

UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD

PANEL ON THE ENGINEERED BARRIER SYSTEM (EBS)
Current and Planned EBS Research

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Board Members Present

Dr. John E. Cantlon, Chairman, NWTRB
Dr. Ellis D. Verink, Panel Chair, EBS Panel
Dr. John J. McKetta
Dr. D. Warner North
Dr. Dennis L. Price
Dr. Garry Brewer

NWTRB STAFF

Dr. William Barnard, Executive Director, NWTRB
Dr. Carl Di Bella, Senior Professional Staff
Mr. Russell McFarland, Senior Professional Staff
Dr. Victor Palciauskas, Senior Professional Staff
Ms. Linda Hiatt, Management Assistant
Ms. Donna Stewart, Staff Assistant

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1 and systems engineering and director of the Safety Projects
2 Office and coordinator of the Human Factors Engineering
3 Center at BPI and many of us think of that also as Virginia
4 Tech. Dr. Langmuir sends his regrets. He is not going to be
5 able to be with us today.

6 Other Board members who are in attendance include
7 Dr. Warner North who is consulting professor in risk
8 assessment in the Department of Engineering and Economic
9 Systems at Stanford and is a principal of Decision Focus,
10 Inc. I'd also like to introduce Bill Barnard, wherever Bill
11 is, he's around here somewhere. Oh, there he is. He is the
12 executive director of the Board. And, Dr. Carl Di Bella who
13 is a member of the Board of Senior Professional Staff and
14 assists this panel, the EBS Panel, among other duties.

15 There are several others present here, as well.
16 Let me introduce them briefly. The lovely lady back at the
17 desk that you talked with this morning is Linda Hiatt who is
18 in charge of meeting arrangements. She has been assisted by
19 Donna Stewart who is a member of the support staff. Russ
20 McFarland is senior professional staff member serving the
21 Panel on Structural Geology and Geoen지니어ing. Dr. Victor
22 Palciauskas is one of our new members who joined the senior
23 professional staff in February. He serves the Board's Panel
24 on Hydrogeology and Geochemistry. He's no longer our newest

1 senior professional staff member, however, since within the
2 last week Dr. Daniel Metley who is also with us joined us
3 just at the beginning of this week. Dan will be working on
4 socioeconomic, institutional, international, and related
5 areas and many of you will recall that he was the task force
6 director of the study on Earning Public Trust and Confidence,
7 Requisites For Managing Radioactive Waste which was published
8 last November by the Secretary of Energy Advisory Board. So,
9 welcome, Dan, we're pleased to have you aboard.

10 The last time the Board or any of its panels had a
11 meeting near Livermore was, I think, in August of 1990,
12 almost three and a half years ago. At that time, I remember
13 we were very interested in what we called a 10,000 year waste
14 package. We never really defined what that meant, but it was
15 clear that it was something much more robust than the 300 to
16 1,000 year package proposed in the site characterization
17 plan. We've been calling on DOE to consider robust, long-
18 lived waste packages ever since. And, I think it's
19 reasonable to say that we're at least partially gratified
20 that DOE seems to be moving more in that direction than away
21 from it.

22 The thing of today's meeting is current and planned
23 EBS, Engineered Barrier Systems, research. Much of the EBS
24 research is performed by or directly under direction of

1 Lawrence Livermore National Laboratories. So, it seemed
2 particularly fitting that we have our meeting here. We know
3 that the materiabeen at a low level, but we're glad to see
4 that attention there is apparently turning the corner
5 somewhat.

6 We're trying what's called a top down approach on
7 today's agenda. We'll start with an overview and then move
8 into performance assessment related topics for the morning.
9 This afternoon, we'll discuss materials research and waste
10 package environmental research. We'll end the day with
11 comments from the public and a 45 minute to an hour of
12 general discussion among the panel and our speakers for the
13 day. Tomorrow, those of you who signed up will have a tour
14 of Lawrence Livermore National Laboratories where those
15 people who are involved in Yucca Mountain research are
16 located. Mike Revelli of Livermore will give us some
17 logistics information briefly right after the morning break.

18 Now, I know that each speaker has much more that
19 could be said in his or her topic area than we have time for.
20 I'm very concerned that we stay on time so as to allow those
21 speakers late in the day their fair share of the agenda. So,
22 to the speakers I say, please, stay on the schedule and I'll
23 give you a five minute and a two minute warning and we'll put
24 the hook on the line after that so that we can allow time for

1 questions. I'll be soliciting questions from the Board and
2 the staff and, if time permits, from the floor after each
3 speaker. I'm going to do my best to keep us on schedule,
4 however. So, if I don't get to your question or comment,
5 please try to hold it until we have the public comment period
6 at the end of the day.

7 Are there any general announcements that ought to
8 be made before we get started? Does anybody have any?

9 (No audible response.)

10 DR. VERINK: I see none. Okay. Our first session is an
11 overview session. We'll hear about how the waste package and
12 repository designs are evolving and how that affects the EBS
13 research. We'll hear about Lawrence Livermore EBS research
14 activities and other activities supporting the national high-
15 level waste management system. We will also hear about
16 material study plans associated with what's called the large
17 block test.

18 Our first speaker was originally going to be Bill
19 Simecka, but in his place we're privileged to have Mackaye
20 Smith as the first speaker. And, I'll turn it over to you
21 now, Mackaye?

22 MR. SMITH: Thank you, Dr. Verink.

23 Good morning. I am Mackaye Walter Smith. I am the
24 waste package WBS manager for the Department of Energy at the

1 Project Office in Las Vegas. I would like to welcome
2 everyone here on the behalf of the Department of Energy and
3 the Project Office. Dr. Simecka extends his apologies for
4 being unable to attend today, but he is involved in several
5 planning sessions at the Project Office. In his absence, I
6 will be giving a brief overview of the evolving waste package
7 and engineered barrier system development.

8 If the viewgraphs I show here look familiar to you,
9 they may be for I have borrowed them from Dean Stucker. The
10 waste package and engineered barrier system design had its
11 beginning starting with site characterization plan conceptual
12 design phase of the program, with the final design
13 publication in December 1987. This was followed by a pre-
14 advanced conceptual design study phase and, in October 1992,
15 we began the advanced conceptual design phase of the program.

16 Last month, February 1994, we had a baseline change
17 for the program which incorporated the multi-purpose
18 canister. Very briefly, the multi-purpose canister or MPC is
19 a metal canister that is loaded with spent nuclear fuel and
20 sealed at the utilities; then, moves through the waste system
21 with various overpacks for storage, transportation, and
22 disposal. This program change in the multi-purpose canister
23 has had significant impacts on the waste package and
24 engineered barrier system design development.

1 In order to implement the multi-purpose canister
2 into the disposal program, we are using the focused advanced
3 conceptual design approach to the development of the waste
4 package and engineered barrier system. With the focused
5 advanced conceptual design process, the management and
6 operating contractor design team in Las Vegas will be making
7 design assumptions including alternatives using current
8 scientific and engineering bases. These design assumptions
9 will then be substantiated using either trade studies or the
10 scientific basis of design.

11 The scientific basis of design consists of
12 laboratory testing and modeling inputs used to substantiate
13 the design assumption. And, the waste package and engineered
14 barrier system will be provided by the Lawrence Livermore
15 National Laboratory. This process of design assumptions and
16 substantiation is an iterative process and part of design
17 development.

18 In the next portion of this presentation, Dr. David
19 Stahl will provide you with more details regarding the design
20 assumption data needs for the waste package and the
21 engineered barrier system.

22 Thank you.

23 DR. STAHL: Thank you, Mackaye.

24 Good morning. I'm David Stahl with Civilian

1 Radioactive Waste Management M&O, particularly the B&W Fuel
2 Company. I think most of you know me. I've been in the
3 nuclear business since about 1958; in nuclear waste since
4 1981; and with the Yucca Mountain Project since 1987. Today,
5 I'm going to talk about design-focused waste package R&D
6 needs.

7 I'm basically going to use this chart as an outline
8 for my presentation and talk about the design inputs that
9 lead into the basis for design, a little bit about regulatory
10 requirements and engineered barrier system design
11 requirements, a little bit about interface requirements, talk
12 about waste package environment needs, a little bit about
13 waste form needs, but focusing on cladding. I'm not talking
14 about the waste form properties, per se. That's the subject
15 of another Board interaction. And, lastly, talk about some
16 of the container material needs.

17 The major sources of our regulations and
18 requirements come basically from these four documents; the
19 most important of which is 10 CFR Part 60 dealing with
20 disposal of high-level radioactive wastes in geologic
21 repositories. In that document, it references Part 20,
22 standards for protection against radiation. We have our own
23 DOE document, 10 CFR Part 960, which has the general
24 guidelines for the sites. Part 60 also references, as you

1 know, requirements from the EPA and, of course, those are
2 under discussion and recommendations, as you know, are due
3 from the National Academy of Sciences to the EPA later this
4 year. Also, we have a YMP document which deals with the
5 engineered barrier design system requirements and it's a very
6 lengthy document indicating requirements that flow down from
7 the system requirements documents to the engineered barrier
8 design.

9 I don't intend to go through any of these in
10 detail; basically, just to list some of the preclosure
11 requirements. Certainly, criticality is important,
12 radiation protection. We do have the requirement for
13 retrievability in the system and that does impact the design
14 of the underground system and many other things which flow
15 from 60.135.

16 Post-closure again is a series of requirements.
17 These are 60.113 and 60.112, respectively. Containment for
18 300 to 1,000 years and, as Dr. Verink noted, we do extend
19 that well beyond 1,000 years. Controlled release occurs
20 after the containment period and we're mandated to limit
21 releases to less than 1 part in 10 to the 5th of the 1,000
22 year inventory of each radionuclide. Certainly, overall
23 performance from 60.112 deals with the performance of the
24 entire system and the off-site dose consequences. And, also,

1 we need to talk about long-term criticality and Tom Doering
2 is going to address that issue later on. Certainly,
3 performance confirmation, we have to be aware of and,
4 certainly, as you know, we have to be cognizant of the
5 various options in thermal loading and we'll talk about that
6 today, as well.

7 Now, we believe we have an integrated system. We
8 have waste package design, we have testing and modeling, and
9 we have performance assessment. And, as far as waste package
10 design needs, we have two. Basically, data needs from the
11 materials and performance, how does that material degrade and
12 serve us? And, we use performance assessment which, as
13 indicated here, you have compliance determinations and
14 assessments come back which feed to the design hopefully in
15 an iterative manner so that we can improve the design based
16 on testing and modeling needs and the performance
17 assessments. We also do what we call interim performance
18 analyses internally to see how the design performs against
19 the subsystem requirements. The testing and modeling, as you
20 will hear, is done mainly at Lawrence Livermore National
21 Laboratory and some of the other national labs like Argonne.
22 You'll hear Dr. Park speak about some of the testing work
23 that we're performing there.

24 Other inputs that we have in addition to the

1 requirements documents, we have other requirements. There
2 are system type requirements that we have to input; the
3 repository system, for example, waste acceptance and
4 transportation and storage requirements that come into waste
5 package design. And, as Mackaye Smith indicated with the new
6 baseline of the multi-purpose canister, that input is very
7 important from the storage and transportation side. And, of
8 course, certainly, from performance assessment, hopefully,
9 this serves to create a framework for the license application
10 that Department of Energy must submit.

11 Most of you are familiar with the components of the
12 engineered barrier system. The waste forms, the fillers,
13 containers, and the packing material are defined in 10 CFR
14 Part 60 as part of the waste package. Any backfill, invert,
15 or other man-made materials would be part of the engineered
16 barrier system.

17 I show a schematic here on the next chart which the
18 Board has seen where we show the latest concept from the
19 subsurface facility where they're looking at a 4.2 to 4.5
20 meter emplacement opening. This is the multi-barrier
21 container. It would be resting on supports here either a
22 ceramic support or it could even be a rail support. The
23 engineered invert, they're currently looking at concrete, but
24 that gives us the option of putting in some packing material

1 which could be crushed tuff and some zeolitic material;
2 hopefully, one that would withstand the thermal regime of the
3 waste package. Here, we show a PWR-21 assembly package. We
4 might have some buffer or filler material around that, either
5 iron or iron oxide as we indicate. This is the inner barrier
6 which we currently are looking at a corrosion resistant
7 material like in Alloy 825 or another nickel-based alloy.
8 And, an outer containment barrier of carbon steel or other
9 corrosion allowance barrier. And, depending on the sizing of
10 these two units, we may or may not have an intermediate
11 separator.

12 Okay. Now, we get to the heart of the issue. What
13 are the R&D needs as far as the waste package design
14 perspective is concerned? Starting off with the environment
15 --and you'll hear Wunan Lin talk about some of these aspects
16 --certainly, temperature, rock stability is a very important
17 issue. As you know, there's a tradeoff, the smaller the
18 opening, the more stable it is; the larger the opening, the
19 less stable. But, you do have then thermal effects. As you
20 shrink it, the rock gets hotter. So, you have to have a
21 balance there and rock stability work is being done both at
22 Lawrence Livermore and Sandia National Laboratory. Water
23 chemistry, pH and Eh, are very important to assessing the
24 corrosion resistance of the package and, certainly, what the

1 flow rate is and the water contact mode. And, you'll hear a
2 little bit about that from Bill Halsey from Lawrence
3 Livermore Lab.

4 Lastly, effects of colloids, microbes, and
5 introduced materials. This is an area that we've just begun
6 to study. We do have some colloid work, as you've heard
7 before from John Bates, and radiocolloids and, of course, Los
8 Alamos and others are studying natural colloids. You'll hear
9 a little bit from Dr. Penny Amy from UNLV talk about microbes
10 and Annemarie Meike will address some of the introduced
11 materials. Now, there's a whole gamut of considerations here
12 for the waste package environment that influences design.
13 And, we need to have answers to these.

14 As I said in regards to waste forms, I'm focusing
15 mainly on cladding--only on cladding, I should say. The
16 question to be addressed is whether we can take containment
17 credit. We're certainly evaluating that. We feel that
18 cladding can be considered as a redundant barrier and the
19 question then is can we include it in our regulatory or
20 licensing argument? You'll hear from Kevin McCoy and Bill
21 O'Connell on that subject. We're utilizing a damage function
22 approach where creep rupture is the principal concern, but
23 we're also looking at stress-corrosion cracking and hydrogen
24 attack. And, certainly, we need to be able to develop a

1 predictive model if we're going to take credit for the
2 cladding over thousands of years.

3 Now, I mentioned that the inner container, we're
4 looking at a corrosion resistant material. Most of those
5 materials are pretty much immune to general oxidation and
6 general corrosion. Those rates are very low. However, they
7 do suffer from stress-corrosion cracking and pitting and, as
8 indicated here, there is a potential for crevice and galvanic
9 corrosion and we've started programs in these areas and
10 you'll hear Dan McCright discuss them.

11 Many years ago, Ellis will know, I said we needed
12 to start long-term tests. We still need to start long-term
13 tests and, hopefully, a budget increase next year will enable
14 us to do that. We've unfortunately had to put this off for
15 several years now and we're getting to the stage where it's
16 becoming critical. Lastly, certainly, predictive models are
17 needed for all of these mechanisms and we need to have the
18 long-term testing to substantiate that. And, you'll hear a
19 little bit about that from Jangyul Park.

20 On corrosion-allowance, less is known even though
21 it's a common material. For example, oxidation rates as a
22 function of temperature and humidity for carbon steel. Not
23 well-studied. We've done some extrapolation that we used in
24 the total system performance assessment to come up with some

1 rates of corrosion, but these were extrapolated from low and
2 from high temperature. We need to do that and Dan McCright
3 will talk about the work that's been initiated--I'm sorry,
4 no, it's not Dan; Greg Gdowski will be talking about that.

5 Aqueous corrosion is a function of temperature and
6 solute concentration. Again, there's a raft of data out
7 there on carbon steels, but not on the conditions that are
8 relevant to Yucca Mountain. Certainly, we need to look at
9 localized galvanic and microbiologically-influenced corrosion
10 and we're just beginning to get some of these studies
11 underway. Certainly, in regard to long-term tests, those
12 again need to be initiated and, hopefully, we'll do that next
13 year. And, certainly, we need to have predictive models for
14 all of those.

15 Lastly, as you know, we went through a total system
16 performance assessment last year and many of the institutions
17 that were involved indicated what their data needs might be
18 to improve the TSPA. And, as you can see, I've identified
19 six from those studies. Interaction of natural and man-made
20 components, we've just begun to evaluate that. Container
21 degradation and waste form alteration rates, certainly there
22 is some data, but for new fuels and for the altered case we
23 need to have additional data. So, there is some sensitivity
24 there. Feasibility of maintaining long-term reducing

1 environments, as I indicate here, to reduce neptunium and
2 perhaps technetium solubility. The TSPA showed that for
3 10,000 years it's not a problem. In fact, mostly ¹⁴Carbon was
4 the major dose element. But, in 20,000 to 100,000 years,
5 that's when the neptunium and the technetium came in and we
6 have to look at what we can do for the engineered barrier
7 system design, for example, to possibly retard the movement
8 of those materials from the engineered barrier.

9 As I mentioned, there's a potential for performance
10 allocation to cladding and we've begun to study that.
11 They've asked about packing and backfill materials and the
12 potential for radionuclide retardation. Certainly, we've
13 indicated that is our concept to evaluate various materials
14 and we've just begun to study the materials that we could use
15 in this application.

16 And, lastly, I'll identify it again, water contact
17 modes, a very important issue in trying to determine actual
18 conditions that a waste package or degraded waste package
19 might see in the repository.

20 So, there's a lot to be done and I think we've made
21 a start in many of these activities, but as you know, there's
22 a lot more that we need to do.

23 Any questions from the Board?

24 DR. CANTLON: I want to ask you kind of a top down

1 question.

2 DR. STAHL: Sure.

3 DR. CANTLON: You've identified a rather massive amount
4 of work that needs to be done to lay the base for the
5 engineered barrier. Yet, at the same time, I understand the
6 program is moving rather rapidly to an RFP for a multi-
7 purpose container.

8 DR. STAHL: Yes, uh-huh.

9 DR. CANTLON: How confident are you of the basis on
10 which that RFP is being offered?

11 DR. STAHL: Well, we've had input to the RFP in
12 identifying materials. In fact, in the focused-ACD approach,
13 you've heard great detail on that from Dean Stucker
14 previously and a summary this morning by Mackaye in that we
15 will make some basic assumptions on materials for the MPC
16 design concept multi-barrier package. Then, we'll be moving
17 forward with the R&D program or the substantiation program
18 that supports those assumptions. So, there is a risk, but we
19 feel by focusing the design on a particular concept, we can
20 move the program effectively. Recognize that there's that
21 degree of risk and that we do have an R&D program that
22 supports the decisions.

23 DR. CANTLON: Right. Now, as you rank order those areas
24 of risk in this list that you've given us of the major R&D

1 programs, where are the high risks and where do you think the
2 low risks are?

3 DR. STAHL: Well, I think from our level of
4 understanding the introduced materials, colloids and
5 microbial interactions, are very important because we know
6 least about them. So, I think that's where the high risks
7 are. Lower risks are on some of the materials performance
8 where we do have at least some data either generated at
9 Livermore or from industry that have addressed some of those
10 issues.

11 DR. CANTLON: Now, on those material performance
12 experiments and so on, how many of them are done with any
13 kind of knowledge about what the repository environment is
14 going to be?

15 DR. STAHL: Well, we made some assumptions in regard to
16 the environment and Dan McCright will talk about the range of
17 conditions, for example, that we'll be using for testing.
18 So, we hope to cover the range of anticipated conditions,
19 certainly.

20 DR. CANTLON: Thank you.

21 DR. NORTH: I wonder if I could follow that up, as well.
22 Maybe Mackaye Smith would be the more appropriate recipient
23 for this question. I'm concerned about the word
24 "substantiated" when we're clearly talking about risks. I

1 think we understand that the Department of Energy feels a lot
2 of pressure with respect to the 1998 date for fuel acceptance
3 and would like to have a system that can be used in the near-
4 term to meet DOE's needs in that area. On the other hand,
5 you've given us a long list of issues which I will
6 characterize as potential risks and I can imagine a situation
7 where a few years from now we learn that some of the choices
8 made in these early MPCs were indeed the wrong choice. My
9 concern is that, one, we not make any assumptions that the
10 research is going to substantiate. Hopefully, we'll be
11 right, but it could be we're going to be wrong.

12 The point I'd like to ask you about is how you are
13 coming along in going through a planning exercise where you
14 can identify where you are most likely to be wrong with
15 consequences that you have to redesign the MPC. So that if,
16 in fact, that's needed, it can be done earlier rather than
17 later because it's clearly going to be quite expensive. So,
18 I hope as we go through this meeting or very soon subsequent
19 to this meeting, you can give us a plan showing really how
20 you are going to manage this risk of being wrong in the MPC
21 design.

22 DR. STAHL: Yes. Did you want to say something,
23 Mackaye, before I jump in?

24 MR. SMITH: Not really.

1 DR. STAHL: Okay.

2 MR. SMITH: The word "substantiate" was chosen as an
3 alternate to verify or verification because that has
4 implications for computer modeling and those. So, we just
5 looked up the thesaurus and found "substantiate". That's
6 where that came from.

7 DR. NORTH: Good. Can I be reassured then you really
8 mean that it can be changed if we want?

9 MR. SMITH: We can change it again, you know.

10 DR. STAHL: Let me just mention in regard to the timing,
11 certainly the MPCs are not going to be put into place before
12 1998. The initial number will be small. So, we'll have
13 hopefully an R&D program in place so that by 1998 we can have
14 greater assurance that the material choice is the right one.
15 Certainly, as far as the MPC is concerned, we don't
16 currently take credit for the canister material that the
17 utilities would use. There's always the question of what is
18 the integrity of that package after being moved from the
19 utility, being stored, being transported, et cetera.
20 Whereas, at least, when we put it into the repository, we
21 have great confidence about the integrity of the package.

22 Additionally, as I say, we'll have some R&D and we
23 can recommend modifications to the design. I'm less
24 concerned about the package material than I am about some of

1 the internals; for example, the structural and neutron
2 absorbing capability of the basket material and we will have
3 some supporting R&D on that. Tom Doering is going to talk a
4 little bit about that issue.

5 DR. VERINK: Okay. Well, I think we'll need to move
6 along now. Next talker will be Will Clarke.

7 DR. CLARKE: Well, I'd like to welcome a lot of you out
8 here to shaky California. If it will make you feel any
9 better, the next projected major earthquake is on the Hayward
10 Fault which is about 10 miles away. So, we'll try to get
11 this through as quickly as possible. In fact, it was very
12 humorous the other day, one of the political cartoons shows
13 the old family and the old rattle trap and the kids hanging
14 out the side leaving California with a sign beside that said
15 "Oklahoma or Bust".

16 Carl asked me to go over where Livermore's
17 reorganization stands. I know many of you do not know that
18 we now--the Yucca Mountain Project is part of the energy
19 directive under J. Baldwin at the laboratory. And, within
20 that, is the fission energy and safety systems program under
21 C.K. Chou. That particular deputy associate directorship is
22 broken up into what's called three associate programs and
23 then the Yucca Mountain Project which is on an equal level
24 with those programs, but is not specifically an APL. We are

1 listed as a special project. Almost everything that you see
2 there is in one form or another connected with the nuclear
3 industry or nuclear waste. Most of the work in the first
4 three boxes has been associated--or the first two, I might
5 say, is connected with the Nuclear Regulatory Commission
6 assessments and work over the past probably, I don't know, 10
7 years or so. But, more recently, a lot of the emphasis is
8 shifting to helping the Department of Energy in many of the
9 areas that we're working on here.

10 More specifically, in the facility review, nuclear
11 technology in the storage and transportation area, we're
12 doing criteria development reviews, reactor site storage
13 reviews. We also have worked on the small MPC which is not
14 part of the baseline right now, but there has been a report
15 issued on that. We did work with the M&O in Las Vegas to put
16 out the seismic hazards assessment report that I don't know
17 if it's out right now, but if it isn't, it's imminent. It's
18 about to come out. And, also, we are working in the national
19 phenomena hazards area for reactor operation.

20 In the other, the computer controls and human
21 factors area, we are working on a locator based on some of
22 the Gulf War technology that we developed and that is to be
23 able to locate workers in the tunnels, 100 miles of tunnels
24 or whatever it is eventually--not starting with ESF,

1 eventually into emplacement. And, it's a combination badge
2 type thing where it's a radiation detection, it's an
3 emergency beeper, it's a locator so we'll know where people
4 are at all times. We have a demonstration on that available
5 at the lab if anybody is interested in the future.

