly, yes. Max?

5 DR. PETRIE: It's budget to address the timeliness but
6 not whether or not it gets done.

7 MR. BLANCHARD: This is Max Blanchard with DOE. Although
8 it's clear, like Mike mentions that timeliness and budget
9 factors enter into this, I think when you look at the
10 regulations that govern the program that had been in existence
11 over the last ten years, it's clear that there is some very
12 high level policy issues that were established in the process
13 of originating those regulations. And those, although may
14 have encompassed some technical aspects, they were basically
15 strategies.

16 For instance an example of a strategy is primary
17 reliance on a natural system and not allowing an engineered
18 barrier to compensate for deficiencies in natural barriers.
19 That's a judgment call on the part of those who are involved
20 in creating the regulations. And there is no way for the
21 Department to do anything except to try to build a program
22 that demonstrates compliance with that strategy.

23 In a similar fashion, the length of time the
24 repository is to remain open for retrieval, that also is a
25 policy call on the part of those who are creating the

1 regulations. They are asking for comments from other people
2 as of the time they create these regulations, but someone has
3 to take the first step. And at some point in time the first
4 step was taken back in the early '80's when NRC started after
5 EPA was involved in setting up 40 CFR 191.

6 I think one of the reasons why this board was formed
7 was to look not only at the DOE technical program but also to
8 attest to the viability or the reasonableness of some of those
9 policy calls that were made in the early regulations.

10 To that extent, I think the topic of a long life
11 waste package is right for discussion. And I would suggest
12 that the NRC would be just as interested as the DOE is in
13 looking at that aspect, even though the current program is
14 geared towards emphasis of the natural barriers.

15 MR. NIEDZIELSKI-EICHNER: My question is down to one of
16 process and sequence. When you look at the discussion of
17 taking the systems approach to looking at alternatives and you
18 have recognized the programmatic policy of requirements that
19 come into play there, can you enter into a systems approach
20 without--if you readdress policy issues, can you enter into
21 this systems approach without first looking at those or
22 somehow setting up a mechanism for getting those integrated
23 with your process? That's really where my question comes in.

24 MR. BLANCHARD: I think the systems approach accommodates
25 that quite well. And as far as we've been able to deal with

1 that in our existing decision analysis methods that are
2 applied to the ESF alternative, Calico Hills risk benefit and
3 the surface base testing prioritization activities this year,
4 we have tried to encompass an aspect of this policy judgment,
5 which in some ways is geared towards trying to build
6 confidence in the other parties that are involved in this
7 program including the public that aren't up to the technical
8 aspects.

9 MR. NIEDZIELSKI-EICHNER: Nye County has just submitted a
10 letter to Carl on the question of outside or external or
11 independent involvement in that type of a process because of
12 the public confidence issue.

13 The other question that I had was this one of the
14 waste package plan and the greater than Class C consideration.

15 MR. CLONINGER: Okay. Would you like to repeat that
16 question for me.

17 MR. NIEDZIELSKI-EICHNER: Sure.

18 MR. CLONINGER: Thank you.

19 MR. NIEDZIELSKI-EICHNER: I was just looking for an
20 elaboration on why that waste element that 10,000 canisters
21 that Dr. Notz would indicate was not considered--will not be
22 considered during pre-ACD?

23 MR. CLONINGER: Oh right. The main reason we haven't
24 considered or planned for disposal for greater than Class C
25 waste is we don't know what that encompasses at this point.

1 The waste stream is not well defined at all in terms of
2 amounts or radioactive content or chemical form. As I
3 mentioned in my second talk yesterday, the Environmental
4 Restoration and Waste Management office is going to issue this
5 calendar year, a scope of greater than Class C report. At
6 that point we'll have a planning basis or an initial planning
7 basis.

8 MR. NIEDZIELSKI-EICHNER: Okay. That's helpful. Thank
9 you.

10 MR. MIKE LEE: My name is Mike Lee. I'm from NRC. I
11 have a couple of questions.

12 In today's presentation there was reference to this
13 data base. Is this the same data base that's going to be used
14 to compile the waste form characterization report described by
15 Dr. Jardine yesterday?

16 MR. CLONINGER: That data base will be part of the input
17 into that report. However, the entire last several years of
18 testing and analysis and calculational efforts at the project
19 as well as throughout the DOE program that are referenceable
20 and are available will be included in that report.

21 MR. LEE: Okay. With reference to the waste package plan
22 that Dr. Jardine also described yesterday, has that been sent
23 to NRC for its information?

24 MR. CLONINGER: Not at this point. It was just issued I
25 believe--is Dick Morissette here? I believe he has the issue

1 date. We provided drafts to the NRC and the panel in the
2 March meeting. We have given final uncontrolled copies of the
3 issue document to the board here, but it was only issued I
4 believe either last Friday or this Monday. So, no we haven't
5 yet to the NRC.

6 MR. LEE: Just from a planning standpoint, we are
7 interested in studying these documents so we know what we can
8 do and what we might have to support in the out years.

9 MR. CLONINGER: Just for the record, it was issued as a
10 controlled document, August 17th.

11 MR. LEE: Okay. Thank you.

12 DR. VERINK: Any other questions? Any other questions
13 from the panel? Any comments from you all?

14 MR. CLONINGER: No. I would just like to thank the board
15 very much for their attention and time.

16 DR. VERINK: Well, I know I'm speaking for the board when
17 I say we greatly appreciate the time and the effort and
18 enthusiasm that has gone into this presentation.

19 Thank you very much.

20 (Whereupon, the meeting was concluded.)

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD

In the Matter of: ENGINEERED BARRIER SYSTEM PANEL MEETING

Location: PLEASANTON, CALIFORNIA Date: AUGUST 29, 1990

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