6 Also, we are working with--we have installed the
7 whole badge concepts at the Pantex plant in Amarillo, Texas
8 and is just about to install a whole new badge system at
9 Idaho Nuclear Engineering Laboratory. Also, there's many of
10 us in this room including some of the other folks here that
11 are a part of the new Idaho waste package task force for all
12 the various 105 fuel forms that they have located up there
13 that are not presently tagged to go into the Yucca Mountain
14 site.

15 Then, over in the environmental safety, health, and
16 waste management area, we have done a lot of work in the high
17 enriched uranium area helping with the shutdown of the
18 facility, environmental compliance, packaging, the RCRA, and
19 now in the HEU disposition is the strategic planning and
20 environmental compliance. So, that shows the areas that we
21 are involved in, in addition to the Yucca Mountain Project.

22 DR. NORTH: I wonder if I could ask a question for
23 clarification. Does the environmental health and safety work
24 of Mort Mendelsohn (phonetic), Lyn Anspaw (phonetic), and

1 those people, does that fall into your third category or is
2 that--

3 DR. CLARKE: No. This is under Tom Crites and I should
4 have mentioned that it's located at a new office that has
5 been opened in Washington, D.C. out towards Germantown. So,
6 everything is handled out of that particular office. The
7 environmental that you're talking about, that directorship
8 has not been announced yet. It is part of the new
9 reorganization.

10 DR. NORTH: Okay. I'd love to get a copy of the
11 organization chart showing where those people are and the new
12 system, as well.

13 DR. CLARKE: Sure. Are you going to be on the tour
14 tomorrow?

15 DR. NORTH: Yes.

16 DR. CLARKE: I'll try and get you one tomorrow.

17 DR. NORTH: Thanks.

18 DR. CLARKE: Okay. This is our own Yucca Mountain
19 breakdown. You've seen this many times before, many of you
20 have. But, Carl again wanted me to give a little--well, I
21 read last night sitting there that he expected me to give
22 some historical perspective which I neglected to do. But, I
23 think I can do it here because originally the EBS materials
24 characterization was called container design. And, under

1 container design was the waste form characterization, plus
2 the materials, plus the actual design of containers. The SCP
3 conceptual design was developed in that particular technical
4 area at one time. Now, about two and a half years ago--Dave,
5 I can't remember the exact date--the engineering aspects of
6 this was transitioned to the M&O and then Livermore then
7 maintained the scientific basis, as David Mackaye already
8 announced. So, now, we have the five general technical
9 areas. Waste form characterization, you can see the various
10 task groups under there. The near-field environment
11 characterization. Materials you're going to hear a lot more
12 about today. Performance assessment, you'll hear some more
13 from Bill today. And, now, we have been growing in the
14 international programs arena. Fundamental materials,
15 Annemarie will be talking and bring some of that onto the
16 floor this morning. Spent fuel dissolution, Ray Stout is
17 doing that in conjunction with some of the other work he's
18 doing on the waste form testing. Then, we have a small
19 effort with Sweden and Hard Rock Laboratory and also with
20 Cedar Lake in New Zealand in the natural analogs arena.

21 I'm going to just leave this up as I go through
22 this morning so you'll kind of get a feel for where we're at.
23 In words, it's on this other viewgraph. But, essentially,
24 what Livermore does--and one of the unique things, I think,

1 about our relationship with the project for several years is
2 that we've sort of had one foot in to the geosciences arena
3 and one foot in the engineering. This has been very valuable
4 to us because it allows us then to do our own self-
5 integration and cross-fertilization between the two areas.
6 And then, everything that we are doing in these two areas--
7 and that is working on the various concept development with
8 the M&O, doing the basis for design in the geosciences area,
9 also in the waste form and container degradation. Then, we
10 feed all of this up into development of the mechanistic
11 models and that and this is where Bill Halsey and his group
12 then convert this into subsystem models and eventually feed
13 it up for a source term in the total systems PA. But, along
14 the way, of course, we are all very heavily in site test
15 planning and evaluation--you'll hear some of that from Wunan
16 --and then also in the EBS design and sensitivity analysis.
17 So, it isn't just a single activity.

18 Now, I'm going to present something just to talk
19 about the evolution of this program. A few years ago, I
20 probably would have been fired if I brought this up. Now,
21 it's actually being listened to and I think is having an
22 impact on the project. And, that is looking at a safety
23 strategy starting from the inside and working out. As you
24 very well know, most of the activity has been going on out

1 here for several years. Our strategy which I think is
2 starting to gain endorsement is that, look, we ought to be
3 taking credit for some things in the waste form as we begin
4 to understand them. That includes not only the difficulty in
5 dissolution of the fuel, but also in the integrity of the
6 cladding that is there. We move from there then and this is
7 your defense and depth and redundant barriers as you move
8 through the process. As of two days ago, politically correct
9 because we now have an MPC shown here. The waste package
10 area, David went over very well. I won't go into any detail.
11 You'll hear more from Dan, but that provides your next level
12 of protection as you move through. The engineered
13 repository, as David went over, some design yet to be
14 determined. Your next level of protection, the near-field
15 environment which there's many different types of scenarios
16 that we're working on that may or may not be adopted involved
17 in thermal loading which again may keep the site dry and dry
18 for a longer period of time. That's your next level of
19 protection.

20 And then, I like to stand up here like a carnival
21 barker and says, hey, if anything gets out of there, we've
22 got this wonderful far-field to sponge it up and keep it from
23 going to the accessible environment. I think this is a
24 safety strategy that we can sell to the public. If we can't,

1 I really don't know where we're going to head.

2 Now, the next few viewgraphs are saying again in
3 words what I just showed and getting back to the triangle.
4 And, I'm not going to go through these in any detail.
5 They're in your book; you can read them. However, the one
6 thing that you keep in mind is the products that come out of
7 all these activities. Starting with the performance
8 assessment, we have the integrated, abstracted details and
9 that involves, as Bill is going to go over with you this
10 morning or today, hydrology, geochemistry, the mechanics, the
11 corrosion, man-made materials, waste form. radionuclide
12 mobilization and transport. And, that's all based on that
13 water contact that David was talking about a little while
14 ago. The two main products out of here that Bill, I'm sure,
15 will go into in more detail is the PANDORA and the Yucca
16 Mountain Integrated Model. This is a detailed time evolution
17 just of a single waste package and then this is the
18 integrated subsystem descriptions and then all the various
19 types of things that's on the triangle over there comes out
20 of the work that the PA folks are doing.

21 A little bit about the waste form characterization
22 since we're not going to cover that at this meeting today and
23 again the objectives are very clear, but the products that
24 are coming out of this is the Preliminary Waste Form

1 Characteristics Report and that will contain everything that
2 we know to date that's been developed on this program. This
3 will be updated every one or two years as we go through the
4 process. And, the contents of all of that then are the
5 physical property data, both for the spent nuclear fuel and
6 also for the defense high-level waste glass; whatever
7 radionuclide data that's available at the time; and then, the
8 test data and the models for that. And, I did want to
9 indicate to you where this work is being done and what the
10 status of it is because you won't hear any more of that
11 today.

12 Three areas have been delayed because of budget
13 priorities over the years; the gaseous release response, the
14 cladding failure response, and also the hardware dissolution
15 response. But, we do have work ongoing now. The Materials
16 Characterization Center at PNL, that's where we gather up all
17 of the material that we need to create samples, characterize
18 the samples, and then supply them to these folks to do the
19 rest of the testing. The work we're doing is the oxidation
20 response. Most of that is at PNL. There is some
21 international cooperation work with the AECL in Canada. And
22 then, there's also dissolution response work again at PNL,
23 Argonne, some at Lawrence Berkeley Lab, and also at
24 Livermore. The glass waste form response mainly at Argonne,

1 some at Livermore, and this is the thermo-chemical database
2 work that is being done at the three laboratories.

3 I'll spend no time on this since Dan is going to
4 cover the materials in detail this morning; only to tell you
5 that, like the other projects or the other tasks, we are
6 going to develop an engineered materials characterization
7 report summarizing everything that we've done on this program
8 for the last 10 years down, I guess, or whatever. The draft
9 of that is scheduled to be completed this summer. Also, we
10 have a survey on the non-metallic barrier materials that was
11 started at Livermore. The PI working on that retired here
12 recently. He was one of the lucky ones. And, we have
13 subcontracted the remainder of the completion of that to Dan
14 Bullen at the University of Iowa. Is it University of Iowa
15 or Iowa State? Whatever. He and his staff--and, that will
16 be completed this year.

17 So, the contents of that then is going to be all
18 the various types of things that you're going to hear about;
19 the corrosion, oxidation behavior, all the various properties
20 of the different materials that are being considered, and
21 then the status on the technology and fabrication of non-
22 metallic barriers. We did put some money out of our own pot
23 into a non-metallics effort this year to get that effort
24 started. It's a paper study right now, but we're in the

1 process of trying to bring other funds, even if they're
2 internal funds from Livermore, and to create some prototypes
3 and some closure work in the event that it takes something
4 like a ceramic barrier to overcome any aspects of something
5 like microbiological activity or whatever. It is a backup.
6 It is one of the alternates that we will consider.

7 We do interact and this is important. We have
8 started interaction. Dean Stucker has started design
9 interface workshops. We meet almost at least once a month
10 and we meet with the repository design people, in addition to
11 our own and the M&O. Then, also, with the M&O, hopefully,
12 we're going to meet on a monthly basis. We've had three
13 sessions already on technical information exchange.

14 The near-field again, you can read the objectives
15 because I'd like to get into the end of this portion of it.
16 But, we have published the Near-Field Environment Report.
17 It's a very comprehensive piece of work and we are
18 continuously publishing the model and technique development
19 work that we're doing. Here, of course, we're getting into
20 the area that David mentioned and that's water contact and
21 water quality, especially as it affects the waste packages.

22 This particular is the largest area that we have
23 here at Livermore right now and it's broken down into many of
24 the things that you see over here; the mechanical loading

1 that impacts the waste packages. Obviously, thermal
2 environment is going to be extremely critical for this. We
3 are now working and thinking about the formation of the
4 colloids and their interaction for man-made materials. The
5 biological activity, you'll hear a little bit more about that
6 today. There is something that nobody has ever considered,
7 but we've measured in G-Tunnel and that's natural system
8 electrical potential interactions up to a volt difference
9 between different regions within the rock formations. Is
10 that important to a metal waste container? We're not sure at
11 this point. And then, the various transport and retardation
12 mechanisms in the altered natural system.

13 Now, what I want to do is just spend a few moments
14 going through--and, I want to thank Ardyth Simmons for this.
15 Ardyth prepared this somewhat with our help for the latest
16 project review meeting that took place in Las Vegas. And, I
17 think it's important because what it does is it gives an
18 indication to you as to where the program was especially in
19 the near-field environment arena and how it impacts the waste
20 packages and then how we have evolved through that process
21 and since that time. I think the evolution is critical and I
22 think it's important and, from Livermore's perspective, it
23 indicates something that we have been striving for for some
24 time and that is for everybody to understand--I really wasn't

1 going to use that, but being as I said it, I can't resist.
2 Whether you believe it or not, heat does happen and you'll
3 never believe what a struggle this has been to get people to
4 accept this.

5 So, as we've gone through, we'll start with the
6 original testing objectives and that was--there was an
7 objective to understand the effect of the thermal pulse and
8 then to understand any of the changes in the waste package
9 environment that was influenced by that. The conditions that
10 could cause failure, we cannot determine a source term if we
11 don't have some information on waste package failure rate and
12 we can't get waste package failure rate until we understand
13 water contact and water quality. So, this is an extremely
14 important goal. Then, we have to predict the transport
15 through the engineered barrier system and through the altered
16 zone as altered by the emplacement of waste. The big thing,
17 of course, is to understand how these coupled processes
18 interact and then be able to provide that to total systems
19 PA. And, that's no simple task as I think most of you will
20 appreciate.

21 The reasons for this came out of the SCP and that
22 was the various issue numbers for anybody that's ever read
23 that. For the engineered barrier system, Issue 1.5, we need
24 to understand the changes to the chemical conditions that

1 could alter the radionuclide transport, the mobilization and
2 transport. There was a groundwater travel time issue, 1.6,
3 to understand how the geochemical data changed as it went
4 through the disturbed zone. Then, there are the other two
5 issues for the waste package, 1.10, and 1.12 for the seal
6 characteristics and we needed to understand how the vadose
7 zone water chemistry changed.

8 The important evolution, I think, was the original
9 extent of the near-field was the borehole wall. If you
10 remember the SCP conceptual design, you have a half to a one
11 inch air gap between the borehole wall and the actual
12 container. And, that was then at that time recognized as the
13 extent of the near-field. So, anything that we could do
14 should go no further than that.

15 Then, the next evolution was that based on the work
16 that Tom Buscheck was starting. And starting to understand
17 the impacts of heat, we now discover that the altered zone
18 could extend many meters away from the waste package. And
19 here, more recently now, we know that that is a much, much
20 larger area; tens to hundreds of meters and, in some cases,
21 kilometers away from the waste package. So, the altered zone
22 now has become a term that is being used. It actually shows
23 up in titles in WBS. And we are going to examine all of the
24 effects of the heat in that respect.

1 There's been some programmatic influences in this
2 evolution of thinking. There was a letter--I think it's been
3 about two years now--where the NRC allowed DOE to take credit
4 for more than 1000 years of substantially complete
5 containment. This then brought into play things like the
6 extended dry concept that we could take credit for if we
7 could demonstrate containment for a longer period of time.
8 As I know the Board knows because you've spent some time with
9 these people, there's been a tremendous emphasis from the
10 international community coming out with long-term containment
11 and anything that would enhance the engineered barrier system
12 and the altered zone characteristic studies. So, this has
13 had an impact back into the United States and onto the Yucca
14 Mountain Project.

15 And then, there's been an emphasis on the man-made
16 materials, as it should have been, and it's now developed
17 into its own study which I'll show you on the next slide and
18 what you're going to hear about this morning or today from
19 Annemarie.

20 These are the approved changes then by the
21 Department of Energy. We have added the altered zone
22 characterization studies. The work that used to be under the
23 1.22 in the engineering area has now been moved out of that
24 area and it has been moved into the 1.2.3.12 and 1.2.3.10

1 for--if you like numbers. Ardyth Simmons is the WBS manager
2 on that. She's here today if anybody wants to discuss any of
3 these aspects with her.

4 The man-made materials activity has been separated.
5 It used to be part of the geochemistry waste package
6 environment studies; so, therefore, it always occupied a
7 lower status of the importance of the work that had to be
8 done. It has now been recognized as an important study and
9 it's been made part of its own--it has its own number. Then,
10 of course, the addition of a large block test at Fran Ridge
11 which you're going to hear about next.

12 The recommended changes to the testing objectives
13 was early access to a large-scale heater test to try to test
14 the hydrology and the temperature-dependent models. You all
15 know that there's a Scenario A or I think you know. There's
16 what's now called the administrative proposal that's being
17 worked on as we speak; rewritten that has been presented by
18 Dan Dreyfus to Congress on March 1. Within that, there are a
19 lot of--in terms of when we will do testing, when the heater
20 test will start, when they will finish, and how much we will
21 take to licensing. It's too big to go through any of the
22 details of that, but we certainly can discuss it later if
23 anybody is interested. But, in our plans is as early an
24 access to a large-scale heater test as possible and that is

1 upheld with the Scenario A investigations.

2 There's also an acceleration of man-made materials.
3 As you know, we're moving very quickly in ESF. As soon as
4 the tunnel boring machine starts, we're going to be involved
5 in all different kinds of fluids and tracers and different
6 types of things that Annemarie will discuss. And, as a
7 matter of fact, we're involved in a special study that's
8 starting up very quickly now just looking at diesel exhaust
9 fumes and that and how they may impact the studies that we
10 will be doing.

11 There's now been a greater emphasis, finally, on
12 the characterization of the altered zone and we're not going
13 to spend any time talking about that today, but that is an
14 area that now has gained influence. Then, we will go back
15 and re-evaluate the interface between these information needs
16 and how they impact the altered zone.

17 The integration and this is another important part
18 of the work that's being done and, thanks to people like
19 Ardyth and Claudia Newberry and that, we are starting to
20 integrate with all the other aspects of the program in these
21 areas. We have the testing to link geochemistry studies with
22 design. There's the geochemical integration task group, the
23 hydrology integration task force, solubility working group,
24 and they meet quite regularly and all that information then

1 is fed back into the design process because we're all part of
2 the same team now which is mentioned here. And then, the
3 other important thing is all of the inputs from the
4 unsaturated and the saturated zone hydrology and geochemistry
5 is now finally being brought together. Then, of course, the
6 influence from the international programs.

7 And, I won't spend any time on this last viewgraph
8 here, only to show you if you look in your thing, as in the
9 flow diagram, how all of these things are now a part of both
10 the design process and some of the site characterization
11 processes. You see man-made materials shows up, metal
12 barriers is in here, this is the area in the altered zone
13 work here, and the waste package geochemistry, hydrology,
14 integrated testing, and EBS field test flowing down into the
15 waste package performance assessment, and then into the total
16 systems PA. So, we do have an integrated program.

17 The last slide that I'll put on is one Carl asked
18 me to give you; sort of a breakdown of the funding under the
19 Livermore activities. It was 12.9 million of this past year
20 broken down as shown; the environment area being the largest
21 part, waste form being second, and the materials testing
22 being the third area of significance.

23 So, with that, I will quit and answer any questions
24 if anybody has any.

1 DR. PRICE: As I understand what Lawrence Livermore
2 generally is doing, it's more directed toward research and
3 science than designs specifically. However, I'd like to ask
4 a question here that's related to the overall system. In
5 transportation, it seems that it's desirable or more
6 desirable to have large capacity in terms of a cask or a
7 container; whereas, in the repository that the size of the
8 container or cask is related to thermal loading. So, it's
9 desirable to have a flexible capability with respect to
10 thermal loading because that decision has not yet been made.
11 Has this type of problem, this--there's an apparent
12 difficulty here between the requirement for transportation
13 having a large capacity and the repository need for
14 flexibility with respect to the size of the container. Has
15 that been addressed? I understand there was a four pack
16 study of some type done here and I just wonder what it's all
17 about and could you tell me?

18 DR. CLARKE: Well, I'll start it and David is probably
19 closer to the MPC than I am. The baseline MPC is the 125
20 ton--21 assembly, is that what it is--unit. The backup is
21 the 75 ton unit, but also on the books is the four pack that
22 you're referring to that Livermore has submitted to the M&O.
23 That has been published formally. I don't know if that will
24 go any place right now, but it certainly is on the table as

1 an option especially for those utilities that cannot handle
2 the bigger packages. It also does provide some flexibility
3 when you get to the actual repository in movement. The
4 repository people are working, of course, with us though and
5 don't feel that they have any problems with moving the
6 packages around if they have to to accommodate whatever
7 thermal loading decision is going to be made in the future.

8 That's about the extent of my knowledge with the
9 MPC.

10 DR. PRICE: I don't believe we've been briefed on the
11 four pack.

12 DR. CLARKE: No, nobody has. But, it is out. I mean,
13 we could--you know, the reports are all over. We've
14 submitted them already. We'll give you as many as you want
15 to carry home tomorrow. You know, this is not a new thing.
16 In fact, even in the--I don't know what you call it, the
17 design document or whatever, there is a smaller MPC there
18 and, in fact, at the TPR meeting a few weeks ago, there was
19 a--on the poster session, there was a placard there that
20 showed a smaller MPC design. That design, the one that was
21 submitted through here, was submitted by the fellow up here,
22 Larry Fisher in transportation and that was something that he
23 designed when he was at General Electric in 1982. So, it's
24 not anything that is particularly new. It's something that's

1 been around for some time. The thing that makes it a little
2 different is his design is a square rather than a round and
3 there's reasons for that. It has some attractiveness and
4 some flexibility, but then also there's reasons for the
5 others also.

6 DR. BARNARD: What will your budget be if OCRWM is fully
7 funded at \$532 million?

8 DR. CLARKE: Okay. The latest breakdown we saw just a
9 couple of days ago was, I think, 14.8 for the waste package
10 area, but we don't know how much the 1.2.3, that was broken
11 out of that, has in it or not in it at this point. We also
12 don't know specifically what the split between the M&O design
13 and the Livermore research studies would be. So, right now,
14 the number that I've seen published for fiscal year '95 is
15 14.8 in the waste package area. Now, that could be more
16 substantial if, in fact, the near-field environment area was
17 taken out and put into the 1.2.3 area. I don't know.
18 Ardyth, maybe you can comment on that?

19 MS. SIMMONS: We're still trying to work that out.
20 Those numbers haven't been put into the 1.2.3 area yet. I
21 think we're talking about probably adding ten or fifteen more
22 if we can in that, to cover the near-field environment work.

23 DR. VERINK: I think we'll have to move on now. The
24 next speaker will be Wunan Lin.

1 DR. LIN: Good morning. I apologize, I don't have a
2 shaking joke for you this morning.

3 What I'd like to do today is talk to you about a
4 very small area of the engineered-barrier system field
5 testing that we intend to do, and this is almost like a
6 progress report to you, because in October last year, we
7 reported to you, also, on the large-block test, and so, I may
8 skip part of the view graphs in your book.

9 We are in a very dynamic program, but one thing for
10 sure, I'm not Dale Wilder here. I'm Wunan Lin. I'm not
11 going to go through the first eight pages in your book,
12 except page number three, which I need to put on because we
13 need to fulfill our advertisement in the agenda today.

14 The agenda today says that we're going to talk
15 about large-block test material study plan, and, therefore, I
16 need to put this up because this is provided to me by Dr.
17 Daniel McCright, that we are going to do some material
18 testing in the involvement of the large-block test, and I
19 think this is probably the first time that waste package
20 materials are being tested in the rock environment. We've
21 got to learn something from that.

22 Also, during my talk, in a certain part, I will
23 show you where we are going to put this material in the large
24 block, and if you have any detailed questions about how we do

1 the testing, I think Dan McCright will be the person to
2 answer that question.

3 I'll put this table of contents on this side of the
4 view graph, and to guide what I'm going to talk about. You
5 probably still remember that we are going to have a large-
6 block cut in the field at Fran Ridge. The block will be
7 about three meters by three meters, four and a half meters
8 tall.

9 The diagram shows a kind of rectangular that way,
10 but, actually, it's a square if you look from the top, and
11 this is showing all kinds of instrumentations that we're
12 going to put in the large block, including borehole for
13 moisture content measurement, which will be the bright color,
14 and in some of your books will be called neutron, moisture
15 sensor borehole. For this, we're going to use neutron
16 logging to determine the moisture content. We're going to
17 use, also, moisture sensors, including resonant cavities in
18 the cap to measure moisture content at points.

19 The blue color are designed for measured
20 temperatures. We are going to use RTD to measure temperature
21 at various locations in the block. The brown color will be
22 for geomechanical instrumentations, including extensometers,
23 a measurement of displacement of cross fractures, and so on.
24 This green color will be the borehole for geochemical

1 sensors, and that includes the micro-electro array sensor
2 that is developed by Bob Glass of Livermore.

3 The red color, of course, stands for heat, and that
4 will be the heater holes. A heater hole will be put in the
5 block at about one and a half meters from the bottom of the
6 block, so we are going to have a three-meter area above the
7 heater hole that we're going to study the dehydration and the
8 saturation in the block itself.

9 On the surface, we are going to have electrodes for
10 electrical resistivity tomograph mount on the surface, and
11 also in a hole near the middle of the block to measure the
12 two-dimensional cross-section of moisture content variations.
13 In those arrays, we are going to also include acoustic
14 transducers that we're going to use to measure acoustic
15 tomograph to help us also understand the mechanical response
16 of the rock.

17 We also have 2 ERT holes at the bottom of the block
18 going into an angle where we try to also monitor the area
19 below the heater zone to see how the moisture's distributed
20 in that region.

21 The block will be surrounded by a low retaining
22 frame, which will be something like 192 inches ID, inner
23 diameter, and about 25 feet tall, with a domed top.

24 This is indicating the block itself. We are going

1 to have bar heaters mounted on the surface so that we can
2 keep one-dimensional heat distribution, or one-dimensional
3 temperature distribution in the block. One dimension means
4 from bottom to top. We're going to have insulation materials
5 outside of the heaters, and then, outside of that insulation
6 material, we're going to have loading devices, and right now,
7 we are thinking using bladders that can provide about 40
8 atmospheres pressure, 600 psi loading on the side of the
9 block.

10 At the top of the block, the vertical loading will
11 be provided by a flat jack, same kind of pressure, about 40
12 atmospheres.

13 So, that covers the test concept, and the next one
14 will be the planning controls, and we have to do QA assurance
15 gradients on various activities of this large-block test.
16 This includes activities for isolated block; the designs and
17 the fabrication of the loading frame; a whole bunch of
18 scoping property determinations to help us to design the
19 tests, characterization of the block; and a unique feature of
20 the large-block test, is that we can characterize the block
21 before and after the test, and that's very important for
22 calibration and verification of models.

23 We do some scoping laboratory tests on small blocks
24 to understand individual processes, that one-dimensional

1 thermohydrological process, hydrochemical process, and
2 thermomechanical process. Then we're going to do integrated
3 tests on the large block itself. This is to study the
4 microscopic coupled thermomechanical, hydrological, chemical
5 process.

6 Of course, we do model calculations to help us
7 design the test. We do model calculations after we collect
8 the data to analyze the result, and those are all graded
9 according to quality assurance programs of Livermore, such as
10 are shown here.

11 This test is a combination of laboratory tests and
12 field tests. Whenever you go to the field, you need to have
13 job packages, and those are the job packages at Los Alamos,
14 the topical coordination office helping us provide those job
15 packages, different phases, and then when we do the test,
16 we're going to have test planning packages that will cover
17 any field support for Livermore to do testing.

18 On the construction site, we have finished cutting
19 a bench. This will be 16 feet tall, and this will be the
20 block, the area of the block, and this was a sump for sawing,
21 because we need to drain the water from the saw. This is a
22 catching sump for the water.

23 We have finished sawing as of February 25th, and
24 just to show you that we actually, indeed, sawed the block,

1 this is a 19-foot saw, a belt saw, like a big O-ring, 19-foot
2 long. You can see water spreading during the sawing. This
3 is diamond imprinted on the outside of the rubber. And when
4 they are doing the saw, this is--you probably cannot see it
5 in the back, but this is a slot, very nice cut, 16 feet tall,
6 and this will be cut all around the block itself.

7 And, as I mentioned earlier, we finished the sawing
8 as of February 25th, so I can color green the area
9 surrounding the block. Green means we are safe. That means
10 it's finished. This is all cut. We made four cuts; this
11 cut, first, second, third, and fourth cut. The saw is still
12 on site. We do that to benefit the international program,
13 that they may use it to make additional cut here so that they
14 can collect a meter-sized rock for their purpose.

15 When I'm on this slide, I may as well indicate that
16 after we do the sawing, the next thing to do, the next major
17 thing to do is to remove the rock surrounding our wake for
18 excavating. We are going to use a hydraulic jackhammer.
19 Before we do that, we want to drill release holes, and this
20 will be an array of holes that will be drilled 16 feet deep
21 around this block, so this will be used to release any impact
22 that the excavation activity will have on the block itself.

23 Right now, the slot, the block itself is protected
24 by foam. We put a foam pack in the slot to protect the block

1 itself from any vibration due to future activities. Before I
2 take that away, right now, as we speak, Sandia National Lab,
3 Bob Blass from Sandia, is pouring water in the area here, and
4 the water is dyed by food dye, and this is so-called fracture
5 flow visualization test, and we already map the fractures in
6 this area, about 10 x 10, ten feet by ten feet. We also
7 mount electrical resistivity tomograph electrodes on the
8 surface, and also in four boreholes, about ten foot deep,
9 each one, so that we can monitor how water infiltrates into
10 the block.

11 Then, after the water is gone, we are going to take
12 this apart, do an excavation process, and actually look at
13 the fracture surface to see how the dye stained the fracture
14 surface, and also to know which fractures is conducting the
15 water. So, this is a fracture flow, we show this, and, also,
16 it's a good chance for us to calibrate our electrical
17 resistivity tomograph technique.

18 And this is just to show you that we actually look
19 at the operation of these huge hydraulic jackhammers, after
20 cutting a piece of rock nearby. The block is somewhere in
21 this area here. This thing is very efficient. It doesn't
22 create very much vibration on the block, and we hope that by
23 doing that, we can finish the excavation much quicker.

24 We are somewhere in here, and all this green color

1 means we are complete, and if you compare this one with the
2 one you saw in October, you can see that we are not only
3 making progress, also, the schedule is also making progress.
4 Actually, the schedule slipped a little bit from October.
5 We were hoping that we can start the main test on August 1st,
6 but now we're looking at about the beginning of December.

7 As you can see from here, that the test includes
8 not only the main tests on the large block; also, laboratory
9 tests on the small blocks.

10 We need to protect the block. This is about
11 somewhere in here, block support and design. When we
12 excavate the rock away, we'd like to do it step-by-step so
13 that when we reach about a couple feet deep, we'd like to put
14 some sort of protective device around the block itself, and
15 ISN is right now designing this kind of protection device for
16 us so that the block will not fall apart.

17 As you can see from the next view graph, the rock
18 is highly fractured, as you know. This is fractured Topopah
19 Spring tuff. This is a surface map of the fracture
20 distributions. This is the northwest corner of the area.
21 This is the location of the large block itself. Most of the
22 fractures are a very high angle, about 70 degrees, dipping to
23 that direction, dipping to southwest, or to west.

24 With this kind of fracture, we decided location of
25 the block based on the number of fractures that we can
26 include in the block itself, because it is very important

1 that we have enough fracture to conduct the motion and
2 movement. Also, we don't want to have any piece of rock
3 falling away from the block during the excavation. That's
4 why we need this protection device.

5 This is just to show you that most of the fractures
6 are deep, very high angle, and strike about north/south.

7 We have done some characterization work, and I
8 think I have to change this view graph. I forgot to mention
9 that before we started sawing, we drilled all the vertical
10 holes. We drilled all the vertical holes that will be used
11 in the future for instrumentation.

12 When we drilled the first vertical hole, we did air
13 injection to measure permeability of the block, because our
14 model told us that in order to have a dry out zone in the
15 block, we need to have at least one millidarcy of the block
16 permeability. This is a measured permeability in the block,
17 starting from the top to near the bottom, and the heater will
18 be put somewhere here.

19 We have a region about 10 millidarcies above the
20 heater, several feet, and probably by a region of very high
21 permeability, about seven darcies. So, the block is probably
22 suitable for the response that we intended to see.

23 We also did some neutron logging. We used a
24 neutron logging tool to measure moisture content in four of
25 the small holes, the vertical holes, and those are the
26 neutron counts, not moisture content yet, but using this

1 equation to calculate the moisture content based on
2 manufacturer's calibration constants, we found out that the
3 moisture content started from about 10 per cent by volume
4 near the surface, to about maybe 17 per cent near the bottom,
5 and we are in the process of measuring the porosity of the
6 rock. If we assume a 15 per cent porosity, this will be like
7 65 per cent saturation, and, of course, this is totally
8 saturated.

9 So, in our model calculations, we always assume
10 that we need a 50 per cent saturation, moisture saturation in
11 order to have enough water, enough moisture to move around,
12 so that looks like the block has enough initial moisture
13 content.

14 We did model calculations to help us design the
15 test, and this is the calculated temperature distribution as
16 we expect to see by putting heaters, about 300 watts each, in
17 these five heater holes. We expect to see temperature about
18 135-140°C. This was based on keeping the temperature at the
19 top of the block at about 20°C.

20 These two calculations, they start a curve,
21 assuming a homogeneous permeability in the block, the dashed
22 line assuming the actual permeability that we determined as
23 function with depths, and you can see, as far as temperature
24 is concerned, these two models actually are not different

1 very much from each other, indicating that the heat
2 conduction is still the dominating mechanism in the block, in
3 such a fractured block.

4 We also calculate the expected moisture content
5 change. Again, here is a heater here, and the top of the
6 block is here. With uniform permeability, this is the
7 expected dry-out zone, about a meter away from the heater,
8 and then condensate saturated zone above the heater. That
9 actual permeability distribution is shown by this dashed
10 line, we still see significant condensate zone above the
11 heater, and the larger condensate zone below the heater.

12 Those are the regions where we are going to
13 concentrate our measurement of moisture content, our
14 measurement of geochemistry, and also, we're going to put the
15 waste package material--it will be carbon steel and copper--
16 in those areas. We're going to see how the material's going
17 to respond by exposure to the high humidity.

18 We're also going to put the material in the heater
19 hole to see how they respond to the high temperature dry
20 environment, and I think Dan McCright may want to talk about
21 that even more.

22 I have only two minutes left. And on the
23 instrumentation, we're going to measure temperature,
24 displacement, electrical resistivity tomograph, acoustic

1 emission to find out if there is a new fracture developed,
2 and also to help determine the mechanical response. We're
3 going to put pressure on the top and outside of the block, we
4 need to control that pressure, control the temperature, and,
5 also, we have a whole bunch of geomechanical and geochemical
6 instrumentations that we need to put in the block.

7 The calibration, we hope that we can utilize the
8 REECo and EG&G facilities for the calibration. I think they
9 are still the project-qualified calibration facilities. I
10 should also mention here that we also do user calibration for
11 something that--the neutron logging tools, the ERTs, and so
12 on.

13 And I think this will be my last one. For the data
14 acquisition, we are going to have about 900 channels. We
15 hope that we can develop using this SMIDS system that has
16 been developed by the test program, and, also, we are going
17 to develop our own data acquisition system so that we have a
18 dual kind of system that we can use.

19 I'm going to stop right here. If there's any
20 questions?

21 DR. VERINK: In order to preserve our schedule, I think
22 we'll skip the questions at this time, take a break, and
23 reconvene at ten-fifteen.

24 (Whereupon, a brief recess was taken.)

1 DR. PRICE: I'm Dennis Price, and I'll be chairing this
2 particular session.

3 Before we begin, I'd like to introduce Mike Revelli
4 of Livermore who has a few brief things to say about the
5 logistics of tomorrow morning's tour. He's at the podium.
6 So, if you'd please kind of clear the way for him. Thank
7 you.

8 MR. REVELLI: Thank you very much and good morning.

9 For those of you have made arrangements either
10 through the TRB or directly through my office to participate
11 in the tour of Lawrence Livermore Laboratory tomorrow, I'd
12 ask that each of you check with me and confirm sometime this
13 morning so that we may expedite badging tomorrow morning. At
14 that time, I can provide each of you with an agenda for the
15 tour, a map to Livermore, and a map of the site, as well.

16 The tour itself will run from 8:30 in the morning
17 until approximately 11:00 or 11:15. And, I'd ask each of you
18 to arrive at the Livermore's west gate badge office, which
19 will be identified on the map, no later than 8:15 so that we
20 may complete badging and be ready to depart at 8:30. I know
21 there are a few early departures from the tour, but in
22 general, you should allow about an hour and a half to two
23 hours to return to San Francisco Airport from Livermore,
24 especially if you have to check in a rental car. For those

1 of you with later flights, check with me and I'll be happy to
2 show you the location of an on-site cafeteria, the visitor's
3 center, other things in the area.

4 Finally, if any of you have found it necessary to
5 change your plans and cancel your participation in the tour,
6 I'd also like to know that sometime before today's meeting
7 concludes so that we won't be waiting for you and again
8 expedite the departure of the tour.

9 So, thank you very much. I will be located toward
10 the back of the room during this morning's session for no
11 later than the lunch break. Please check with me. Thank
12 you.

13 DR. PRICE: Thank you, Mike.

14 I'm sure that you all know that the Board feels
15 strongly about the role of performance assessment in guiding
16 research. The first presentation of this session will deal
17 with just that. The latest Yucca Mountain performance
18 assessment exercise used waste package corrosion models for
19 the first time. As expected, the PA results showed that
20 corrosion is an important factor for isolation. The next
21 question is were these models adequate? If not, what
22 research would be needed to make them adequate? I hope we
23 are well on our way to answering that question.

24 Zircaloy cladding poses an interesting systems

1 problem. Superficially, it looks like it could serve as one
2 fairly superior barrier in a multi-barrier defense in depth
3 system in a repository. Yet, it appears that the longer it
4 is held at high temperatures, the shorter is its lifetime as
5 a barrier. This has very interesting implications for
6 consideration of the so-called extended dry thermal loading
7 strategy. The tradeoff studies to answer this problem have
8 yet to be done, but today we'll hear about some of the
9 analysis of temperature versus cladding lifetime both in a
10 repository and at-reactor dry storage.

11 Criticality control is another systems issue that
12 spans all aspects of the waste management system; storage,
13 transportation, and disposal. Clearly, we already have some
14 solutions to criticality control for storage and
15 transportation because we are storing and transporting spent
16 fuel already. DOE has been working on burnup credit for
17 transportation for some time and I guess they will eventually
18 obtain permission to use burnup credit for transportation.
19 Today, though, we will hear about what may be a much thornier
20 issue; long-term criticality control in the repository.

21 Our first speaker is Bill Halsey of Livermore who
22 will talk about corrosion models and performance assessment.
23 Bill?

24 DR. HALSEY: Thank you, Dennis.

25 The Board was presented the results of TSPA 1993 in

1 the Arlington meeting in January, but there was not time
2 there to go into very much detail about the subsystem model
3 that was incorporated. I'm Bill Halsey from Lawrence
4 Livermore Lab. I'm the technical area leader for engineered
5 barrier system and near-field environment performance
6 assessment. A brief outline of the talk; talk a little bit
7 about what subsystem performance assessment is, how we
8 approach the waste package performance modeling, what models
9 were incorporated in TSPA 1993 for container performance, and
10 then some examples of the iterative interaction that we're
11 trying to foster between performance assessment and the rest
12 of the technical program.

13 I think most of you have seen the performance
14 assessment model hierarchy, the pyramid of mechanistic
15 models, subsystem models, total system models with
16 sensitivity and uncertainty flow. We won't go through that.
17 This is Livermore's little portion of the pyramid analogous
18 to the pyramid that Bill Clarke showed. At the bottom, we
19 have the mechanistic models in the near-field environment
20 which is the environment in which the engineered system
21 operates. And, we have the different technical activities
22 which develop detailed mechanistic models and data. We have
23 to combine those to provide a subsystem model. If you just
24 take all of the detailed mechanistic models and try and put

1 them together in a fully coupled way, it becomes much too
2 complex, much too large a problem for computers to handle.
3 So, we need a process of simplification and combination which
4 we call abstraction. And, by abstracting and combining these
5 models, we end up with a subsystem model which hopefully
6 contains all of the appropriate interfaces and
7 representations.

8 I'm told that you can see better from the other
9 viewgraph machine. So, we'll move. And, in the middle here,
10 we have the integrated testing and model abstraction process.
11 Integrating testing is a process of taking certain
12 components and portions of the subsystem and testing them
13 together so that you end up with an integrated test of
14 various processes working together. This allows you to see
15 if your abstraction process still represents reality.

16 EBS subsystem modeling in total system performance
17 assessment 1993, we had a lot of ambitious goals to try and
18 improve the details in the subsystem model. I think we
19 accomplished a fair amount of that. There's always a lot
20 more to be done. The TSPA, as was presented to the Board,
21 was actually two separate analyses by two separate modeling
22 capabilities. Sandia National Lab used the TSA package of
23 codes and the M&O contractor represented by INTERA used the
24 RIP package which was developed by Golder Associates. They

1 both were looking for improved source term and subsystem
2 representation. And, we incorporated our model in different
3 ways into these two analyses.

4 We have a model here at Livermore called the Yucca
5 Mountain Integrating Model which we have been adding more
6 mechanistic detail to in the past year to get ready for this
7 total system performance analysis and we ended up taking a
8 smaller subset of that code, whittling it down to the portion
9 that we wanted to use, and producing a subroutine which can
10 be called from TSA and providing that to Sandia and they
11 incorporated it into their analysis. The abstracted
12 descriptions that were incorporated into the integrating
13 model were provided to INTERA and they wrote those into the
14 EBS portion of the RIP code. They ended up with the ability
15 to do slightly different level of detail in the engineered
16 barrier analysis which I think is very useful.

17 This is a one viewgraph representation of the
18 functional structure of this model showing that it
19 incorporates the near-field processes of hydrology,
20 chemistry. It has rod and fuel waste package containers for
21 temperature distributions. And then, the flow, water contact
22 descriptions into the fuel and the waste package. Container
23 failure, there is a cladding module, radionuclide accounting
24 system which gets into--goes through the accounting and into

1 a source term as a function of time. We didn't use all of
2 this in TSPA 1993. What we incorporated into the TSA was
3 approximately this portion of it with a few modifications to
4 the water flow and the--we didn't use the cladding portion.
5 The algorithms for a variety of these were provided also to
6 INTERA for use in the RIP model.

7 To see what we did accomplish, here's a comparison
8 of TSPA Version 1 versus TSPA 1993. In the first round
9 several years ago, there was one waste package considered.
10 It was a small, thin-walled waste package. It was the SCPCD,
11 conceptual design. We also looked at that in 1993, but also
12 included the large multiple wall material or multiple barrier
13 design such as the MPC. The design was provided from B&W.

14 We looked at just the borehole emplacement the
15 first time around. We looked at both borehole and in drift
16 emplacement in the more recent analysis. Thermal loading,
17 there was no explicit thermal processes in the previous
18 analysis, but the abstracted model implied the SCP thermal
19 loading of 57kW/acre. Here, we had some explicit thermal
20 dependence and we looked at 57 kW/acre, twice that, and half
21 that.

22 Container performance in the previous analysis had
23 been an arbitrary or specified container failure
24 distribution. It was assume to be hot and dry for the first

1 1000 years and that it was miraculously isothermal at 1000
2 years. The containers all got wet and started to fail over a
3 specified distribution. We tried to do a little more detail
4 this time around and put in some deterministic temperature
5 dependent models for oxidation and general aqueous corrosion
6 and an abstracted stochastic localized corrosion model which
7 also had a temperature dependence. This is not the entire
8 suite of corrosion models that could be considered, but they
9 were what we could get done with the resources and time
10 available.

11 Waste form performance again in the near-field
12 environment had been isothermal and fairly arbitrary. This
13 time, we tried to put in the first version of temperature
14 dependent oxidation, alteration, dissolution processes. And,
15 first version of coupled hydrothermal modeling abstracted to
16 give some--to reflect the dry out and refluxing effects. The
17 possibility of having more water due to refluxing or less
18 water due to drying out a zone around the rock. I can't say
19 we got all of that done in a final version, but we had a
20 beginning start or a start on all of those.

21 The near-field environment, I won't go on this a
22 long time. We did start putting in temperature dependence.
23 The water flow represents both ambient percolation due to
24 meteoric infiltration and hydrothermally-driven effects such

1 as dry out and refluxing. We did not put in the detail of
2 extended dry out where the resaturation front lags
3 substantially behind the boiling isotherm return. We assumed
4 that the rock resaturated as it dropped below boiling.

5 This work was abstracted from VTOUGH analysis and
6 provided to both Sandia and INTERA. INTERA did some
7 additional analysis using the VTOUGH code to get a wider
8 suite of water flow range.

9 To represent the heterogeneity and spatial
10 variation of the near-field environment, both INTERA and
11 Sandia took a few group representation of the variation from
12 the center to the edge of the repository and then represented
13 each group by a separate set of analysis and then combined
14 them. When I say few group, I think there was as few as two
15 groups in a couple of the analyses or as many as seven, nine,
16 or 11 in some of the more complex analysis. We provided a
17 log-normal representations of localized flux to represent the
18 heterogeneity.

19 A couple of things to note: transient geochemical
20 effects were not incorporated this time around. We wanted to
21 try and get some incorporated. We ran out of time. The
22 effects of man-made materials was not incorporated this time
23 around. We just didn't have enough details of how to
24 incorporate it. Those are all things we'll have to do in the

1 future and again the extended dry out effect was not
2 incorporated.

3 To the corrosion modeling, during the time period
4 where the containers were considered hot and dry and you do
5 not have aqueous processes occurring, the primary degradation
6 of the waste package is dry oxidation. The dry oxidation
7 rates were extrapolated from higher temperature data for iron
8 and steel. It was put on an Arrhenius temperature
9 dependence. It was primarily used for the early time
10 oxidation of the thick steel overpack for the multiple
11 barrier large container. And, a key question which remains
12 open is under what temperature-saturation conditions do we
13 switch from dry to aqueous conditions?

14 This was represented several different ways in the
15 analysis. What we wrote into the integrating model was a
16 temperature switch. We simply at 100 degrees Centigrade
17 allowed the aqueous processes to start. INTERA did some
18 additional analysis using a temperature switch and also a
19 saturation-dependent switch looking at the saturation in the
20 near-field environment and saying at what point, putting in
21 an arbitrary saturation, at which point the aqueous process
22 is turned on. This is the first step in answering the
23 questions of water contact. What water moving in the near-
24 field environment is detrimental to the waste package, the

1 waste forms, and transport processes? I think we need to do
2 a lot more in that, but it's beginning to allow us--putting
3 it in a crude way allows us to do some sensitivity studies on
4 it and find out if indeed it makes a difference.

5 The way the dry oxidation was incorporated was a
6 simple Arrhenius rate dependence taking some example data out
7 of the literature. This was put in as a default into the
8 models. There was also the ability to put in arbitrary
9 oxidation rates and there was a few runs with different rates
10 provided by other people. So, that's not the only data that
11 was used, but that's the example of what we built into the
12 model as a default.

13 After you switch to aqueous corrosion, we split it
14 into just two processes; an aqueous general corrosion and
15 then a localized corrosion. The aqueous corrosion or general
16 corrosion model, we used a general corrosion with a pitting
17 factor to represent localized variation. This is fairly
18 common in modeling aqueous corrosion in irons and steels. We
19 put in a selectable average rate and put in default values
20 which are extracted from iron and steel corrosion data that
21 were provided by the corrosion folks. The temperature
22 relationship was fitted to a quadratic shape which I'll show
23 you in the next viewgraph and this was primarily used for the
24 wet corrosion of the thick steel overpack. And, again, the

1 same question; at what water contact conditions do you turn
2 on this process?

3 This is represented with this quadratic function.
4 This represents two conflicting processes. As the
5 temperature increases, the kinetics of the dissolution, the
6 corrosion, increase, but at the same time, solubility of
7 oxygen in the water is decreasing and you actually go through
8 a maximum and then it declines again. And then, with the
9 temperature switch, you turn it off at about 100 degrees
10 Centigrade. This is a few degrees above the boiling point,
11 but you can have a water film on the surface. It retains
12 above boiling. And, here's the example data that was used
13 from the literature as the default values and there was some
14 sensitivity study on changing those to other rates.

15 The localized corrosion model, I'm not going to try
16 and describe in detail. It's a whole separate discussion.
17 But, we combined all of the localized processes of pitting,
18 crevice corrosion, cracking phenomena; were all represented
19 in one model. This is quite a simplification, but it's the
20 first time we've been able to incorporate a mechanistic model
21 for localized corrosion in this kind of analysis.

22 A couple of years ago, Greg Henshall at Livermore
23 took pitting data on corrosion resistant material and
24 proposed a stochastic model of pit birth, growth, and death

1 to fit that with that kind of data and it seems to represent
2 the observed pit depth distribution as a function of time on
3 corrosion resistant materials such as the Incoloy 825. We
4 had to abstract that model substantially and it was
5 abstracted using an extreme value statistics to look at the
6 probability distribution or the deepest pits. Over how many
7 pits might you have on a container under different conditions
8 and that gives us the probability distribution of penetration
9 as a function of time. The temperature dependence was
10 represented by an Arrhenius relationship on the growth rate.
11 There are a number of parameters in this model and we put
12 the growth rate as the only temperature dependent.

13 And then, from the corrosion experts, we had to
14 elicit median, upper bound, and lower bound growth rates for
15 different environmental conditions. So, we ended up
16 eliciting nine different numbers. These are represented
17 here. This is the mean and the 95th percentile for three
18 different corrosion aggressiveness combinations. This is
19 environment material. Whether there's a low corrosion,
20 median, or high and then estimates of the mean and the 95th
21 percentile and we actually elicited these six at two
22 different temperatures. You can see that there's a fairly
23 simple order of magnitude relationship and we aren't going to
24 try and defend these as the correct numbers, but they are

1 representative of what is seen in corrosion under a variety
2 of conditions. We got these primarily from Dan McCright,
3 Greg Henshall, and the literature. It allows us to start
4 putting this kind of model in for sensitivity studies. In
5 other words, don't believe the final numbers, but we believe
6 this is the first step at representing the kind of corrosion
7 process in the total system analysis.

8 When you put all this together, what happened?
9 Well, here's some simplifications from the results. I think
10 the Board has been made available draft copies of both
11 reports, is that correct? And you know there's a lot of
12 information there. The waste packages which were wet could
13 fail in as little as 100 years. Those waste packages which
14 stayed dry, some of them never failed in a million years.
15 Water contact is important. The average lifetimes under a
16 variety of different scenarios were several thousand years
17 and there's some caveats here of effects which were not
18 incorporated which can change those results.

19 With the last couple of minutes, we keep getting
20 asked how is this being used? How are we interacting with
21 the rest of the technical program? Well, we've been arguing
22 for a long time that the subsystem analysis needs to be used
23 to help indicate what tests or what data is needed, what
24 model development is needed, and to be--to assist the design

1 program. These are just some examples. Let's see, an
2 improved model was developed for this. Interactions with the
3 waste package design team has begun. We've made available a
4 version of the integrating model to B&W and they are now
5 evaluating it to design analysis and what design details they
6 can help us incorporate into the model for the next round of
7 analysis.

8 I'd like to point out that subsystem performance
9 requirements were not addressed in TSPA 1993. That is a
10 substantially complete containment and the part in 10^5
11 release, these two criteria here, some of these results do
12 exist in the data and we may be able to extract some of that
13 from the information later and then perform additional
14 analyses. And then, right now, we are starting to perform
15 sensitivity and uncertainty studies using this model to
16 assess the value of information at different points and
17 parameter space to look at analysis of design features, test
18 planning, and model development.

19 The last viewgraphs are examples of these. The
20 transition of container corrosion mechanism from aqueous to
21 non-aqueous was identified during the development of this
22 model for TSPA '93 as an important issue. So, in conjunction
23 with the material testing program, we fed this back and said,
24 "What we really need to know is where do we make that

1 transition?" There was summary of some changes in the
2 priorities of the testing program. The test planning has
3 been revised to address this issue earlier and controlled
4 environment corrosion tests have been planned. The material
5 has been procured and I think Dan or Greg--I think Greg is
6 going to talk about this test later.

7 Examples, model development, we needed a way of
8 extracting abstracted hydrothermal information from the
9 VTOUGH. So, subroutines were developed and a process for
10 extracting that. Site testing, for example, water contact
11 again was determined to be very important and now the large
12 block test, as you just heard, is going to include some
13 material corrosion and environmental sensors to start
14 addressing those questions. There's a few other small
15 examples.

16 I can't say we have a complete iterative
17 interaction with all parts of the program, but we're
18 starting. And, part of the reason is because now we have a
19 tool for the first time, I think, that's actually useful.
20 When you have a model that just gives arbitrary
21 distributions, you can't get a lot of useful sensitivity
22 information out of that. It's whatever you put in. When you
23 start putting in mechanistic descriptions of these processes,
24 you can start extracting information from them that is useful

1 in determining what is needed.

2 I think I'll stop there.

3 DR. PRICE: Questions from the Board?

4 DR. CANTLON: What sort of input has this kind of work
5 had on the MPC?

6 DR. HALSEY: The design that was incorporated into TSPA
7 1993 is very similar to the MPC. It's the design that was
8 provided by B&W and it is consistent with the MPC design. We
9 did not include any performance credit for the MPC shell, but
10 then there was a two-layer material which would be the
11 disposal overpack of Incoloy and then carbon steel had
12 various thicknesses. So, the analysis was consistent with
13 the MPC and some of those results can be fed back into the
14 MPC design process.

15 DR. PRICE: Other questions?

16 DR. NORTH: I'm impressed at the progress you've made.
17 It looks like you're learning a great deal and you're gaining
18 a lot of insights as to what's important from a performance
19 assessment viewpoint to tell to the rest of the program. So,
20 having been relatively critical of other presentations of the
21 lack of progress, I'd like to commend the progress that
22 you've made here and urge others to study your reports, as I
23 look forward to doing.

24 DR. HALSEY: Thank you.

1 DR. PRICE: Other comments or questions?

2 (No audible response.)

3 DR. PRICE: All right. Thank you.

4 Our next speaker will be addressing zircaloy
5 cladding as a disposal barrier. Kevin McCoy?

6 MR. MCCOY: During reactor operation, the fuel cladding,
7 these long, thin tubes of zircaloy, perform the function of
8 containing the fuel pellets and the fission products. Can we
9 expect these zircaloy tubes, the fuel cladding, to perform
10 the same function during disposal? That's the question that
11 I have looked at and that I'll be addressing today.

12 First, a quick outline of my talk. I'd like to
13 briefly run through the prognosis for cladding life. Second,
14 I would like to give an overview of the different mechanisms
15 by which cladding can degrade. And, finally, I'd like to
16 treat in some detail creep rupture by diffusion-controlled
17 cavity growth.

18 First, we have reasons for having uncertainty in
19 the life of cladding. For one thing, the cladding life may
20 be consumed before disposal. It could just be shot. Second,
21 cladding is highly variable. We have zircaloy 2 cladding, we
22 have zircaloy 4 cladding, we have low and high burnups. High
23 burnups, as I mention in the third bullet, may be
24 detrimental. There's events that cladding starts to corrode

1 more quickly particularly at high burnups. Finally, if we
2 wish to take credit for cladding, we need to characterize it
3 and characterizing it is expensive and time-consuming for two
4 reasons. First, the cladding is radioactive and it has to be
5 handled in a hot cell. Second, because the cladding is so
6 variable, it is necessary to examine many samples to properly
7 characterize the entire population.

8 On the other hand, we do have good reasons to
9 expect significant performance from cladding during disposal.
10 First, more than 99% of fuel rods are intact at discharge.
11 They have no breaches, at all. They have complete mechanical
12 integrity. Second, zircaloy is corrosion resistant. This is
13 evidenced by their performance in the reactors themselves.
14 If they were not corrosion resistant, they could not last
15 through the years of exposure at high temperatures and high
16 pressures under water. Third, failures are usually
17 microscopic. Most cladding failures are either pinholes or
18 tiny hairline cracks. As a result, even a failed cladding
19 can provide substantial protection for the contents of the
20 clad. We may conclude, therefore, that cladding is
21 potentially important as a barrier to release and that it can
22 serve as a redundant barrier to containment should there be
23 defects in the containers.

24 Let's move on now into some of the mechanisms for

1 cladding degradation. In most of these cartoons, I show
2 cross-sections of the cladding. In this one here, I show an
3 entire fuel rod. We'll start with fuel-side stress corrosion
4 cracking. Iodine is perhaps the most notable stress
5 corrosion cracker in the cladding. It's produced as a
6 fission product and promotes growth of cracks which would
7 form from the inside and progress through the cladding.

8 Hydride reorientation. Normally, because of the
9 microstructure of cladding, hydrides which are brittle and
10 tend to promote cracking form parallel to the surface of the
11 cladding and are, thus, fairly innocuous. During long
12 storage and with changes in temperature, the hydrides can
13 reorient, reprecipitate into a radial direction in which they
14 are much more detrimental.

15 Delayed hydride cracking is similar. Here, a crack
16 forms and then its growth is sped up by the diffusion of
17 hydrogen through the clad to the area of triaxial stress at
18 the head of the crack. Thus, the cracking is accelerated by
19 the motion of hydrogen.

20 Hydrogen also tends to diffuse down thermal
21 gradients and will go to the cold parts at the end of the
22 cladding. Thus, in axial hydride redistribution, we see
23 hydrogen moving from the center of the cladding out to the
24 ends where it can accumulate and produce more rapid

1 degradation.

2 More mechanisms here. Creep rupture in which we
3 assume that the cladding simply fails if it is extended
4 beyond its limits of ductility, if it's stretched too far.

5 Strain rate embrittlement, depending upon the rate
6 at which the cladding is stretched/strained, the ductility
7 can be reduced.

8 Irradiation embrittlement occurs during reactor
9 service. Neutrons irradiating in the cladding cause damage
10 and reduce the ductility.

11 Finally, after the package has breached, we can
12 have oxidation and aqueous corrosion shown here as a layer at
13 the top which is penetrating into the zircaloy matrix.

14 Now, if that's enough cladding degradation
15 mechanisms, we can find some sub-mechanisms in creep rupture
16 itself. Ductile transgranular fracture is the sort of
17 fracture we see in tensile tests where the specimen simply
18 necks down and finally fails because it exceeded its
19 ductility limits.

20 In triple-point cracking, we see where three grains
21 come together, two or more of them starts to slide over each
22 other forming wedge shaped cracks, and initiating a failure
23 in that way.

24 Finally, two types of cavity growth failure where

1 bubbles basically form through the cladding and grow; their
2 growth being accommodated either by power law creep or by
3 diffusion, grain boundary diffusion.

4 Here's a schematic of the type of growth we see in
5 diffusion-controlled cavity growth. I've sketched here two
6 grains which are being pulled apart, as is indicated by the
7 four sets of arrows. They're separated by grain boundary,
8 the horizontal line, and a cavity. The cavity grows as
9 vacancies--places where there ought to be atoms but there
10 just aren't, where vacancies migrate along the grain
11 boundaries to the cavity and cause it to grow.

12 What is the most important degradation mode? The
13 Nuclear Regulatory Commission and Pacific Northwest
14 Laboratories independently concluded that diffusion-
15 controlled cavity growth is the most important mode for dry
16 storage. The conditions for dry storage and for disposal are
17 very similar. In both cases, the cladding is sitting at a
18 high temperature in an inert gas environment and so we expect
19 that diffusion-controlled cavity growth is also the most
20 important mode for disposal.

21 I've spent some effort looking at diffusion-
22 controlled cavity growth and the models that were presented
23 by the Nuclear Regulatory Commission and Pacific Northwest
24 Laboratories to see what they predict in the way of cladding

1 life for fuel that has been disposed. In particular, I was
2 interested in seeing if the models have any excessive
3 conservatisms in them that would tend to cause us to
4 unrealistically underestimate the life of the cladding.

5 We treat damage in storage and disposal by the
6 usual damage accumulation approach. Here the equation simply
7 shows that the rate of damage accumulation is inversely
8 proportional to the rate under the current conditions; the
9 rate of damage accumulation under the current--excuse me. Is
10 inversely proportional to the lifetime under the current
11 conditions.

12 Using the physical model of diffusion-controlled
13 cavity growth that I described previously, we find this
14 equation for the predicted lifetime of the cladding. And,
15 you see that there are lots of parameters here that we can
16 use to make the equation fit the data. And, there are two
17 approaches to this equation. One approach is to lump them
18 all, the grain boundary diffusion, the various constants m
19 and n in there, the grain boundary thickness, and use them as
20 fitting parameters. The second approach which was used by
21 the Nuclear Regulatory Commission is to attempt to get
22 realistic, but nevertheless, conservative values of these
23 numbers, and predict a priori, without recourse to data, how
24 long the cladding will last under these conditions.

1 I've used the second approach, the NRC approach,
2 with a few small changes, places where I feel that the
3 Nuclear Regulatory Commission has made errors in
4 interpretation of the model. Also, I have taken more account
5 of the microstructure, this constant m , in determining how
6 long the cladding will last. Here are the numbers I put into
7 the equation. I won't go into those. I just provide this
8 slide for your information.

9 Effective microstructure is one of the places where
10 the Nuclear Regulatory Commission was most conservative in
11 their development of the model. Because of the way that
12 cladding is cold formed before it is put into service, most
13 of the grain boundaries in fuel cladding are oriented to
14 resist diffusion-controlled cavity growth. Second, they use
15 an unrealistic representation of strain; a triaxial strain so
16 that all the grain boundaries are under the same normal
17 stress and provide for fast growth of cavities. I tried to
18 improve the realism of the treatment by approximating the
19 grains as ellipsoids and calculating the average normal
20 traction over the surface of the grain. In this way, I hope
21 to reduce the excessive conservatism in the NRC's model.

22 Here's a sketch of one grain and the principal
23 stress components being applied to it. The ellipsoid
24 represents the surface of the grain. The arrows indicate the

1 principal stress components. We have a large circumferential
2 stress approximately half that much in the axial direction
3 and very little in the radial direction. As you see, this
4 flattened ellipsoid provides for fairly rapid cavity growth
5 only around the edges. That's the only place where we have a
6 large normal traction on the surface of the grain. Out here
7 on the large flat top and bottom surfaces of the ellipsoid,
8 there's very little normal traction and, thus, very little
9 tendency for cavities to grow. As a result, the rate of
10 damage accumulation is substantially lower, about a factor of
11 6 lower than what was predicted by the NRC.

12 Here is our prediction of cladding life using
13 constant temperature and stress for various temperatures.
14 Should we hold the cladding at 500 degrees C, for example, we
15 have a life of less than one year. As temperature decreases,
16 we see a very rapid increase in life until, say, at 200
17 degrees C, we have a life of over 100,000 years.

18 Of course, in disposal and in storage, for that
19 matter, we don't have constant temperature conditions. So, I
20 made a more realistic calculation here. This is not a design
21 basis calculation. However, it is intended to be fairly
22 realistic and fairly representative of typical fuels. I took
23 a PWR fuel with 40 GWd/MTU burnup, assumed that it was stored
24 in a fuel pool for five years, and then stored in a CASTOR

1 V/21 dry storage device for another five years. I'll get
2 back to the five years dry storage later. At 10 years time
3 since discharge, the fuel was disposed in repository without
4 backfill at a power density of 80kW/acre. This was in waste
5 packages of 21 PWR assemblies per package.

6 This plot tells the story of how damage accumulates
7 with time. Initially, we start out with very high
8 temperatures in dry storage. The temperature drops steadily
9 as the decay heat decreases and the fuel becomes less
10 radioactive. As a result of the high temperature exposure,
11 we see accumulation of damage in the fuel. However, the
12 fuel's heat output is dropping so quickly and the temperature
13 is dropping so quickly that after five years essentially all
14 the damage from dry storage has been accumulated. Additional
15 storage out to 40 years produced perhaps half a percent of
16 the cladding's life. The repository is not as effective at
17 dissipating heat as is the dry storage device. So, upon
18 emplacement, we see a large increase in temperature and a
19 corresponding increase in the rate of life consumption.
20 Eventually, however, even in the repository the temperature
21 does drop and the rate of life consumption also drops.
22 During the first 100 years, essentially, all of the damage
23 due to diffusion-controlled cavity growth occurs. And,
24 during the remaining 9,900 years for which I calculated, very

1 little damage accumulates.

2 From this model which, of course, is based on the
3 NRC's approach, we conclude that cladding can potentially
4 provide significant performance in disposal. However,
5 because of the variability among different types of cladding,
6 obtaining credit for this containment may be difficult.
7 Cladding can definitely survive the calculated temperatures
8 for that particular repository configuration for disposal for
9 10,000 years.

10 There are always future studies to look forward to.
11 This is only for one type of fuel under one particular
12 condition, set of conditions. During the future, I would
13 like to look at the effects of extended burnup which will
14 increase the amount of heat output from the fuel. Using the
15 other types of dry storage devices besides the CASTOR,
16 changing the thermal loading in the repository, and finally
17 looking at the effects of backfilling and the resulting
18 thermal spike.

19 Are there any questions?

20 DR. PRICE: All right. Thank you. We do have ample
21 time for questions.

22 DR. CANTLON: Yes. I would gather from your curves that
23 extended dry storage is not going to be a big problem because
24 you used 10 years--10-year-old fuel in your model, but at the

1 rate we're going, there isn't going to be very much 10-year-
2 old fuel in the repository.

3 MR. McCOY: Yes, that's certainly true that there won't
4 be any 10-year-old fuel.

5 DR. HALSEY: You didn't backfill your repository in that
6 analysis?

7 MR. McCOY: That's correct.

8 DR. HALSEY: And, that's when the temperature spikes can
9 get quite high?

10 DR. CANTLON: Right. No, my question had to do with the
11 dry storage component. Extended dry storage, say out to 30
12 or 40 or longer years, I would gather from your curves is not
13 going to be a significant degradation of the cladding?

14 MR. McCOY: Yes, the dry storage will not cause
15 significant additional degradation because the temperatures
16 are dropping quickly.

17 DR. CANTLON: All right. Now, I would think Halsey's
18 question is correct.

19 MR. McCOY: No. Now, should we go ahead and then pack
20 the fuel close together so that we get the same initial power
21 density, then the extended dry will have high temperatures
22 for a longer period of time.

23 DR. PRICE: Other questions from the Board?

24 (No audible response.)

1 DR. PRICE: Let me ask you, have you had any feedback
2 with NRC about the results of your study? Theirs would
3 appear to be perhaps from their viewpoint more conservative
4 with respect to the view of this. Do you offer more hope
5 with respect to the effectiveness of zircaloy as a barrier?
6 Have you discussed this with NRC?

7 MR. McCOY: I have not discussed it with the NRC. And,
8 though, certainly, my approach does provide more confidence,
9 more hope for--credit for this zircaloy as a cladding
10 barrier--

11 DR. PRICE: Okay. Carl?

12 DR. DI BELLA: I hate to use the word or term "extended
13 dry" in a different way than it was just used, but under the
14 extended dry scenario in the repository, as I recall, the
15 thermal loading is somewhat higher than 80kW/acre or am I
16 wrong? Was that 80kW/acre the extended dry repository
17 scenario?

18 MR. DOERING: With the evaluations that we have done to
19 date at the M&O, we have not placed the backfill into it
20 because of the variations in backfill thermo-conductivity.
21 We plan to do that in the next couple of years. But, the
22 80kW/acre is essentially--does provide an extended dry
23 repository from a loading issue. Extended dry and dry is all
24 relative depending on how long you'd like to have it. It is

1 thousands of years that we see, you know, the near-field
2 being dry at that areal power density.

3 MR. McCOY: Bill, would you like to make any additional
4 comments on extended dry? I guess I would like to reiterate
5 that under disposal conditions, we expect to have very small
6 failures in cladding. And, that once those occur, the gas
7 pressure inside is relieved and there's no additional driving
8 force for further degradation. The gas will hiss out and
9 that's the end.

10 DR. PRICE: You also indicated that variability was kind
11 of the buggaboo with respect to the condition of the rods
12 being so variable. Do you have any thoughts about how that
13 might be mitigated?

14 MR. McCOY: I think that really will require substantial
15 experimentation to characterize the fuel. For one thing, we
16 don't know what the future cladding is going to be like.
17 Presumably, new alloys could be licensed for uses as
18 cladding.

19 DR. CANTLON: My question is related to Dennis'. Are
20 you funded well enough to get the kind of replications that
21 you need to handle the variance that you're witnessing in the
22 cladding?

23 MR. McCOY: No.

24 DR. CANTLON: No scientist ever answers that question.

1 DR. NORTH: John, that may be an appropriate question
2 for the next speaker.

3 DR. STAHL: In regard to the issue of taking credit for
4 cladding, what we try to do if we did see that this was
5 necessary is to develop an experimental program that would
6 look at a bounding case for cladding performance. The
7 variability is such that there's no way that you can have a
8 complete database. So, you try to envelope the results and
9 see how useful it will be. And, as Bill Clarke indicated
10 earlier, that was one of the programs that has been delayed
11 and we hope to pick that up in the future.

12 DR. DI BELLA: Bill mentioned that this time around in
13 TSPA the cladding models were not incorporated. Do you
14 expect them to be incorporated in the next go-around and, if
15 so, will it be modeled similar to these or actually these?

16 DR. HALSEY: We hope so. It's always a decision of what
17 are you going to incorporate each time around. We considered
18 incorporating cladding this last round, but it would have
19 added considerable complexity to the time steps of the
20 subsystem model because we would have had to account for
21 prior to container failure. As it is, we were able to not
22 worry about the details until after the container's corrosion
23 occurred. If we do incorporate it the next time around, we
24 would use the best available model for this type of

1 degradation and we would try and incorporate some other
2 possible degradation modes under more extreme scenarios; some
3 of the aggressive environmental scenarios, also, for
4 corrosion of the zircaloy.

5 DR. PRICE: All right. Thank you very much.

6 Our next speaker again on zircaloy cladding, but
7 with respect to performance in dry storage, William
8 O'Connell.

9 DR. O'CONNELL: Okay. I'm Bill O'Connell from Lawrence
10 Livermore Lab. I'm going to give you another perspective or
11 another run-through on many of the same questions on the
12 zircaloy cladding and its potential performance. I'll
13 present the prepared material. Our co-author, Dr. Rosen, is
14 here also today and available for questions. I'm the systems
15 analyst and Dr. Rosen is a materials scientist.

16 Now, Dr. McCoy covered a number of possible
17 mechanisms. I'm just going to talk about creep of the
18 cladding because that seems to be the main mechanism that we
19 have to be concerned about. I'm going to approach this--
20 well, first, I'm starting to look at the load, the cause of
21 the creep problem, but anyway I'm going to look at the
22 experimental literature and the interpretations of the
23 experimental literature on creep and what it tells us.

24 Now, first, the creep depends on temperature and

1 time duration. And, the main factor controlling the
2 temperature besides design is the heat generation rate due to
3 the radioactive decay in the spent fuel. That radioactive
4 decay drops off with time and, depending on how old the spent
5 fuel is when you place it into dry storage, then its
6 subsequent proportional decline would be rather rapid for
7 younger spent fuel and slower for older spent fuel. If you
8 pick a peak temperature and you have an ambient temperature
9 here, then--say a drop off $1/6$ of that difference between the
10 peak and the ambient--in about seven years duration for the
11 10-year-old spent fuel and about 15 years duration for 50-
12 year-old spent fuel. Other factors also influencing the
13 decline of the actual temperature are the near-field heat
14 capacity of the interim dry storage medium, or of the
15 repository. And the thermo-conductivity of the various
16 components depends on the temperature. So, it provides some
17 modification to these curves. But, on the order of seven to
18 30 years is the period of high temperatures even though the
19 actual period of storage may be much longer.

20 Now, just to complete the guiding force, the
21 pressure inside the fuel rods generates the stress and the
22 pressure also depends on the temperature according to the gas
23 law. And, there's a typo here, this scale to the hoop stress
24 in the cladding. Now, the margin for peak temperatures in

1 dry storage or in disposal, if you want to preserve the
2 cladding, are somewhere in about 330 to 400 degrees
3 Centigrade. You know, that's where we have to look most
4 closely at the performance. And, this is for a fuel rod
5 which has--well, for 33 MWd/MTU burnup of pressurized water
6 reactor, this says 20% fission gas released to the gap in
7 plenum, but the most you could expect is about 10% fission
8 gas release and to get the same amount of actual gas mass,
9 you would have to go to about 50MWd burnout and about 13%
10 fission gas release. And, the initial preload gas is about
11 half of what I've shown here. So, the fission gases can add,
12 oh, say, one-half to an amount about equal to the preload gas
13 in the case of the PWR. In the boiling water reactor fuel,
14 the preload pressure is somewhat less and the fission gas
15 release is also somewhat modest, but could be up to about the
16 same amount as in the pressurized water reactor.

17 Now, why we have taken a look at this, there's a
18 dual interest that has been becoming more active in the last
19 couple of years. First, in the Yucca Mountain Project, the
20 cladding performance is assigned some performance during the
21 period of substantially complete containment. So, you have
22 to watch out what the peak temperatures are. And, with the
23 movement toward larger packages in in-drift emplacement, the
24 peak temperatures are a controlling factor in the design.

1 So, we were interested in looking again at what limits do you
2 really have to set on the peak temperature? And, again, the
3 time period for the peak temperatures is about 30 years which
4 would give you a peak temperature of about 350 degrees
5 Centigrade using the present design criteria. And, at the
6 same time, I'm involved in another project also sponsored by
7 the Nuclear Waste Fund and the Civilian Radioactive Waste
8 Management Program. Looking at transportation risk
9 assessment and in terms of fire accidents, we were interested
10 in the cladding performance. How much of a fire could the
11 cladding endure? Now, this becomes a concern only in quite
12 rare, very severe accidents which are considerably more
13 severe than the design basis accidents and have a frequency
14 of occurrence of on the order of 10^{-5} per fraction of all
15 the transportation accidents. So, very low frequency when
16 you consider the low number of transportation accidents.
17 And, the period of high temperatures is on the scale of one
18 day. It's governed by the thermal inertia of the cask rather
19 than the duration of the fire and, corresponding to it, you
20 could have a higher peak temperature.

21 So, several groups and several interests are
22 interested in revisiting the creep lifetime; you know, what
23 limit do you have to set to protect the cladding from failure
24 due to creep? In listing the factors here, I should mention

1 that besides the Yucca Mountain Project, the people who
2 design dry storage have an interest in getting more
3 flexibility in the dry storage loading and performance and
4 there's a report in the pipeline of the Electric Power
5 Research Institute by authors from Brookhaven National Lab
6 which is also revisiting the question of what limits one
7 should set for application to dry storage. Now, the factors
8 you have to look at are, first, the creep limit states, how
9 much creep or how much creep damage would give you the
10 threshold for rupture. An associated question is what are
11 the creep rates and the mechanisms of creep that are going
12 on? The third is the driving force for the creep which is
13 the hoop stress which depends primarily on the amount of gas
14 inside the fuel rod, both preload and fission gas which has
15 been released from the surrounding pellets to the cladding
16 gap and on the gas volume which depends on the cladding
17 pellets and--the pellets and the cladding.

18 And, as just came up in questions after the last
19 talk, there is a considerable statistical variability in the
20 properties of the zircaloy cladding material and somewhat in
21 the stress load because of the dependence on fission gas
22 release. So, I'll take a survey of saying at least a little
23 bit about all of those questions.

24 Now, first looking at the existing literature on

1 creep, the creep rate data are available for the temperature
2 and hoop stress region of most interest; precisely, because
3 it is of most interest. Experiments, as I will just show you
4 next, take up to a year to get creep rate data and, of
5 course, creep lifetime, if you're looking at a period of high
6 temperatures of 10 years or 30 years, then you would need
7 about that long to get the creep lifetime data. And, the
8 data do show a large variability. And, finally, the changing
9 rates of dependence of the creep rates on temperature and on
10 stress indicate that different mechanisms come into play in
11 different parts of the temperature and stress zone and,
12 therefore, a simple extrapolation of the data is not
13 feasible.

14 Now, as I just said, the long creep lifetimes that
15 we need--we have to pick a design temperature low enough to
16 give us a long lifetime, say, on the order of five to 30
17 years at the peak temperatures which would require a
18 considerable time for experiments. And, creep rates in the
19 same ball park of performance, you can collect creep rate
20 data on the order of one year experiments which I'll show in
21 the next.

22 Now, here, on the right, is some data from a paper
23 by Mayuzumi and co-workers at roughly 350 and 400 degrees
24 Centigrade and with hoop stresses spanning the range that's

1 of interest for the fuel rods. And, in the upper curve, they
2 run out to about 8,000 hours which is nearly a year of
3 measurement time. At the higher temperature, they only have
4 to run out to about 2,000 hours to gather a comparable amount
5 of rate data. Now, this next curve compares--let's see, this
6 lowest curve and these two other dashed curves are from sets
7 of experiments. In the case of the lower curve, the data run
8 out to 6,000 hours and the fit to the data is pretty good.
9 So, this represents real data. In the case of the two upper
10 curves, they're running out to about 1,000 or 2,000 hours
11 which is up to here. So, in this region where there is data,
12 there is a difference of about a factor of five between these
13 particular data sets. In the extrapolations, the longer
14 time, it can get up to differences of a factor of 10. Now,
15 these three data sets are all with zircaloy 4 tubing,
16 unirradiated, and in a hoop and a pressure test. So, to that
17 extent, they're fairly comparable. But, you get a wide span
18 of difference in the actual materials. If you look at the
19 broad literature, then you have different types of zircaloy,
20 different types of stress and stream tests, as well as
21 different material treatments. Now, overall, the cladding
22 material variability might show creep rates or creep
23 lifetimes under similar conditions that are varying by about
24 a factor of 10 or perhaps more if you consider a broader

1 range of materials.

2 Now, the irradiated cladding versus unirradiated
3 typically has about a factor of 2 or lower of creep rate,
4 although I've seen some data sets with a higher creep rate
5 for the irradiated versus the unirradiated. But, the creep
6 lifetime, the threshold for rupture may differ, as well, for
7 the irradiated versus the unirradiated. So, if you're
8 looking at lifetimes, there may be a factor of two difference
9 between the irradiated and the unirradiated, but I'm not sure
10 which is which. And, the wide variability and a wide range
11 of parameters just has to be taken into account and the
12 irradiation is only one of those. I know in Kevin McCoy's
13 presentation, he had a long list of parameters and the one
14 equation for the one mechanism and that shows a sample of the
15 microstructural parameters, you know, which do have
16 variability according to the material and method of
17 manufacture.

18 Now, in different mechanisms, apparently control in
19 different regions of the load, in terms of stress and
20 temperature--if you look at a low creep lifetime where it's
21 relatively easy to collect data, one mechanism may control
22 which has a high dependence on temperature or on stress, you
23 can get a similar plot with stress. Say, it has a high
24 activation energy so that at lower temperatures it's not

1 running very fast, but at high temperatures it runs rather
2 quickly. So, it is the controlling process. And, in another
3 part of the temperature zone and another process with a
4 different activation, energy would be controlling. And, as
5 far as rates, we have data in here. In terms of looking for
6 the lifetimes that we really need, then we have to bring
7 theory to bear, as well as the experiments. Now, Kevin McCoy
8 just presented a theory based on diffusion of cavities and,
9 besides looking like a potential or plausible theory, it also
10 has the advantage that it has a rather low rate of dependence
11 on both temperature and stress. It has sort of a grain
12 boundary type of activation energy and has a low dependence
13 on stress, the first power of stress. So, if you're
14 extrapolating from data, you know, that is the most
15 conservative among the different mechanisms which are in the
16 books.

17 Now, before I get to design approach, I should list
18 the performance criteria that are placed on cladding. First,
19 in interim dry storage which may last for a period of 20 to
20 40 years, the NRC's basic requirement--in, I think it's 10
21 CFR 72--is that the spent fuel cladding must be protected
22 during dry storage against degradation that leads to gross
23 ruptures or the fuel must be otherwise confined. And the
24 purpose is such that degradation will not pose operational

1 safety problems with respect to its removal from storage.
2 And, in several dry storage designs which have been licensed
3 and built, the cladding is relied upon to provide most of
4 this protection for the eventual period of removal from
5 storage. Now, the specific proposal to implement this
6 guidance is recognizing that creep rupture is the problem.
7 You could get some small through-wall breaches due to creep,
8 but these would be small. And, the proposal was to allow
9 only up to 0.5% of the spent fuel rods to have such a breach.
10 So, Chin and Gilbert proposed this limit and they provided a
11 calculation method which allows for changing temperatures and
12 meets this criterion. And, the NRC has accepted the
13 calculation method and the associated temperature limit. I'm
14 not sure if they--they might put an accumulated strain limit
15 sort of on the low side of what could be accommodated by the
16 theory, but they accept the way this calculation brings
17 changing temperature into it. Both of these are based in
18 different ways on the concept of diffusion of vacancies at
19 the grain boundaries.

20 Now, for permanent disposal in the site
21 characterization plan for the Yucca Mountain site proposed
22 potential site, during the first 1,000 years which bracket
23 the period of substantially complete containment, there is a
24 performance requirement placed on the cladding so that less

1 than 2% of the spent fuel rods would be breached in a dry
2 state prior to a waste package possibly being contacted by
3 water. After 1,000 years, there's no performance goal. Now,
4 these performance goals could change if different elements
5 are brought into the design.

6 Now, in the probabilistic design approach, you
7 require that the components or the systems capacity to resist
8 a load be greater than the applied load in a large enough
9 fraction of the cases. And, as I just mentioned, it's 0.5
10 fraction would be allowed to have breaches, you know, under
11 the one design criterion. This shows the component capacity
12 --actually, I've written lifetime here. It would be
13 preferable to reform this in units that are directly
14 comparable to the applied load, such as the peak pressure
15 that goes along as part of a pressure time history. And,
16 this other axis shows the load which might be in terms of
17 stress or the associated pressure. And, there is a
18 probability distribution for the load from different fuel
19 rods under the same design conditions and it depends on the
20 amount of gas in the--gas volume inside the fuel rod. And,
21 most of it is towards the low end. There is an upper end
22 which is determined primarily by the power ramps during the
23 reactor operation and there's a standard method of
24 calculating an upper bound on this.

1 Now, for the component capacity, there's also a
2 probability distribution and, by picking a design
3 temperature, you pick a point compared to the capacity of the
4 materials to sustain the load. And, where the capacity of
5 the materials is below that, you get failure; where the
6 capacity is higher, you get success. You have to pick a
7 design threshold so that the zone of failure has a low enough
8 fraction and success, a large enough fraction. Chin and
9 Gilbert's paper does this in an approximate way recognizing
10 the life variability in the materials data.

11 Now, in the gas volume inside the fuel rods, there
12 are several factors, which if you want to do a thorough
13 recalculation and re-examination, these factors should be
14 taken into account. Looking at a fuel pellet after it comes
15 out of the reactor, the gas volume consists of the plenum
16 volume and the volume made up by dishing of the fuel pellets
17 and the fuel cladding gap. Now, before reactor operation,
18 these three are roughly equal. After reactor operation, most
19 of the fuel cladding gap gas volume is gone. But, if you
20 then further take into account the creep of the cladding
21 during the dry storage, as the cladding expands in creep, it
22 restores some of this gas volume and reduces the pressure.
23 So, there is a decreasing applied stress and you get some
24 benefit from that which has to be tracked if you're getting

1 large enough creep. This gives an example of a calculation
2 with and without tracking that increased volume due to
3 expansion due to the creep. Here, after about 90,000 hours
4 --that's about 10 years--at constant temperature in this
5 particular calculation, you could get creep strain of up to
6 10 or 12% without taking the expanded volume into account.
7 But, the expanded volume sort of reduces things to about 3 to
8 4% total creep. So, if you do get into a few percent creep,
9 it's worthwhile tracking that factor.

10 Now, also, I want to say a few words concerning the
11 potential performance and permanent disposal of cladding
12 which comes from interim dry storage. Now, as I listed the
13 performance criterion for dry storage earlier, it essentially
14 says that they're only concerned with the dry storage period
15 and they could use up most of the creep lifetime as long as
16 they don't exceed the creep lifetime. But, in practice, they
17 don't actually use up most of the creep lifetime. And,
18 further, the performance requirement for permanent disposal
19 could accept a 2% fraction breach. So, it's a somewhat
20 broader requirement. So, you do have some margin between dry
21 storage and the permanent disposal requirement as things
22 stand now. The great majority of fuel rods in dry storage
23 have less than the maximum loading conditions and also
24 there's possibly some conservatism in the amount of

1 accumulated creep that's allowed. But, if that limit is
2 changed, then the dry storage may take that into account for
3 flexibility in their operations.

4 Now, in experimental approaches to the long creep
5 lifetime region, I've mentioned some further things that
6 might be done to improve the situation. This is just a first
7 cut. If we plan to implement that, then we'll have to have
8 more detailed discussions with the waste form characteristics
9 technical area at Livermore and with other participants in
10 the project. But, certainly, besides just measuring the
11 microscopic observed creep, we could look for microscopic
12 evidence by sectioning samples and look at the actual dry
13 storage performance.

14 So, in summary, if we're going to re-examine the
15 cladding performance, we should look at all the factors and
16 we have creep rate data, but rupture limit data is not so
17 easy. And, there is potentially a margin in the actual
18 performance.

19 Thank you.

20 DR. PRICE: Questions for Mr. O'Connell?

21 (No audible response.)

22 DR. PRICE: Thank you very much.

23 Our final speaker for this morning's session is Tom
24 Doering; criticality control in a repository.

1 MR. DOERING: Well, good morning. As noted earlier, I'm
2 Tom Doering with the Las Vegas M&O. I'm with B&W Fuel
3 Company. I've been the nuclear power industry since 1976. I
4 have designed nuclear fuel assemblies for quite a few years.
5 I have been involved with low-level waste and high-level
6 waste since 1984 and was brought on with the M&O back in 1991
7 when the first initial people were brought on. So, we do
8 have some history there.

9 I'm going to switch from more of the research side
10 now to a little bit more of the engineering side and, having
11 been a research engineer and an engineer at present, we like
12 to have a basis or a criteria that we're dealing with for
13 long-term criticality. Now, we've worked a great deal with
14 the MPC design team to look at the short-term and essentially
15 the storage and transportation and also now the long-term
16 criticality needs. 10 CFR 60 is sort of our--is our
17 governing rule and things that we want to point out shall be
18 designed to ensure nuclear criticality through not only the
19 accident situations, but through isolation phase; placement,
20 isolation, and radio-isolation. So, we have the short-term
21 requirement and also we have through isolation. Isolation
22 phase, this is being re-evaluated to see what the time frame
23 is. So, we are waiting to see what the review of that one
24 is, but we are looking for longer periods of time, as I'll go

1 into a little bit later what those periods of time really
2 look to us. And, as noted earlier, we're looking at a multi-
3 barrier design, defense and depth, to mitigate essentially
4 the two unlikely independent events. Essentially, we're
5 looking at the outer barrier and the inner barrier of the
6 waste package to provide two independent environments. Also,
7 the engineered barrier system that goes around it, if we do
8 have a backfill around it to help us in that area; to
9 essentially shed the moisture away.

10 Now, we come down to the new area that the 10 CFR
11 60 has brought in. 10 CFR 72 essentially is a storage
12 requirement where you say you prevent moisture from getting
13 into it. We put the storage device above the flood plain,
14 the 100 year flood plain, or if some moisture or some water
15 comes up, we start moving the devices because it's readily
16 accessible. 10 CFR 71 is a transportation. They have gone
17 with a--essentially, a 2% margin as the basis in 10 CFR 71,
18 but they have also had some regulation through licensing
19 process. The NRC has asked them to look at a 5% margin and
20 most of the transportation is actually licensed with a 5%
21 margin in it. What we've done in 10 CFR 60, it says
22 essentially the NRC has incorporated what has been reviewed
23 and dealt with in storage and transportation.

24 Now, I'm going to define how we do the calculations

1 or the process in how we do the calculations. We're looking
2 for the K in effective. Research laboratory, Sandia, has
3 been very helpful in this area in developing processes and
4 they typically looked at k infinity. What we're looking at
5 specifically is k effective? How does the geometry play? We
6 also--because there is reflectivity, there is different
7 methods for the neutrons to bounce around inside of it, we're
8 looking for the effective design process, very much focused
9 in that area. So, we're looking at the k effective
10 calculational methods. We have biases and uncertainties that
11 are built in in the calculational method of the isotopics and
12 how they break down and how there are the probabilities of
13 them occurring and that's all grounded with the Oak Ridge
14 National Laboratory developing the biases in this area of the
15 different isotopes. So, we take that into consideration.
16 Then, we have the regulatory margin of safety.

17 Again, criticality is a little bit different than
18 other areas of margin safety like tensile tests or loading
19 situations where you have a gradual increase of it. Even at
20 .99, you do not get enough multiplication factor that you
21 have a so-called criticality event. You cannot be partially
22 there. All we're doing is allowing more margin for the
23 uncertainties that are built into the system. So, what we're
24 saying, until this factor--actually, the multiplication

1 factor of the neutrons receives--is achieving one, we do not
2 have a continuous reaction to the system. So, all these
3 margins that we're dealing with right here are simply
4 conservatisms that we're building into the system.

5 I'm going to reverse a couple of the slides here,
6 the next two, and say we're doing the strategy at the
7 repository and, also, the strategy that we have with the MPC,
8 essentially, with--what we're looking for is burnup credit
9 and neutron absorber. We feel those are the two most viable
10 approaches that we have. Sending fresh fuel to the
11 repository to throw away really is not really what we think
12 the utilities would want to do with their fuel with the
13 economy of the neutrons. So, what we're saying is that let's
14 take credit for the reduced stored energy in the devices and
15 the fuel assemblies. So, we take credit for that. Knowing
16 that we do have to have some neutron absorber for the higher
17 enriched, maybe not so heavily burned material--which you do
18 have a percentage of the fuel out there that has that
19 situation we have to look at and accommodate--if this
20 strategy doesn't work with the Nuclear Regulatory Commission,
21 what we'd like to do is go back to say, okay, how do we
22 prevent any kind of moderator to become involved in the
23 situation and that provides us filler materials. We provide
24 filler materials inside the waste package to prevent or

1 displace any moderator intrusion into the system throughout
2 time. If this system essentially is not accepted or it is
3 not practical, we fall back to much smaller packages. We're
4 looking at larger packages, 12 pressurized water reactor
5 packages or 24 BWR or the 21 to 24 pressurized water reactor
6 larger packages through the MPCs, and now we'd have to drop
7 back all the way down to 4 or 3 and we probably would have to
8 borate the 4 depending on the enrichment also and the burnup
9 on it. So, this is a major process change really where we
10 need to have interactions with the Regulatory Commission and
11 the switch would be thrown there. And then, if this doesn't
12 work, we always have reprocessing. It's always been shown to
13 work where the waste stream is very uniform and very defined.

14 Now, switching back to the earlier slide, I'd like
15 to explain the process that we essentially use at defining
16 the design evaluation. Now, evaluations that we have done to
17 date deal with what we call the uncanistered fuel,
18 essentially some of the fuel that would come to the
19 repository that would not go through a MPC process. Or where
20 we spend a great deal of time is looking at the MPC process
21 that the M&O has developed. So, most of the evaluation and
22 most of the results you see today are based on the MPC
23 design, conceptual design, that we have and have completed.

24 What we do assume right away at the repository is

1 the burnup credit. We have a reduced stored energy. What
2 we're doing over that is taking a look at the geometry
3 effects. We're looking at no additional neutron absorbers
4 initially to see how much neutron absorber we need to put
5 into place before we simply make a simple statement that says
6 we need this much. And, we also are assuming the worst
7 possible case where we do have a moderator intrusion into the
8 system sufficient to make it go critical. Remember the
9 proposed site is a very dry, unsaturated site and so what
10 we're saying, that this is truly the worst case situation
11 where we do have moderator there through the full period of
12 time. That's just sort of saying like the old Garrison
13 Keeler Show that they used to have where they have the worst
14 case scenario. If you went down to the movie and saw the
15 house, your house would burn down and all this; this is truly
16 the worst situation where you have moderator in the system.

17 Now, as mentioned earlier, we do look at the
18 consideration in determining the initial amount of neutron
19 absorber we need to have and, through time, since we're
20 dealing with a long period of time, we're looking at how the
21 neutron absorber material is removed in the system. So,
22 we're moving more in the probabilistic approach. Now, we're
23 looking at longer term situations where the probabilistic
24 approach really becomes a factor. So, we're saying how much

1 is leached, how much is actually--essentially, burned out?
2 How much B-10 that you need to have initially? Then, what we
3 do is repeat this calculation for each fuel design--well,
4 essentially, each design of the packages also. Since we are
5 not the--M&O is not the designers of the MPC, the vendors
6 will come through and provide us this data and we will have
7 to review this data on this. We have provided the industry
8 with a conceptual design that does meet the requirements.

9 What we have done here also is that we've taken a
10 look at the spread of fuel that's available out there and
11 have developed a design basis fuel so we don't have to handle
12 each enrichment and each fabrication separately. We're
13 looking to bound it.

14 Now, moving on to long-term considerations of the
15 fuel, what are the long-term effects? The long-term effects,
16 the criticality potential of spent nuclear fuel changes with
17 time. As different isotopes decay, they create some more
18 fissile material and also they create what we in the
19 industry--some neutron absorbing materials. So, it actually
20 balances out at different points in time and crosses over in
21 different points in time which I'll show a little bit later.
22 Like mentioned earlier, some of the neutron absorber
23 materials that are initially in place--some of the isotopes
24 are natural neutron absorbers--do go away with time. So,

1 it's important to understand the whole fissile chain and also
2 the materials that are borne and lost at the same time. And,
3 what we're looking at is sufficient neutron absorber material
4 to remove any process over time to prevent any kind of
5 criticality event. Again, we're looking at the very
6 conservative point of view where we always have moisture.

7 What I'd like to do is lay the groundwork a little
8 bit for the next slide. We've run a whole host of different
9 isotopics in our Monte Carlo code which is a continuous
10 energy spectrum. So, we do get a very good spread of these
11 energies and the isotopics. These are the main players; as
12 we'll show later what happens. The Plutonium 241 essentially
13 is a fissile material. It builds into the system for the
14 first 100 to 200 years. After those have gone away, what we
15 have is Plutonium 240 which is a neutron absorber. It's
16 removing neutrons from the system. It starts actually--it
17 starts going out around the 20,000 time frame and then we
18 also get some Plutonium 239 decaying away which is a fissile
19 material beyond that. Now, these are the major players,
20 major isotopes in there. There are a lot of other ones that
21 we track, but these are the major contributors to the next
22 slide that we want to show.

23 What we have done here is taken the time and the
24 review of the--this is again the MPC, 12 PWR design because

1 we are effectively looking at the unique design features
2 which has to be licensed. And, what we've done is
3 essentially said requirement--this is 10 CFR 60 requirements
4 without biases. These are 10 CFR 60 with the biases of a
5 calculation method put into it because we have the
6 calculational method that must impose its bias upon it.
7 These is the isotopics that are on some of the--isotopic
8 uncertainties involved in it. The calculational method,
9 uncertainties. And, luckily, with MCNP, the calculation of
10 uncertainties are a little bit less than other earlier
11 methods that are available. So, we feel our tolerance band
12 is a lot tighter and can be justified a lot better.

13 What we see here is essentially 3.75% enriched
14 Uranium-235 initially into the system assuming zero burnup
15 through time. What we've shown here is that with a burnup
16 credit design, it's very difficult to say this design could
17 go in burnup credit. This design actually is much more like
18 the 10 CFR 71 criteria where you assume you do not see any
19 burnup and, therefore, you have to go to what they call a
20 flux trap designed to essentially have the neutrons be
21 absorbed in a space in between the fuel assemblies. So, this
22 is truly a high poison material internally, a lot of neutron
23 absorbing material like B-10, and you separate the plates and
24 separate the fuel assemblies.

1 More realistically what we're moving into the waste
2 package design essentially saying, okay, 3%--somehow, in your
3 slide package, you have the newer ones that we've done for
4 3.75 all the way down. This was generated before the new
5 ones were put in, but I think you should have the newer 3.75.
6 What we're showing here is that with the removal of some of
7 the stored energy, the k effective essentially is dropping
8 and much more realistic. And, as noted earlier, we see
9 decrease of k effective through time. Most of us who have
10 done earlier calculations for storage and transportation, we
11 always figured k effective would always go down. But,
12 surprise, we found that in the 200 year time frame, we see a
13 turnaround. Again, this is earlier--from the different
14 isotopics that were mentioned earlier that we see a reversal
15 of that and the k effective comes back up. Now, this is
16 assuming fully moderated conditions throughout the period of
17 time. If we do not have a moderated conditions, k effective
18 would be in the .2 to .3 region. So, it would be very low.
19 And, the .2 to .3 region which you're seeing there is simply
20 the fast spectrum of the neutrons where we simply get some
21 behavior and some reactions with the fast neutrons. These
22 are all thermal neutrons that we're dealing with here with
23 some fast spectrum, of course, from a generator.
24 What we're seeing lower here, 3.75 40 GWd burnup,

1 essentially, this is the MPC design basis fuel right here
2 that we have and the MPC design basis fuel is designed to
3 take care of the first 10 years of the requirements and the
4 needs of the system. If we move up here, we're saying the
5 design basis fuel that the repository has to look at for all
6 of the 86,000 metric tons. We don't know how many--which of
7 the 86,000 metric tons that we're going to receive. We're
8 only allowed to receive 70,000 metric tons as it is right
9 now. But, we don't know which 70,000 we're going to take.
10 So, we're looking at an 80 percentile. Essentially, this
11 line would capture all 80--essentially, 80% of all the fuel
12 out there and, if we borate the system to that, we would be
13 very much assured that we would meet those requirements. So,
14 with the utility--at the repository what we would have is a
15 curve, essentially a burnup curve, and say, okay, at the
16 initial enrichment with this burnup, do you fall within that
17 region? If you do, you can load into this package;
18 otherwise, for the other 20%, we'd be looking at different
19 processes that we can do. Download or not load the package
20 that much or even put some additional boron in there where
21 the fuel--or where the guide tubes would be. So, there are
22 different ways of handling it.

23 That method is essentially developed so we don't
24 penalize the bulk of the fuel out there with essentially the

1 low burned highly-enriched fuel. There's essentially a low
2 percentage of that total fuel out there that reaches that.
3 Again, the utilities are trying to get the most neutron
4 economy out of the system they can. So, that's what we're
5 looking for. Moving down this curve, essentially, now
6 overplay put upon it, how much boron is really required to
7 handle it after a five year cooling of the fuel, essentially
8 in the pool or the reactor site some place in dry storage.
9 So, what we're seeing here is essentially the different
10 curves with how much boron is essentially needed to capture
11 the requirement of .95 and also the added safety factor that
12 brings us down below .95 which is like .895.

13 So, again, with the designs we have, it looks like
14 we do have to have some initial enriched B-10 which would
15 cost a little bit. We've calculated the cost on the initial
16 with B-10 to be around \$200,000 for the first buy which is
17 relatively low-cost considering the other costs involved in
18 it.

19 We've also taken a look at different time frames.
20 We have the substantially complete containment time frame and
21 then also the long-term. The long-term, we're looking at
22 more of a probabilistic approach to it. And, understanding
23 that as the deterministic approach works very well for the
24 storage and transportation, you can simply go down and take a

1 look at that and work through the equations, long-term is
2 really more of a probabilistic and how things behave and
3 material properties. The material properties that we're
4 dealing with are very important in how they degrade.

5 And so, what we're looking at is a different
6 degradation modes of the basket; very important. Where is
7 that material staying around, where does it fall, and how
8 does it degrade with time? For a substantially complete
9 containment phase where it's 1,000 years or so, we know the
10 material will be where it should be. As it degrades, we
11 don't know exactly where that material is and how the
12 material is actually being redistributed. With a burnup
13 credit design, essentially the mean free path of the neutron,
14 we believe, is essentially small enough that it can be
15 captured with essentially a boron inside the matrix of the
16 plates. If we move over to a flux trap design, essentially
17 the flux traps with the spaces provides some of the neutron
18 capturing. With time, as it degrades, we don't know quite
19 sure where that is going to go. With the conceptual design,
20 what we've been able to do there with the M&O MPC conceptual
21 design, this is also the 12 PWR, but it has sufficient amount
22 of boron or poison material in it that when it goes in this
23 configuration, it can be still looked upon as a burnup credit
24 design if we do all the administrative calculations and keep

1 track of it. So, for the MPC initial conceptual design, both
2 systems work with long-term criticality. We are still
3 seeing--have to take a look at and evaluate when the other
4 vendors really will design the MPC and, if they give us this
5 offer, how that degrades with time and how the materials
6 degrade with time.

7 So, what we're looking at is a configuration from a
8 nuclear point of view, a nuclear engineering point of view.
9 If you go from here to here, it actually becomes less--what
10 we believe is less reactive because the nuclear engineers for
11 the reactor site are trying to maximize the neutron economy
12 so you put the rods at the right spacing, the neutrons will
13 be captured in the right time. When we start degrading the
14 system, not all the fuel will go at one end and all the
15 cladding will go to the other end. There will be simply a
16 settlement of the system sort of generally down and you'll
17 have a good mixture of the cladding and the fissile material.

18 Some people say if you have a stream or something
19 going through it, what happens there? Well, that's a
20 different problem that we tend to look in a probabilistic
21 approach and, there, you probably have a larger problem than
22 just worrying about if the fissile material flows down
23 through one area. So, essentially, the areas are very much
24 locked together and the initial configuration is the most

1 conservative, we believe.

2 The approach that we do is identify the possible
3 modes of degradation which we're doing right now. Dr. Kevin
4 McCoy is working with us on that. We work with the PA and
5 also a probabilistic approach to it. We're defining what is
6 the failure modes and the probabilities to do with it. Also,
7 then we simply do a probabilistic approach out in time.

8 Considering this is a dry site and we do have a
9 sort of fault tree that we're building right now, these are
10 some of the things that must occur before we get a
11 criticality thing. We have to have enough water flow inside
12 the repository to essentially fill the waste package
13 substantially for anything to become close to critical. We
14 do have to breach both barriers of the package and also we
15 have to look at the engineered barrier system; if we have a
16 backfill, how that sheds the water. That also has to break
17 down. So, we're increasing our barriers and the problem is
18 getting smaller even yet. No filler material or, if we do
19 have a filler material, somehow it's left. We don't know why
20 it's left, but it's left. Failure/inadequacy of the neutron
21 absorber material. Now, the neutron absorber material must
22 leave some place and with the burnup credit design with
23 enough neutron absorber material, even if it would relocate
24 within the package, the mean free path of the neutron would

1 be such that it would still find--if you still moderate it,
2 and you would still find the neutron absorber. And then,
3 after all that, you may have a potential of a criticality
4 there. So, we believe the criticality then inside the
5 repository with the situation that we have, even probably in
6 a saturated site, is very, very low. Somewhere in the 10^{-10}
7 region. As noted earlier, 10^{-5} was noted to be very
8 improbable. We're looking at much lower probability than
9 that.

10 I've always been asked what would happen--we don't
11 anticipate this occurring and we don't anticipate all these
12 --if something like this would happen. The probability is
13 that all the waste package reaching enough water or having
14 enough water available to it, is really again less probable.
15 So, we have one or two maybe that may go critical in the
16 10^{-10} region.

17 So, what would really have to happen?
18 Requirements: breach--you do need a moderator. You must have
19 a moderator to make it go and a neutron absorber material
20 must be gone. Essentially, what would happen? This is the
21 worst case scenario. Gee whiz, well, we have natural analog
22 of OKLO. We simply see a very slow rise in the flux
23 distribution of neutrons. We have a brief spike of neutrons
24 where it goes up really--some people say the blue flash, but

1 really there's really no blue flash. You just simply come up
2 close to a k effective of one. It would cross k effective of
3 one and essentially then the water would get warmer and
4 warmer and essentially the neutrons can't moderate themselves
5 and they shut themselves down very nicely, very quietly, and
6 you would see no mass boiling. You would now and again see a
7 decrease in the flux distribution inside the package and then
8 what you would really end up with, some of the short-lived
9 isotopes now that you had earlier, you would regenerate that.
10 But, also what you would do is decrease the long-term
11 actinides and actually decrease the stored energy. So, it's
12 sort of one way or the other. It's really not all that bad.

13 The conclusions that we have is that the approach
14 that we're doing is we're bounding it--and we have noted this
15 to the Nuclear Regulatory Commission and they seem to be very
16 positive with this statement--we're bounding analysis, what
17 we have seen today, as a deterministic approach; very
18 deterministic, very much like 10 CFR 71 and 72. What we're
19 moving into, as I noted earlier and showed you a slide--we're
20 moving into the probabilistic approach to it and say, yes,
21 this is the occurrence of it and this is the outcome of it.
22 But, the occurrence of it is such, so low, that over the time
23 frame that we're dealing with, it's tangible. Again, if it
24 doesn't work, if we don't get burnup credit, if we don't get

1 this licensing through, we do have to go to smaller
2 packages.

3 Then, long-term performance of materials is very,
4 very important to us. There are a lot of materials out there
5 that have historically been used that will fail with time and
6 the material evaluations that we're doing at Lawrence
7 Livermore are very important to feed this information into
8 the design area. Some of the materials we are guarding
9 against is straight 304. We know it sensitizes. 304 is used
10 as all the material bases. If you can crack 304, that's your
11 basis. Now, see if we can crack some other material. So, we
12 know we can crack 304 and that has been one of the materials
13 of use in the industry for short-term storage. So, we're
14 very concerned about that. And, overall, we're looking at
15 the low probability of criticality. It's a concern. We have
16 to cross it. We have to deal with it. But, as a safety
17 factor in long-term, we don't really see it as a major driver
18 with it.

19 We are doing different isotopic degradation modes
20 and how things change with the fast flux to support the
21 performance assessment area also because no matter what you
22 would--if it's a dry environment or if it's a wet
23 environment, you do get some changes in it. So, we are
24 supporting that area.

1 With that, I'd like to say thank you. Any
2 questions?

3 DR. PRICE: Questions from the Board?

4 DR. DI BELLA: Your very first slide or maybe your
5 second one, you put the--you don't have to put it up again.
6 You put the language of the 10 CFR 60 criticality control up
7 there and then you said something about the time period being
8 re-evaluated. Who is doing that re-evaluation and--

9 MR. DOERING: The Academy of Science is doing that.
10 That's the isolation phase and they're taking a look at both
11 the release rates and what is isolation phase of it. So,
12 that is being reviewed at this time.

13 DR. DI BELLA: What are you taking the period of--that
14 you have to be concerned about criticality control? What are
15 you taking it as now?

16 MR. DOERING: As you noted on the slides, we're taking
17 it out quite a bit further than even the 10,000 years as
18 noted in the earlier 1040.

19 DR. DI BELLA: That's what I'm asking.

20 MR. DOERING: So, we're actually taking it out to, you
21 know, 1,000,000 years. We're taking a look at it out that
22 far and just saying that should bound all the situations at
23 this time. Some of the probability or some of the areas that
24 we're looking at also, we're looking with Sandia National

1 Laboratory. I'm a member of the burnup committee that has
2 the storage and transportation, Department of Energy, and
3 essentially Oak Ridge National Laboratory and Sandia National
4 Laboratory. We're looking at this and how things--the
5 isotopes change and how the boundary condition, how the
6 biases should change. So, we are developing a method through
7 time, out in time, that things might be changing. So,
8 they're very sensitive to that.

9 DR. CANTLON: Has the idea of fillers actually--I didn't
10 see you mention fillers in any of the later--have they been
11 dropped entirely now from--

12 MR. DOERING: No, they haven't. We actually have what
13 we call an engineering development program within the waste
14 package engineering end that we are going to investigate
15 different filler materials if we can get it in. Both the
16 Swedes and the Canadians have looked at liquid filler
17 materials. They have found difficulty with getting that in
18 in a full uniform way. They get freeze-out even though the
19 fuel assemblies are relatively warm. We're banking on their
20 experience in that and we're trying to look at maybe on a
21 different end a little bit and looking at maybe some
22 essentially small iron shot that we can maybe get into the
23 system. Again, the fuel assemblies have a very small opening
24 at the top. The water flows through them very easily, but

1 iron shot or other material may not. And so, we actually
2 have an engineering development plan right now. A technical
3 requirements document has been generated asking, you know,
4 what is the background, what is the things that we want to
5 find out about, and we are looking hopefully for funding so
6 we can go off and do this evaluation.

7 DR. PRICE: Tom, do you have an idea about the
8 comparison between the probability of criticality at the
9 repository as compared with in-transit or transportation?

10 MR. DOERING: We haven't done those calculations
11 directly. So, the best answer is we haven't done that.

12 DR. PRICE: Would you think that transportation
13 likelihood is higher than that in the repository because of
14 the potential for an accident condition in the presence of
15 water?

16 MR. DOERING: To us, it's a little bit different and I'm
17 not going--I guess I'm not answering your question directly
18 because we don't know yet what it is. And, until we do the
19 probabilistic approach and take a look at the transportation
20 maybe in the probabilistic approach, it would be very
21 difficult to come up with a definitive engineering answer.
22 From just a subjective feeling, we feel it's maybe equal or
23 less probable at the repository given the situations that we
24 have and the fact that we've taken a look actually at the

1 worst case situation where we assume enough moderator
2 throughout the lifetime.

3 DR. PRICE: All right. Thank you very much, Tom.

4 It's time to go to lunch. We were going to see if
5 we didn't have a little time for questions from the audience,
6 but hang onto those; we'll get to them a little bit later.

7 (Whereupon, a luncheon recess was taken.)

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

19 DR. MCKETTA: We have an interesting session this
20 afternoon on materials research and we're going to get
21 started early. We have three good presentations in this
22 session. One is an overview of materials research and the
23 others talk about specific ongoing materials research
24 projects.

1 And, we'll get started right away with Dr. Dan
2 McCright. Dan is going to tell us about current materials
3 research. Go right ahead?

4 DR. MCCRIGHT: I'm going to be talking about the current
5 and planned material research and, of course, the question is
6 why are we doing this work? And, the reason is two-fold, two
7 main reasons, and that's to provide the information basis for
8 the container material selection because we have to decide
9 what kinds of materials to make the container out of, and
10 then we have to provide the information base for the long-
11 term behavior predictions.

12 If you remember from Dave Stahl's talk earlier this
13 morning, he talked about some of the requirements in
14 preclosure and post-closure. And, again, where these
15 interweave with one another, for the preclosure parts of it,
16 we have to deal in picking our material with available
17 technology. In other words, using materials that are readily
18 available off the shelf and processes for fabricating and
19 welding them and making the container also have to be
20 available technology. And then, in the longer-term, we had
21 to deal with the requirements in post-closure of containment,
22 controlled release, and then the emplacement environment and
23 what the container will do to the environment; and then, how
24 that will affect controlled release and migration of any

1 radionuclides away from the vicinity of the waste package.

2 In our particular area in the container materials,
3 we have four major activities. And, we do these activities
4 in parallel and it's a very iterative process. But, we deal
5 with degradation modes of the candidate materials that we've
6 identified. The degradation modes indicate what's known
7 about these materials, how they've behaved in the past, other
8 applications, and different mechanisms and modes that they
9 are degraded; corroded or otherwise degraded. Then, we test
10 these materials in the environments and conditions that are
11 specific to Yucca Mountain. We model what the behavior is
12 from our experiments to project for long periods of time.
13 And, these two activities go on in tandem. The modeling
14 drives the testing and the testing drives the modeling.

15 Then, when we've done all these things and we've
16 started with a longer list of candidates, we make
17 recommendations of materials to the rest of the project.
18 We're very closely linked with some of the other parts of the
19 project that you've heard talk about earlier today.
20 Certainly, we're very closely connected with waste package
21 design and, by extension, the repository design, and so on.
22 And, from the design area, we get information on the
23 requirements that the waste package has to perform to and the
24 configuration that the waste package will be used in and

1 dimensions and so on.

2 And, the design with the environment, a very
3 important input to us is the thermal load that will be on the
4 individual waste package and on the repository as an ensemble
5 of waste packages. This is very important and has been
6 mentioned in Bill Clarke's talk and others because we're very
7 much concerned about how water will get--if water will get to
8 the waste package, how it will get there, when, and what the
9 chemistry of that water will be.

10 We work very closely with the near-field
11 environment task force. Again, the work that's done there on
12 the hydrology and the geochemistry identify when the water
13 contacts--if and when the water contacts, what the
14 composition of that water would be. We'll be hearing later
15 today about introduced materials and again what those could
16 have, a beneficial or a detrimental effect on the container
17 material. And then, we, in turn, supply information to them
18 about what the corrosion products would be and what the modes
19 of attack would be because the container just won't all go
20 away one day. It will be left there and then any kind of
21 radioactive--radionuclide migration from the now breached
22 waste package would depend on a lot on how it's been attacked
23 and in what areas because there will be enough metal left
24 that it would offer some impediment to any kinds of flow

1 outward.

2 Then, we work very closely with the performance
3 assessment. Again, as Bill Halsey talked earlier, that we
4 provide individual models to them, but they also provide to
5 us a sensitivity analysis that directs our testing, tells us
6 what kinds of things that they need to know, and how
7 sensitive our measurements have to be. And, particularly,
8 performance assessment working with the near-field
9 environment supplies us with information about scenarios.
10 And, it's very important to us because we have to deal with
11 not only the anticipated conditions, but some unanticipated,
12 but credible conditions and particularly with dealing with
13 the issues that are a concern to us on selection and then the
14 long-term performance or some of the scenarios that will lead
15 to aggressive conditions that would adversely affect the
16 waste package.

17 I'm going to leave this slide on because I want to
18 come back to it several times. But, let's talk about some of
19 the materials that we're considering. I mentioned earlier
20 we're focusing on a multiple barrier design where we would
21 have a corrosion-resistant inner barrier and a corrosion
22 allowance outer barrier. This slide lists some of the
23 materials that we are considering in the candidate level
24 right now. We're focusing quite a great deal on nickel base

1 alloys. I've used here the commercial names for these
2 materials; Incoloy, Inconel, Hastelloy. These all have
3 significant amounts of chromium alloyed with the nickel and,
4 in some cases, they have molybdenum, titanium, tungsten, and
5 other elements that are deliberately added to enhance the
6 corrosion-resistance of these materials. These were
7 developed to withstand severe acid conditions, high chloride
8 conditions, and other high electrolyte situations.

9 We're also looking at titanium base dilute alloys
10 and, by dilute alloy, I mean something less than 1% alloy
11 element. And, specifically, Grade 12 has a small amount of
12 nickel and molybdenum added; and Grade 16 which is a new
13 material and that has a very small amount of palladium and
14 iridium added. But, these are very corrosion-resistant
15 titanium based materials.

16 Then, we're also looking at copper and nickel
17 alloys; 70/30 copper-nickel and then Monel 400 which is about
18 67% nickel and 33% copper.

19 Now, for the outer barrier, we're looking at
20 corrosion allowance materials and quite a bit of emphasis on
21 ferrous materials ranging from plain carbon steels to some
22 low alloy steels with chromium and molybdenum as the alloying
23 elements, some weathering steels which have small amounts of
24 copper and phosphorus added, and then some cast irons--

1 ductile cast irons containing nickel and silicon cast irons.
2 We're also considering copper based materials for the outer
3 barrier. This could be unalloyed copper, pure copper, and
4 copper with some very small alloy additions, and aluminum
5 bronzes.

6 Some of you have been following the program for a
7 number of years notice in the past we've focused on what we
8 called the conceptual design which was just a single metal
9 barrier and a relatively thin layer. We had considered
10 copper and then decided that those weren't so attractive
11 compared to some other materials because of the risk that
12 high radiation levels would cause on enhancing the general
13 corrosion and possibly some localized corrosion of the copper
14 based materials. But, in dealing with the thicker waste
15 packages, the objections dealing with radiation effects are
16 minimized because the thickness of the package will mitigate
17 a lot of the gamma radiation field and a lot of the
18 radiolysis effects.

19 Now, some examples of how these materials might be
20 combined would be--could use one of the ferrous materials as
21 the outer barrier and then one of our high performance
22 corrosion-resistant materials inside. We might also consider
23 a waste package that had, you might say, an all copper waste
24 package where we had an unalloyed copper outer and then two

1 inner barriers of 70/30 copper-nickel and a Monel 400. This
2 would have some attractive features, particularly on some
3 fabrication considerations since you'd have some common
4 components all the way through and it would be possibly
5 easier to clad this material and be able to weld and seal it
6 shut more easily than when you have very dissimilar
7 materials. We also might consider a two component outer
8 barrier, both carbon steel and unalloyed copper and then with
9 a high performance material inside.

10 Again, one of the reasons that we're dealing with
11 so many things right now is because we don't know what the
12 decision will be on the thermal loading and that's going to
13 really affect a lot of what we do here. Of course, as
14 materials people, we feel that the extended dry is very
15 beneficial because we just eliminate a lot of aqueous
16 corrosion considerations certainly in the early part of the
17 containment period because water entry into the vicinity of
18 the waste package will be delayed for a very long period of
19 time. But, as Tom Doering alluded to in his talk that that
20 decision isn't so easy and criticality is one of those
21 factors, if we had to deal with a lower thermal load and we
22 were going to deal with aqueous conditions at an earlier
23 stage, then we might be forced to consider one of the more
24 conservative configurations of materials. Another one that

1 I'll talk about later is that maybe one of these corrosion-
2 resistant inner barriers could be replaced with a ceramic or
3 other non-metallic material.

4 Again, the multiple barrier approach, as mentioned
5 before, it's a defense in-depth strategy, synergism between
6 barriers. We've designed this to be a positive synergism
7 that one plus one is equal to three, but we always want to be
8 vigilant that again when you get into a more complex
9 configuration that one might seriously deteriorate the other
10 one. We don't want this to be a negative synergism. Again,
11 as I said earlier, it's corrosion allowance outer, corrosion-
12 resistant inner, and the principle here is that the outer
13 barrier during that long dry period would slowly oxidize and
14 if it got wet, it would corrode to protect the inner barrier.
15 As long as some of that outer barrier remains and it's in
16 contact with the inner barrier, it would galvanically protect
17 the inner barrier, again if we choose the materials
18 appropriately. And then, not only does it protect the inner
19 barrier from general corrosion, but maybe more importantly it
20 protects it from localized corrosion because the
21 electrochemical potential of the corroding outer barrier is
22 so much more active that it brings the potential of the
23 common junction of the two metals down to a region where the
24 inner barrier is protected because we're well below any of

1 the critical potentials that would affect that inner barrier.
2 Now, eventually, if the outer barrier is all corroded away,
3 the inner barrier, because it was such wisely chosen,
4 material could stand on its own and give us even more
5 protection.

6 And, again, the same thing just shown in a more
7 graphical setting is that we would have the corrosion-
8 resistant inner barrier of a dimension, say, one to three
9 centimeters and then that would be surrounded by a 10
10 centimeter outer barrier. Keep in mind that this is a--it
11 wouldn't have near that curvature because we're dealing with
12 waste packages that could be on the order of a meter to
13 almost two meters in diameter if we're dealing with these
14 large MPCs that we've talked about earlier.

15 Now, as the outer barrier is corroded away--and,
16 again, thinking that the water contact is probably going to
17 affect only a small area and that the corrosion is going to
18 just occur in these small areas because of either seepage or
19 drippage or some inundation in a restricted geometry--as this
20 outer barrier is corroded away, the inner barrier seeing a
21 cathodic reaction, which in a neutral pH would be reduction
22 of oxygen to hydroxide ion, and then this outer barrier would
23 be corroding to various oxides of iron if that were the
24 chosen outer barrier.

1 Now, there are always some caveats in dealing with
2 this kind of a situation. And, as I said earlier, we want to
3 demonstrate that we've got the electrochemistry, the polarity
4 of the couple in the right direction, and it's sufficient
5 enough to bring us below the critical potentials and again
6 where we have to be ever mindful. A good example is this
7 galvanized iron that at low temperatures the zinc protects
8 the iron, but if you go to higher temperatures in some
9 waters, the couple can actually reverse. The zinc becomes
10 cathodic to the iron and then the iron can corrode
11 catastrophically. Another example would be in the tin can.
12 As long as you have the tin can enclosed, the tin is
13 protecting the iron. But, when you open the can, that can of
14 tomato juice or orange juice, you notice in a day or two it
15 becomes kind of tinny tasting and we really should say iron
16 tasting because now the couple was reversed. And, now, the
17 tin is cathodic to the iron, and so whenever there's a little
18 break in the coating and there always will be, now the iron
19 corrodes catastrophically and then we pick up the unwanted
20 taste in the tomato juice.

21 And, again, as I'll talk a little bit later at
22 length, is this idea that critical potential that's worked
23 very well in engineering situations of a few decades in time,
24 we really have to convince ourselves that this really holds

1 for very long periods of time because the pitting stress-
2 corrosion in these kinds of corrosion are random processes--
3 we use the word "stochastic" in nature--and that there is
4 always some probability even if we're far away from the so-
5 called critical potential that some pitting or stress-
6 corrosion could occur. And, I said earlier that we don't
7 want unwanted reactions. And, another unwanted reaction
8 would be on that inner barrier, if we start to generate
9 hydrogen and some of those inner barrier materials are
10 sensitive to hydrogen embrittlement, then that could again
11 cause catastrophic corrosion of that inner barrier. And
12 then, also, we have to consider the corrosion products of the
13 outer barrier and what those might do to the corrosion
14 behavior of the inner barrier, particularly since ferric ion,
15 cupric ion, and certain water chemistries can become quite
16 oxidizing and quite--given acidic hydrolysis that would lead
17 to unwanted pitting attack of the inner barrier.

18 Now, let me go to a little bit about the outer
19 barrier. So, I'll be going back to what we were doing--the
20 effort we're doing in the degradation modes of iron steel.
21 And, again, many of you that have followed this project for a
22 number of years when we were dealing with the conceptual
23 design, we published these very lengthy degradation mode
24 surveys on stainless steels, nickel-based alloys, and copper-

1 based alloys. Now, we're in the process of generating one on
2 carbon steels and other ferrous materials.

3 Well, again, to take a curve that illustrates a
4 number of points and that's the corrosion rate, carbon steel
5 is a function of pH. In the middle range of pH which, of
6 course, is where the J-13 or other groundwaters that are
7 associated with the site would be expected to fall--and
8 measurements we've done in the laboratory, even grinding up
9 rock and exposing it to water over long periods of time,
10 suggests that the pH is going to be in the neutral and
11 slightly alkaline range--we find that the corrosion rate of
12 carbon steel is governed by really the amount of oxygen
13 that's present in the environment and the amount of oxygen
14 that gets to the surface. And, if we went to alkaline pHs,
15 we get to the region of about pH-11, and so on, where the
16 steel self-passivates. Now, the significance of this is, in
17 the repository we expect to use a considerable amount of
18 concrete and other cementitious materials in lining the
19 boreholes or lining the drift holes and in many of the
20 emplacement arrangements that have been investigated. So,
21 that might condition the water to this area where the
22 corrosion rate of carbon steel would be very small. Now, the
23 proviso is that it would stay at that pH. And, as we'll hear
24 in a talk a little bit later, there are conditions where the

1 concrete can be degraded by microbial attack and actually it
2 runs into the acid regime.

3 The other side again is the pH becomes acid. As I
4 think most of you are familiar, corrosion rate of carbon
5 steel and iron and other ferrous materials increases very
6 dramatically and this is because--now, another cathodic
7 reaction, namely that of hydrogen evolution, takes over and
8 becomes the strong reaction. Now, the significance in the
9 repository is--and, we'll hear some work in just a little
10 bit--if diesel fuels are used and some of these residues of
11 the diesel fuel are left, over time these can react with
12 steam in the environment and form carboxylic acid. It's like
13 acidic gas and formic acid which, of course, would drive the
14 pH down this way. Another way, of course, is microbial
15 attack on the metal surface. One kind of microbe would
16 oxidize lower states of sulfur to sulfate and that would
17 hydrolyze to form sulfuric acid and that would be, again,
18 very detrimental to carbon steel. Another kind of bacteria
19 would take the sulphate and then reduce it to hydrogen
20 sulfide. Well, hydrogen sulfide is again an acid forming gas
21 and not only would it drive the pH here, but hydrogen sulfide
22 also has the specific effect that it promotes hydrogen entry
23 into carbon steel and other ferrous materials and would also
24 embrittle the stainless steel--embrittle the carbon steel.

1 So, you can see that microbial entities could be very
2 damaging to the carbon steels.

3 Now, again, if we were to consider copper as an
4 outer barrier, first of all, the corrosion rate of copper is
5 lower than that of carbon steel in most instances. But then,
6 carbon steel--or with copper and an acid environment if it's
7 a non-oxidizing acid, the rate won't increase because you
8 don't get hydrogen evolution on the copper. It would just be
9 governed by the amount of oxygen on the surface. But, this
10 would be an example of how one would maybe go about choosing
11 between copper and a ferrous material on the outer barrier.

12 As I said, we have degradation load surveys going
13 on on the ferrous materials and these are being done by Dan
14 Bullen who used to be associated with this project when he
15 worked at Livermore. Now, he's a professor at Iowa State
16 University. And, some of the conclusions that have been
17 reached, so far, in the survey is--and, again, it's been
18 mentioned earlier today--dry oxidation, as you well imagine,
19 is negligible and the aqueous corrosion is very dependent on
20 oxygen availability and it turns out that most all the
21 ferrous materials are going to show about the same corrosion
22 rate in static neutral pH waters which is certainly one of
23 the anticipated cases.

24 Now, some of the other materials that we're

1 considering, the weathering steels, although they do it very
2 nicely in a lot of atmospheric applications where you have
3 alternate wetting and drying cycles, don't show any
4 particular improvement over carbon steels when they're in
5 immersion conditions. And, again, these do present some
6 problems with welding considerations again compared to plain
7 carbon steel. So, they may not be so attractive.

8 The alloy steels again, where they might show
9 improvement in oxidation resistance and corrosion under
10 certain aggressive waters, but again because of the alloy
11 content, they tend to form martensite very readily in wells
12 and they could be either embrittled just during the welling
13 operation or in long-term considerations. Hydrogen tends to
14 be absorbed more readily in martensite and it tends to become
15 a more brittle structure as a result.

16 So, the high silicon cast irons, although they're
17 very cheap materials and they are very resistant to many
18 kinds of aggressive waters, they're also very, very brittle
19 materials. So, they certainly are less attractive because of
20 that factor. So, it appears that the statement here that the
21 actual choice of the ferrous material that one might use will
22 depend on factors other than just corrosion, particularly in
23 that neutral, somewhat alkaline range where the oxygen
24 content is the main governing reaction.

1 Now, again, I'd like to switch to give you just a
2 bit of a flavor of all the other activities that are going on
3 with us and that's to talk a bit about our modeling work.
4 Bill Halsey talked a lot about how he was using some of the
5 information we've generated from our models. But, what I'd
6 just like to do is to give you a little bit of the basis at
7 least on the fundamental aspect of how this works.

8 If one considers most of the corrosion-resistant
9 materials that I listed earlier, they work so well because
10 they have a thin passive film that protects them. But,
11 passivity is a dynamic entity. The passive films are always
12 breaking down and reforming. And, particularly, when you
13 consider a surface of a metal and all the heterogeneities
14 that are associated with it, there are some areas on that
15 metal surface where the passive film is going to be weaker
16 than others. And, because of that, there's certain areas on
17 where a pit could be born; at least, a pit embryo could be
18 born. Then, we have the competing processes of where the
19 passive film reforms and so, even though the little pit was
20 started, the film grows back and the pit dies. So, we call
21 that--we have a birth parameter and a death parameter.

22 Well, what's done in a modeling way and this is all
23 --I should emphasize this is done on the computer--is that
24 there are certain probabilities that are associated with the

1 birth and with the death. What's done on the computer is to
2 generate a series of random numbers and then compare those
3 random numbers with the birth probabilities and the death
4 probabilities. And, in a sequence like this where it's one
5 birth event following another birth event and so on, you have
6 a step-wise growth of the little pit generation. Of course,
7 at any one time, the death parameter could take over and that
8 little pit that was formed embryonically then dies. And,
9 that cell then is a no pit and other cells--this is done over
10 a large grid of little areas on a metal surface. One
11 establishes a pit population. And then, from another
12 parameter, compares when those pits grow to a certain size or
13 to a certain age, then they become a stable pit and then can
14 forever propagate from that stage. Now, this has been done a
15 lot with stainless steels and in high chloride solutions and
16 with an applied potential. So, we have a situation where
17 pits are formed very readily.

18 What's been done is to take the computer generation
19 and compare that with data that's actually been generated on
20 monitoring pit formations and pit growth and then to compare
21 the two. What's done then is to keep modifying the various
22 parameters. So, you're going in this birth and death
23 probabilities to match the experimental data. But, you'll
24 notice, of course, this is done for very, very short times

1 and what we're interested in is going to be extended for
2 much, much longer periods of times and also for other
3 materials.

4 We're dealing with a lot of very resistant
5 materials that are sometimes hard to form a pit in the first
6 place. And so, what we plan to do in the laboratory in the
7 very near future is to actually do some pitting work where we
8 apply potentials and again this is from the microchemical
9 point of view. This is one of the readily available ways to
10 us to make pits grow and, of course, we'd have to do these in
11 aggressive chemical conditions, as well. And then, we have
12 to simultaneously advance, use the most advanced techniques,
13 and maybe do some advancements ourselves on surface imaging
14 to be able to detect where those pits are and the
15 electrochemical noises, another way of monitoring those, to
16 quantify the pitting attack. Then, we would generate and
17 determine these parameters and then establish the validity of
18 the critical potential over a long period of time.

19 The investigator here is Greg Henshall. He can't
20 be with us today because he has a birth event or an imminent
21 birth event occurring in his home right now. He's expecting
22 his first child. So, we wish him well.

23 With this one, I just want to show you this because
24 we have been planning what kinds of testing that we should be

1 doing in the very near future. In the talk after this, Greg
2 Gdowski is going to be talking about some of the transitions
3 that we mentioned earlier about from wet to dry. Then,
4 Jangyul Park from Argonne is going to be talking about some
5 of the work that he's been doing with stress-corrosion
6 cracking of some of the candidate materials. Again, he's
7 been doing some work still with stainless steels, 304, 316,
8 all because of the abundance of available information on
9 those materials, even though we're not really considering
10 those as containment materials.

11 Then, some near-future activities, we're going to
12 do those electrochemical based pitting parameter tests.
13 We're going to do some more fracture mechanics tests like the
14 work being done at Argonne with maybe other materials and
15 other environments. Ned Dalder is going to be taking over
16 that work. And then, as mentioned earlier this morning,
17 we're going to be doing some support for the large block
18 test. We will have some specimens of iron copper in for a
19 long duration.

20 What I'd like to just show you here is sort of a
21 program. We've different materials testing evaluations all
22 different kinds of corrosion that we want to consider. It's
23 in the handout. So, I won't go through every one of these.
24 But, some of these, we've defined as long-term, that meaning

1 a year or more; some short-term to be less than a year.
2 Often and under accelerated conditions because it would help
3 in developing our models. Then, whether they affect the
4 inner barrier or the outer barrier. I just would like you to
5 get a feeling for--just take all these and multiply together
6 the different--the testing matrix, all the conditions that we
7 have to consider, and again if we do a sufficient replication
8 of these to make a credible statistical case for our
9 measurements.

10 What we would like to do, as Dave Stahl mentioned
11 earlier, the real need to get on with some long-term testing
12 again in the five to 10 year period of time. But, perhaps to
13 get started on it is to identify some six, or some reasonable
14 number of environments that we would want to use. Because we
15 make a commitment once we start a test, and in some
16 environments where there's a commitment they keep with it.
17 And, again, some of these would be anticipated, some would be
18 unanticipated, but credible. And, we'd have to accommodate
19 several metals. There would be a lot of engineering just in
20 designing the experiments. We would probably want to have
21 these with minimal surveillance. So, we propose a lot of
22 like self-loaded stress-corrosion, flat creviced coupons,
23 galvanically coupled coupons. Again, we'd have to do this
24 under a rigid quality assurance affecting activity. So, that

1 means a lot of planning which we'd want to do technically,
2 but also planning from a QA sense of the word at an early
3 stage.

4 Again, as I said earlier, we are doing some work
5 with non-metals and particularly ceramics. Again, the major
6 advantage would be their chemical resistance. But, we would
7 exchange that resistance for a number of technical issues and
8 these are a lot associated with how one would fabricate a
9 ceramic to the size and the dimension and the quantity that
10 we would need for waste package containers. And, again,
11 there's some degradation issues there with those long-term,
12 slow crack propagation. And, Keith Wilfinger who is in the
13 audience is the principal investigator and he's recently
14 joined the program. He is doing a survey right now of the
15 technology available on ceramics and other non-metals and who
16 can do what and then that should point the way to--that in
17 the next year that we could do some prototypes where we would
18 get to near--near size.

19 And, Ellis is waving me that I'm about out of time,
20 but I'll just--this is in your handout. But, that's just a
21 summary of all the points that I made earlier.

22 DR. MCKETTA: Thank you very much, Dan.

23 We are open now for some questions. Members of the
24 Board?

1 (No audible response.)

2 DR. MCKETTA: Staff?

3 DR. DI BELLA: I think it was your tenth slide where you
4 put your long and short-term research needs. What are we
5 talking as far as what that would cost over the five to 10
6 year?

7 DR. MCCRIGHT: I would say that that's on the
8 neighborhood of a couple of million dollars a year and that's
9 probably--that might be a low estimate. I really haven't
10 come to grips with just the amount of work that each one of
11 these is going to involve because some of it depends a little
12 bit on progress being made elsewhere in the project. Again,
13 like I say, some of the things being--and, I understand the
14 difficulty with not having--since the thermal loading
15 decision tends to make us be more conservative on this. So,
16 we have to test more materials under more aggressive
17 conditions because that's maybe a more realistic problem than
18 otherwise.

19 DR. MCKETTA: Dan, thank you very much.

20 In order that we won't infringe on Greg's time,
21 Greg Gdowski is going to talk to us on thermogravimetric
22 studies.

23 DR. GDOWSKI: Okay. My talk is about an effort that
24 we're putting forth to understand the effect of water vapor

1 on the corrosion of certain metals. The talk is going to be
2 divided into two parts. The initial part will just give us
3 some background on what we know about the effects of water
4 vapor on the corrosion of various materials. The second part
5 of the talk I'll give you will explain the experimental
6 apparatus that we're going to use to study these reactions
7 and also give you some of the preliminary results that we
8 have.

9 Now, for some time, there has been an interest in
10 the effect of atmospheric corrosion on materials. And, by
11 that, I mean the effect of ambient environments on materials.
12 And, from these studies, what they have shown is that small
13 thin water layers on metal surfaces can be severely
14 corrosive. Now, what I want to do is just show you some
15 examples of literature references that indicate how corrosive
16 these thin water layers can be.

17 Now, this first result is very qualitative and
18 shows you some corrosion results that have been long-term
19 corrosion results that have been obtained on pure copper.
20 These present average corrosion rates over 10 year and 20
21 year periods and they show that the most aggressive
22 environments which they classify as industrial or industrial
23 marine and severe marine have higher corrosion rates. These
24 are typically characterized by high humidity and also the

1 presence of pollutants or salts. And, in contrast, the
2 lowest corrosion rates are for those atmospheres which are
3 deemed rural and dry which at the time Phoenix, Arizona was a
4 rural place and it was also dry. The corrosion rates are at
5 the detection limits of the experimenters.

6 Now, this next viewgraph shows the effective
7 relative humidity in sulfur dioxide concentration in the air
8 on the corrosion of copper. What they have plotted here is
9 the funnel weight of a specimen versus sulfur dioxide
10 concentration in the atmosphere. These tests were run for 30
11 days at room temperature. It shows a couple of points. One
12 is that below a certain relative humidity, you have very
13 little corrosion. It's only when you go up into the higher
14 relative humidity that you begin to see the corrosion of the
15 copper specimens. Another point is that even at high
16 relative humidities, if you have low amounts of pollutants in
17 your environment, you have very little corrosion. For this
18 particular instance, it shows that at anywhere above 75%
19 relative humidity is when the corrosion starts to kick in.

20 Now, this next viewgraph shows the effect of
21 relative humidity on the corrosion for various materials.
22 Again, what's plotted is a corrosion rate versus percent
23 relative humidity. These tests were again run at room
24 temperature and in a synthetic pollution environment which

1 included SO₂, NO₂, Ozone, chlorine, and hydrogen sulfide.
2 And, what the authors found was that depending on the
3 material, the accelerated corrosion rate, what you see by
4 increasing relative humidity, was very much dependent on the
5 base metal. In this case, iron corroded at the lowest
6 relative humidity, followed by cobalt, nickel, copper, and
7 then silver was rarely affected. In the article, the authors
8 point out that at 70% relative humidity, the corrosion rate
9 for silver was only 25 times that at 0% relative humidity;
10 while for the other materials, it could vary anywhere from
11 500 to 2,000 times the corrosion rate.

12 This next viewgraph, there are two points I want to
13 make on this. And, it shows the dependence on temperature
14 and water vapor partial pressure. If you look first at the
15 lower graph, that's a plot of a corrosion rate versus
16 relative humidity at three different temperatures; 25 degrees
17 C, 40 degrees C, and 50 degrees C. As you can see, as you go
18 up in relative humidity, the corrosion rates start to
19 increase. I'll just point out that the corrosion rate
20 release starts to kick in at around 60% relative humidity
21 independent of temperature. Now, this is a good qualitative
22 way to look at things, but in a more quantitative sense, what
23 we're really interested in is the water partial pressure in
24 your atmosphere and this is shown on the top graph which

1 shows the corrosion rate versus partial pressure of water.
2 Now, this shows the three graphs for 25 degrees, 40 degrees,
3 and 55 degrees C. What this shows is that for any given
4 temperature, you have to go to higher absolute quantities of
5 water in your atmosphere before the corrosion starts to kick
6 in.

7 This next viewgraph shows a couple points. One
8 point is that--this is again a corrosion rate versus time for
9 copper at room temperature into atmospheres; one, 0% relative
10 humidity, the other one is 80% relative humidity. Now,
11 Curves A and B are for 0% relative humidity. The results
12 show that this is for air which has been contaminated with
13 hydrogen sulfide, five parts per million. It shows that on a
14 surface that has been pre-oxidized in oxygen at elevated
15 temperature where you would form an oxide layer on the
16 surface, this is protective. But, if they just subject a
17 copper specimen that has not been oxidized to this
18 environment, you see a large increase in the relative
19 corrosion rate. So, this indicates that history is an
20 important part of the corrosion process.

21 Now, these other three curves, Curves C, D, and E
22 show corrosion rates in an 80% relative humidity atmosphere.
23 Curve D is for a bare copper surface. Curve C is for an air
24 oxidized copper. And, Curve E is for copper which has been

1 oxidized in pure oxygen. What this shows is that although
2 the effect is smaller, it shows that this copper oxide layer
3 on the surface is still protective.

4 Now, the next viewgraphs that I want to show will
5 show the effects of temperatures on some of the parameters
6 that affect the water chemistry. This first viewgraph shows
7 the effect on water partial pressure over an aqueous solution
8 of sodium carbonate as a function of the weighed percent of
9 sodium carbonate in the water. What is shown is that at any
10 given temperature, the equilibrium water vapor pressure
11 required to maintain the saturated solution decreases as you
12 increase the sodium carbonate concentration in your solution.
13 Another point which is shown is that for any given
14 concentration of sodium carbonate in solution, you're going
15 to get a boiling point elevation. Now, what that means is
16 that when you have a saturated solution, you could go above
17 the normal boiling point of water. For instance, at the
18 Yucca Mountain site, I believe that the boiling point has
19 been estimated to be around 95 or 96 degrees Celsius which
20 corresponds to around a vapor pressure of water of 650. So,
21 if we go over here, we see that by going from essentially a
22 dilute water to one that contains 30% sodium carbonate, we
23 can actually elevate the boiling point by 5 degrees. Now,
24 this is a small effect, but for other materials or other

1 elements or compounds, such as sodium chloride or other
2 chlorides, you can get a much larger boiling point elevation
3 extending maybe 10 or 15 degrees above your normal boiling
4 point.

5 One viewgraph which isn't in your packet, but
6 illustrates I think much better than I can explain the effect
7 of a salt on the amount of water that can be trapped on the
8 surface is this one right here which is a plot of the water
9 increase just due to water on the surface versus percent
10 relative humidity. And, we have two examples here. One is
11 for a nickel surface which was just exposed to air and the
12 other one is a nickel surface which has a salt of sodium
13 chloride on it. Now, for the nickel surface which was just
14 air exposed, you see a gradual increase in the amount of
15 water that is absorbed on the surface as a function of
16 relative humidity. Well, the surface that contains the salt
17 on it, you see a rapid increase in the amount--a large
18 increase, excuse me, in the amount of water that's absorbed
19 on the surface. That's just a relative humidity. It's
20 somewhere between 30 and 40%.

21 Now, temperature also can have a positive effect in
22 that some of the promoters for corrosion may also have a
23 limited solubility in water at elevated temperatures. This
24 shows the oxygen solubility in water as a function of

1 temperature for various solutions. Curve No. 1 is for
2 distilled water and it shows that at room temperature oxygen
3 solubility is around 8 or 9ppm, parts per million, and it
4 decreases down to--we're estimating it to be zero at 100
5 degrees C. Now, as you increase salt concentration in water,
6 it has what they call a salting out effect which means that
7 the oxygen solubility is starting to decrease in the
8 solutions. And, you can see that once we get to very high
9 salt concentrations around 28% sodium chloride, there's very
10 little effect of temperature, but it still is--excuse me.
11 Temperature has a little effect on it, but it is much lower
12 than what would be present in just pure distilled water.

13 Now, as an example of competing reaction rates, I'd
14 show this data that was obtained by Dan McCright and shown
15 previously at one of the Board meetings. But, it shows the
16 corrosion rate of carbon steel in neutral pH water as a
17 function of temperature. Corrosion rates were measured
18 anywhere between 50 and 100 degrees C. And, it shows that
19 the corrosion rate actually goes through a maximum. The
20 reason for this, as they explained it, is that the rate may
21 be increased due to an enhanced rate of oxygen diffusion to
22 the surface where the oxygen can then interact with the
23 surface and corrode further. But, once you go above a
24 certain temperature, your oxygen solubility is starting to

1 decrease and, therefore, the oxygen promotion of the reaction
2 is gone and then you get a decrease in the reaction.

3 Now, what do we know from the atmospheric corrosion
4 studies? Well, we know that the corrosion rates are
5 dependent on the presence of a thin aqueous film on the
6 surface. However, there's quite a controversy as to how
7 thick this aqueous corrosion rate must be in order to promote
8 these reactions. In the literature, references go from
9 anywhere from .001 to 1 micron as the size of the water layer
10 thickness that must be on the surface. I also must mention
11 again that the aqueous film presence on the surface can be
12 enhanced by other species such as salts. The second point is
13 that the corrosion rates are also dependent on the presence
14 of absorbed species in the aqueous film. I pointed out
15 examples that show that the sulfides are necessary to be in
16 --are one example of an enhancer of corrosion rate. And,
17 also, most previous studies have been in the range of
18 temperatures of 20 to 30 degrees Celsius and we're actually
19 interested in much higher temperatures, approximately around
20 70 to 150 degrees C.

21 One other area that we'd like to also look at is
22 the effect of water on the high temperature oxidation of
23 materials. We want to see if the water, even in these
24 atmospheres, has some effect on the corrosion rates of these

1 materials.

2 Now, what I'm going to show are two examples; one
3 which shows that water actually decreases the corrosion rate
4 and another one where it actually increases the corrosion
5 rate. This first example shows the effect of water vapor on
6 the oxidation of Vanadium at two temperatures; 300 degrees C
7 and 600 degrees C. The air was saturated with water at room
8 temperature. So, this corresponds to around 2 or 3% water
9 actually in the atmosphere. These were all done at one
10 atmospheric pressure. What you can see under both
11 conditions, that the saturated air, as they call it, was
12 about--the corrosion rate for the saturated air was about 40%
13 less than that for dry air. So, this shows that even a very
14 small amount of water in these atmospheres can affect the
15 corrosion processes on the surfaces. I should also mention
16 that the others claimed that the reason for this inhibition
17 was that they believed that it affected the protective layer
18 on the surface. It wasn't more of a competing reaction for
19 absorption on the surface between water and oxygen; it was
20 more that the water when it reacted with the surface left
21 behind some hydrogen which somehow formed a more protective
22 layer on the surface.

23 This next example shows the effect of water vapor
24 on the oxidation of low carbon steel. Now, this is much

1 higher temperatures. The reaction was studied anywhere from
2 1000 degrees C to 1150 degrees C. So, that's much higher
3 than we're really interested in, but it's just an effect that
4 I wanted to show you. Again, the air that was used in this
5 reaction was saturated at room temperature before it was
6 brought up to the reaction temperature. So, again, you have
7 a very small amount of water in that atmosphere. It shows
8 that over the whole temperature range again that the--in this
9 case, that the dry atmosphere corrodes somewhere between 20
10 and 30% less than with the wet atmosphere.

11 Now, I'd like to switch gears a little bit and show
12 you the apparatus that we plan to do our experiments in and
13 also present some of our preliminary results. The unit that
14 we're going to use is a thermogravimetric analyzer which is
15 shown here on the figure. It consists of a microbalance
16 which the manufacturer claims can measure down to one
17 microgram. It also has a furnace that we can--so that we can
18 sample the--or test our specimens anywhere from 0 to 1000
19 degrees C. We have a thermocouple in there to measure the
20 temperature of the specimen. It's also computer controlled.
21 So, we set the parameters that we want the system to operate
22 in and all the data is collected also by the computer. We
23 also have a gas control system here which allows us to bring
24 in various gases. Right now, we're operating with dry air

1 and we also have a way of saturating this air with water.
2 And, by varying the air to water ratio, we can get different
3 relative humidities into this chamber right here.

4 Now, I'm going to show you some of our preliminary
5 data. I should point out that we're still presently in a
6 shakedown mode of operation. When we started up with the
7 equipment, we did find a few things that weren't quite
8 operating the way we expected. So, we had to make some
9 modifications. This data is not perfect. So, I don't want
10 you to take it as gospel because we may find out that it's
11 not quite what we wanted.

12 But, this shows corrosion rate data under two
13 conditions for pure copper, commercially pure copper, CDA
14 102, at 250 degrees C. These tests were run for about 48
15 hours. And, it shows the weight gain versus time. In our
16 example, it shows that dry air is much more corrosive than
17 what we would have as water saturated air. In our
18 experiments, what we did was we saturated our air at 90
19 degrees C. So, we have a much higher water vapor
20 concentration in our air than those results previously shown.
21 It turns out that initially we have a--well, what we assume
22 is we have a higher corrosion rate and it seems to be turning
23 over at some point, but our experiment at this point was
24 limited to 48 hours. What we found is that our corrosion

1 rate was about .2 milligrams per centimeter squared which is
2 in pretty good agreement with what literature values predict
3 for corrosion at 250 degrees C. It turns out the corrosion
4 in the water vapor was about an order of magnitude less. So,
5 we're about .02 milligrams per centimeter squared under these
6 conditions.

7 This next viewgraph just shows what our specimens
8 look like after we have taken them out of the reactor. This
9 actually should look more black than it does. It sort of has
10 a greenish tint to it here. But, in dry air, what it looks
11 like is what we would expect and we formed a copper oxide
12 layer on the surface which is CuO . In the case where we did
13 it with the water vapor concentration, it looks sort of like
14 an orange-brown sort of color which in looking through the
15 literature can correspond either to Cu_2O or possibly a
16 compound of peroxide which is $\text{CuO}_2\text{H}_2\text{O}$, but unfortunately the
17 peroxide decomposes at about 60 degrees Celsius. So, we're a
18 little skeptical of that being what we have here. But, this
19 is just a visual examination and we're trying to do some
20 other surface analysis to actually determine what the
21 composition and structure of these layers are.

22 Just quickly then, some of the other data that we
23 hope to get is the data where we go from the transition from
24 what we might expect that we have aqueous corrosion on the

1 surface to where we're going to dry corrosion. Quickly, how
2 we wanted to do that was to just run experiments at a
3 constant vapor pressure and then just ramp up the temperature
4 of the specimen and see when it got back down to a base level
5 where we could assume that we have no water on the surface.
6 We could then do this as a function of other species on the
7 surface, such as salts or things like that.

8 And then, finally, the focus of our TGA work will
9 be two parts. One, to study the oxidation in air/water
10 mixtures, varying the temperatures anywhere to 75 to 300
11 degrees Celsius, do these in various partial pressures of
12 water; and, also, we'd like to determine the temperature and
13 water vapor partial pressure regions where aqueous corrosion
14 will occur. There are five things that we considered this to
15 be dependent on. Obviously, temperature and water vapor
16 pressure, but also the metal and also what absorbed species
17 you have and also the possibility of gas-phase species.

18 Thank you.

19 DR. MCKETTA: Thank you, Greg.

20 Do we have any questions from members of the Board?

21 DR. VERINK: Will you make any attempt to keep track of
22 the carbon dioxide exposed to your samples?

23 DR. GDOWSKI: Yes. Right now, we're using purified air
24 that does not have carbon dioxide, but it's one of the

1 variables that we are considering.

2 DR. McKETTA: Any other questions?

3 (No audible response.)

4 DR. McKETTA: We have about a minute and a half. Are
5 there any questions from the audience?

6 (No audible response.)

7 DR. McKETTA: Can someone find Dr. Park?

8 Jang, come on.

9 Our next speaker is Dr. Jang Park, who is going to
10 talk to us on stress corrosion cracking studies.

11 DR. PARK: I'm Jang Y. Park from Argonne National
12 Laboratory. I would like to present stress corrosion
13 cracking studies for the candidate container material today.

14 The objective of this project is to determine if
15 there is any susceptibility of a candidate waste container
16 material to stress corrosion cracking in simulated Yucca
17 Mountain ground water, or any possible environment in which,
18 waste may sit, and, also, provide experimental data base for
19 predictive models for stress corrosion cracking.

20 Now, when I say stress corrosion cracking, this is
21 a phenomenon where, under certain combinations of material,
22 stress and environment, will induce the cracking of the
23 otherwise sound material. Or accelerate or increase the
24 cracking rate of already cracked--ongoing cracks. This

1 phenomenon has been observed in very many industries of cross
2 component processes, and nowadays, some people, also, they
3 refer to this as a environmentally-assisted cracking
4 phenomena.

5 Now, when we're talking about this, in our case,
6 when I say combinations of stress and the material and
7 environment, and, of course, the environment, we are talking
8 about, ground water or any other environment a container may
9 see, and the material, I'm talking about the candidate
10 container material, and stress is usually involved, or many
11 possible stresses, including, possibly, welding residue
12 stresses introduced during the fabrication of this container.

13 And, from the other researches, for example,
14 welding residue stresses could be very high, up to something
15 like 15 to 18, 20 ksi square root meter in some of the
16 stainless steels, and so we do have the stress involved in
17 this container.

18 Now, I'd like to present some of this; what kind of
19 material and the experimental condition we are involved in
20 here. First, our test is Incoloy 825. That is a nickel-
21 based alloy, fairly resistant to a chloride environment, and
22 Type 304L and 316L stainless steel, which is a very common
23 and popular stainless steel. We have a lot of data based on
24 this, so our study can be compared on this basic data.

1 And type of test is, we use in the fracture
2 mechanics-type crack growth rate. There are many different
3 type of cracking experiments you can do it, but this type of
4 test will provide the sort of very convenient form of test
5 and standardized by ASTM-type of test.

6 And the specimen is a modified ASTM E399 specimen,
7 about one inch by one inch--one inch thick, and about 2 x 2
8 inch specimen, where I have brought this specimen with me.
9 In the break time, you might want to look at this, if you
10 haven't seen this. I'll leave it here, and this is what it
11 is.

12 This is--now, I'd like to, actually, give out every
13 one of you as a souvenir, but anyway, I have also the--I
14 didn't put it in your view graph, because this is not the
15 specimen for this study. This is actually a specimen look
16 like this. I'm looking at a side view. We put a pull rod on
17 these holes, and then pull it on this way, and then the crack
18 will--when the specimen crack, crack will advance like this
19 direction, and we measure the crack length in given time, as
20 experiment going by, and then divide it by--the crack length
21 divided by average test time will give us average crack
22 growth rate.

23 Now, this one shows the specimen which crack was
24 growing into up to almost here, and this is a specimen,

1 carbon steel specimen tested in the oxygenated water. And,
2 incidentally, this is a specimen, was same specimen, except
3 this one was gold-plated, so it's a different program, but
4 I'm showing this effect of plating or some other contact with
5 other element could give a very different result on the
6 cracking behavior.

7 Just pointing out some--previously, Dan McCright,
8 in his slides, showed some effects of--importance of looking
9 into effects of galvanic effect. This is part of the
10 galvanic effect, we can see it, but specimen and environment
11 are different, so don't think this is Yucca Mountain.

12 Now, actually, experimental setup is like this. I
13 have, to save the time and all these monies, we put the three
14 specimens in one batch, in daisy chain. This is the
15 specimen. We put these three specimens in the nickel vessel,
16 and load would be applied this way with the hydraulic
17 machine. And then test solution, which is a simulated J-13
18 well water, we made at our laboratory, and feed it into this,
19 and then just pull it, and under the--and change the
20 different loading condition and measure the crack length at a
21 given time.

22 To remind you, this is sort of a chemical
23 composition of J-13 well water, for calcium, magnesium, all
24 the sort of things which you'll find in your handout.

1 This shows the loading conditions we have
2 investigated in this study. Let me give some definition of
3 this. Load ratio, R , is defined by the minimum load divided
4 by maximum load we applied to the specimen, and this is a
5 load, and time, we applied--if the constant load, since
6 minimum load and the maximum load is equal, that the load
7 ratio is one, and we give a little wiggle in here. It
8 depends on these load ratio changes, so we tested at the high
9 load ratios is .9 to 1 as constant load, and low R test is .2
10 to .7.

11 And we changed the loading shape, like how fast we
12 increase a load, how fast we decrease a load by changing rise
13 time is 12 second, unloading time is 2 second, and the load R
14 ratio, we got the 1 to 5,000 second, 1 to 2,000 second, and,
15 actual load value in stressing test in terms of 25, and this
16 is a range, and initial load we started was a 25 stress
17 intensity factor, 25 square root meters inch. That is a
18 value about twice the value of a typical welding residue
19 stress observed in some other studies. Usually, we got about
20 12 or 13, as I mentioned, MPa square root of meter is
21 observed.

22 Then our test is something like a conservative in
23 that case, because we start at 25, but that is not high to
24 introduce a clastic deformation in our specimen.

1 Now, I show the result of the--in the next slide,
2 and the result of test, and I plotted this at crack length
3 and the given time, and the millimeter here, and this is a
4 test time. We measured the crack length each time. And this
5 is Type 304L stainless steel, and stress value is 25, and the
6 load ratio is a .9. And, typically, we see just about--I
7 don't see any significant increase of crack length. Matter
8 of fact, our resolution of the crack detection is 50 micron,
9 so it's somewhere, and one, two, three, four difference, so
10 it's--this crack length, if there was a crack propagation,
11 it's within the range--within a resolution of our testing
12 machine.

13 And, incidentally, our resolution is fairly a state
14 of art. Value is, I consider is very good, and that next one
15 is 316, and the next slide is Incoloy 825, the same way that
16 we don't see any appreciable crack propagation in this case.

17 Now, from here, we concluded this: Now, this set
18 of tests had to be a long-term test, is accumulated 19,000
19 hours, and now, because--if we didn't see any crack
20 propagation in specimen, this test condition, but if there
21 was any crack propagation, it could be within a resolution,
22 so we put the resolution, divided by a cumulated test time,
23 that's 19,000 hours. If there was any crack propagation,
24 they are probably 8×10^{-13} m/s or less, or zero.

25 Now, if we compare this one, suppose if we have the

1 canister container thickness about the 10^{-2} meter, and then
2 300 years, then to get any crack propagate through that
3 uniform cross-section, the average crack propagation rate
4 should be 1×10^{-12} m/s. So, this test result at present
5 time, at the accumulation time, 19,000 hours, it is less than
6 this value.

7 Next, this is a result of a high R value test, and
8 next I'll show the low R value test. This is--previous test
9 was R equals 1 or .9. Now, this R equals .7. That's a
10 little bit larger wiggles, and we can see there's a definite
11 crack propagation is observed, and we did this through a .2
12 to .7 test on various different stress intensity. We
13 measured the crack growth rate by dividing this crack length
14 propagation and divided by time, and we got some data base
15 accumulated for three different materials, and next slide
16 shows the--this is sort of a list of things we put about
17 this.

18 And, now, instead of going in this, we look at this
19 data base and did some looking into what does it mean to us.
20 Out of those data bases, I plotted this in crack growth
21 rate, which is on the table, which is observed actual
22 experimental data in terms of meters per second, and each
23 data points are the--this case, R, .9, and these different
24 materials. Put this with respect to the ASME air crack

1 growth rate data for austenitic steels, and then this solid
2 line is ASME air crack growth rate data. These are the
3 actually observed crack growth rate data, and is sort of
4 within--it's within the--it does not go beyond this ASME air
5 crack growth rate data.

6 Next slide shown is the same as .7, is very similar
7 observation as ASME Section XI prediction, and this is our
8 measurement.

9 And we plotted our data, again, the different way,
10 see if there is, indeed, any acceleration of this crack
11 growth rate by the environment, this ground water. Now, we
12 plotted it to see that we plotted a crack growth rate in
13 meter per second in terms of frequency. When this is a
14 frequency, I mean we applied these little wiggles and changed
15 their loading time and unloading time, so--and we plotted
16 this in terms of this, and this old data is sort of lying
17 around the Slope 1.

18 If there were any environmental acceleration, we
19 would have expect to see a data somehow lie sort of above
20 this Slope 1 data, but we didn't see it.

21 Now, next slide show the same trend on different R
22 value, same way. All the data is lying on the Slope 1, and
23 there's no environmental acceleration we observed.

24 We plotted the other way, some of the data. We

1 plotted crack growth rate per cycle, each cycle, how the
2 crack will propagate, with respect to the rise time. Then
3 it's flat here, as horizontal. If there was any
4 environmental acceleration, we would see something like this.
5 So, if you apply the load very slowly, and each time you
6 have the specimen, or crack surface will see more chance to
7 expose more time to the environment, so we don't see that
8 environmental acceleration in this.

9 The next one is the same under different
10 conditions. Now, from here, from this, we made the
11 conclusion in the following view graph. There's no crack
12 growth was detected for this Incoloy 825, 304, 316L stainless
13 steel at K 25 and high R value, .9 - 1 for the test time
14 until 19,000 hours. So, based on the resolution of the
15 measuring technique, could be interpreted at least the crack
16 growth rate, average it was less than 8×10^{-13} m/s. That was
17 what the high R value test result, and the low R value test
18 result gives us.

19 There is no cyclic or rise-time-dependent
20 environmental acceleration of crack growth rate in this alloy
21 and simulated J-13 well water at the temperature in the test
22 conditions.

23 Growth rate for this low R test value, and the
24 maximum stress of the 22-40 range agrees with the ASME

1 Section XI correlations for austenitic stainless steel within
2 a factor of 2.

3 And now, these were the tests on the material which
4 were as-received, in mill annealed condition. We all know
5 that it's well-established that one stainless steel, all
6 stainless steels are sensitized, is very susceptible to this
7 stress corrosion cracking, so these are actually the result
8 of the mill annealed condition.

9 I propose that this cannot be taken, because some
10 of the containers may have an area which is thermally-treated
11 and may be sensitized for different heat treatment. So crack
12 growth rate is really needed for different heats of alloys
13 and materials under condition of welding and other thermal
14 aging conditions we may encounter during fabrication.

15 Current effort in FY94, we are continuing to look
16 at this material and has also added these other candidate
17 materials of Titanium Grade 12, and Hastelloy C-4 and
18 Hastelloy C-22. These alloys are very resistant to the
19 cracking or pitting corrosion in the chloride environment,
20 and the material condition we are initiating is mill
21 annealed, as-received condition, and the environment is same
22 as before, is simulated J-13 well water.

23 We are just starting up this test, but, as I said,
24 we feel this additional investigation is really important to

1 do. All these tests has to include the test of material in
2 welding and heat-treating condition and the realistic
3 conditions, and, also, the environmental variability. We
4 chose one condition about simulated J-13 well water, but this
5 composition may change and wet and dry conditions may occur,
6 and also, there is some galvanic--this one is a little
7 different slide I have than you--this galvanic effect may
8 have to be looked into, too.

9 Thank you.

10 DR. MCKETTA: Thank you, Dr. Park. We're open now for
11 questions.

12 DR. CANTLON: Dr. Langmuir pointed out a couple of
13 meetings ago that the vadose zone water will not be like J13
14 water. Has anyone taken that to heart and begun looking at
15 what the chemistry of the vadose zone water will be?

16 DR. MCCRIGHT: I'm not really prepared to talk about
17 water, but my understanding is that most of the groundwater
18 is not that much different than J-13 water composition that
19 is bicarbonate dominated with some minor amounts of chloride
20 and so on. Maybe somebody else from the audience could--

21 DR. CANTLON: Well, I think Langmuir would argue with
22 you. He's done some chemistries of that water and he said
23 it's quite different from J-13.

24 DR. CLARKE: The original test plans called for testing

1 J-13 with various factors of the concentration. As a matter
2 of fact, when we first started the work at Argonne, that
3 series of tests was going to be a factor of 20X. It's
4 unclear to us right now just exactly how much you can
5 concentrate that and that's part of the work that the
6 geochemists are doing that ties in with what we are doing at
7 the laboratory. There is a problem, of course, when trying
8 to test actual J-13 water with various concentration
9 increases because you get the silicon gel formed and it's
10 almost impossible to get this stuff to recirculate or to be
11 exactly like it is underground. And, the geochemists assure
12 me that that phenomena really does not happen underground.
13 But, what we do, in fact, is do some of the testing Dan had
14 showed on here and I think we've reported to you earlier.
15 And that is to do electrochemical tests to compliment the
16 tests that we're doing here. And, in that case, we have
17 taken concentrations of chloride clear up to the Baltic Sea
18 concentrations and we take that information then and cross-
19 correlate it back to here. The machines that Jang is showing
20 you is--you know, those are very high tech, very expensive
21 machines and you can only get so many specimens at a time.
22 Now, we have machines at our place, Argonne has them also,
23 and we do have a whole matrix plan for in the future.
24 I think the significance, though, I would like to

1 get across--I'm not sure everybody really appreciates it--
2 this is what you categorize as a negative result. No
3 cracking is the good news. If you can measure any cracking
4 in these materials in the state-of-the-art equipment that we
5 have and the times that we have to test, it's too fast for a
6 10,000 year prediction. So, the fact that Jangyul was able
7 not to get any environmental crack going in the--what is
8 that, two years, two and a half, or whatever it is--I think
9 our predictions are if we can continue those tests and we get
10 the same result after five years, the prediction then is that
11 that material will indeed last well beyond the regulatory
12 period.

13 Now, that's only one set of data or one data point,
14 but it's better than nothing when we go into a licensing
15 hearing. And, this was the plea that I was making the other
16 day on the new scenario or the new paradigm of the program is
17 that let's not take risks in places where we can do something
18 and we can do something in the next five years as Jangyul has
19 just shown you here on this test regime.

20 The effects of radiation are very severe,
21 obviously. These are some work that was done here at the
22 laboratory before I joined the lab and it was an extensive
23 amount of work, as you know, that we did at GE for years.
24 Once you get up to somewhere around 10^4 rad per hour, your

1 corrosion potential goes up several hundred millivolts which
2 in corrosion terms mean that's a phenomenal increase and the
3 corrosion rates go very, very high. That is one of the
4 things that pointed us away from the thin wall container in
5 the first place and, hopefully, with the self-shielded type
6 containers, this will not be a major issue from the outside
7 of the package.

8 DR. MCKETTA: Dr. Cantlon, any further? Any other
9 questions from the Board or Staff?

10 (No audible response.)

11 DR. MCKETTA: Any question from the audience?

12 (No audible response.)

13 DR. MCKETTA: If not, let's take our 15 minute break.
14 Whatever you time you have, come on back in 15 minutes and
15 we'll start another interesting session.

16 (Whereupon, a brief recess was taken.)

17 DR. MCKETTA: This session is covering the waste package
18 environmental research. And, the period of constructing and
19 then operating and monitoring a repository will occupy a long
20 time and, during this period, many materials will be
21 introduced in the repository; either deliberately or some
22 inadvertently.

23 Annemarie Meike will talk about her project to
24 examine what these could be and how they could influence

1 performance. Annemarie?

2 DR. MEIKE: I am Annemarie Meike and I'm the task leader
3 for the man-made materials task. What I'd like to do is
4 change our focus a little bit from the actual degradation of
5 the material and what happens to the material to what happens
6 to the water; that is, how is the chemistry of the water
7 modified that's in contact with materials? And, not only
8 that, widen the scope of the materials to all the possible
9 materials that could be introduced as a consequence of
10 constructing a repository.

11 Let's examine first four very important points.
12 First of all, there are a wide variety of materials that
13 could be introduced as a result of construction and operation
14 of the repository. These include insoluble metals; organic
15 solids, both insoluble and soluble; miscible organic liquids;
16 and a number of gases. Not only that, but some of these
17 materials may be present in rather large quantities. We're
18 identifying the materials that might be introduced by looking
19 at a number of resources; first, at present and past draft
20 repository designs. We're also looking at other mining
21 operations. We're also looking at estimated and natural uses
22 of materials during the construction of the ESF. The
23 materials that we've identified include shotcrete, diesel
24 fuel, greases, rock bolts, lubricants, and other

1 miscellaneous materials such as polystyrene and bentonite
2 clay.

3 Just to give you an idea of some of the quantities,
4 from the fiscal year 1993 estimated usage, we've seen that
5 they've estimated the usage of 21 million gallons of water;
6 250,000 gallons of diesel fuel, most of it will be burned up;
7 10,000 pounds of rock bolt resin. In this case, fibercrete
8 might be substituted for resin. 1800 square feet of extruded
9 polystyrene, 50 cubic yards of bentonite clay, and 250
10 gallons of cable lubricant. That was the estimate usage for
11 one year.

12 I'd also like to point out that introduced
13 materials include some kind of materials that we
14 automatically think of as man-made materials, but they also
15 include things such as water and also crushed tuff which I
16 hope Dr. Amy will talk about in terms of increased microbial
17 activity. This is something that I feel comes under some of
18 the things that man-made materials need to be interested in.

19 Okay. The third point then is not only that there
20 might be some large quantities of material, but also these
21 materials will not be homogeneously distributed and that some
22 of them will be closer to the waste package than others. We
23 also need to pay attention to the concentrations of various
24 substances. But, primarily, because things are

1 heterogeneously distributed in the repository, we expect to
2 have gradients and these gradients can also drive reactions.
3 Right here, I've got listed some of the gradients that we
4 can expect to exist in the repository; the pH in chemical
5 species, Eh, partial pressure of CO₂, and also bacterial
6 activity just to name a few.

7 The fourth point I'd like to start with is that
8 there is a potential for reaction between groups of materials
9 that are normally considered to be benign. That is, the
10 materials will be exposed to abnormal conditions, abnormal
11 associations, or for extended periods of time. So, I hope
12 just by considering these things that it will be clear to you
13 that to build a high-level radioactive waste repository is to
14 install an extremely heterogenous and complex chemical and
15 thermal system.

16 In this system, materials are expected to degrade
17 and affect the water quality; will affect the chemical
18 species in solution, not only organics and alkali metals and
19 halogen elements, it will also affect the pH and Eh; it will
20 also affect the colloids that are present in the repository
21 because some of the introduced materials can be sources of
22 colloids or modify absorption properties of colloids. And it
23 will also affect microbial activity, and microbial activity,
24 as I'll show you later, can affect the chemistry of water.

1 Now, the degradation of materials depends on the
2 environment. As an example of that, I can allude to an
3 archeological rule of thumb which is that in some saturated
4 environments, like acid peat bogs or marine environment, wood
5 survives, but metal doesn't. And, this can be contrasted to
6 a semi-saturated environment or a sporadically saturated
7 environment in which the opposite is true. This is a
8 reflection of temperature, rate of temperature fluctuation,
9 degree of water saturation, surface area to fluid volume
10 ratio, et cetera, et cetera; all these parameters we need to
11 understand before we can actually--and then, we can model the
12 degradation of materials with respect to that.

13 Our goal then is to satisfy the requirements for
14 chemical data regarding man-made materials or all introduced
15 materials that will allow the appropriate decisions regarding
16 introduction and use of materials in a radioactive waste
17 repository. We have the following options. No limitations
18 and this can be considered a default condition unless some
19 restrictions are made. We can limit usage. We can remove
20 substances or we can substitute materials. And, the man-made
21 materials task considers its goal to be involved in those
22 kind of decisions.

23 As a result of this goal, we've developed a long-
24 term study plan which has three major sections to it. An

1 integration section which is a review of current knowledge
2 and because of the wide scope of the man-made materials task,
3 this is no mean feat. Our largest work right now is in the
4 experimental studies area where we're conducting experiments
5 on materials at ambient temperature and at elevated
6 temperature. The last part which hasn't gotten very far is a
7 matter of computer modeling. That is simulating our
8 experiments and historical analogs to assess the codes in
9 various areas and our ability to integrate our information
10 with the geochemical task and ultimately the hydrological
11 task to be able to provide source terms that we require for
12 the repository.

13 As I said, our biggest activity right now is in the
14 experimental studies area. It involves quite a bit. We're
15 looking at solubility and stability of various materials,
16 reactivity of the products from these materials,
17 biodegradation of the materials, colloid formation--that is
18 not only the formation of colloids from introduced materials,
19 but various ways the chemistry of modified water can affect
20 absorption properties of the natural colloid system--and
21 then, we're also looking at historical analogs.

22 We've only scratched the surface of this rather
23 broad-ranging bunch of activities and, at present, our
24 experimental program includes these things. The diesel fuel

1 stability at elevated temperatures. We're studying water and
2 diesel fuel. This will be described by Ken Jackson. We're
3 studying this at elevated temperature. Just recently, we've
4 initiated a group of experiments that include fibercrete with
5 diesel fuel and water and we'll be increasing the complexity
6 of our chemical system as we understand what's going on.

7 I will explain a little bit about our investigation
8 into cementitious materials. This work is being conducted
9 completely under the international program at present. And,
10 just recently, we've been able to initiate planning for
11 looking at long-term chemical and microbial consequences of
12 diesel exhaust.

13 We've also completed a review of colloids.
14 Unfortunately, we haven't been able to continue with this
15 work this year with the consequences of what we've discovered
16 in the review, but the purpose of the colloid studies were to
17 look at the sources of colloids from introduced materials and
18 provide information that would allow us to determine the
19 options for usage of materials in the repository. And, it
20 wasn't our goal to look at transport absorption mechanisms or
21 the formation of naturally occurring colloids since that's
22 being covered in other areas. But, we do get information
23 from those areas and provide information to them.

24 The composition of colloids that possibly could be

1 derived from introduced materials are quite wide. We can get
2 oxyhydroxides and oxides of metals. We can introduce clays
3 of various sorts, organic particles, and polysilicates from
4 cementitious materials. The size range is also quite large
5 from the very small size, less than 10nm, to larger, greater
6 than 1 micron, particles. And, as I mentioned before, our
7 introduced materials can also influence the formation,
8 transport, and stability of natural colloids. They can
9 effect physical size, bulk charge, density, chemical
10 reactivity, and sorption potential by varying or modifying
11 pH, redox potential, competing ions, organic matter, and
12 modifying microbial activity.

13 And, what remains of the time, I'd just like to
14 talk about the studies we've been doing on cement to show you
15 a little bit of what an integrated study that's directed at
16 one material looks like. Part of this study is being
17 conducted in New Zealand as a part of a large collaborative
18 study between the man-made materials task and the
19 geochemistry task and ultimately we'll be involving the
20 hydrology task, as well. Our goal is to obtain long-term
21 chemical information to be able to validate, if you will
22 permit the use of that word, or simulate chemical
23 environments and eventually be able to use these codes to
24 predict water chemistries that might be applicable to the

1 repository environment.

2 What we're looking at is a geothermal site in the
3 north island of New Zealand. There is a geothermal power
4 plant there that has been operating for 4 years. It's an
5 excellent site to derive materials that have been subjected
6 to certain chemical conditions over a long period of time.
7 We can look at the degradation of organic material. You
8 can't see this very well, but this is a main valve. It has
9 greases that have been exposed to elevated temperatures. We
10 can look at the degradation of metals. Here's a metal
11 drainpipe flowing into a channel. Maybe if you can look and
12 see this white fringe around here, that's silica precipitated
13 here. We're also looking at the degradation of metals in
14 contact with cement. Here's a primarily concrete silencer
15 with lots of hot steam coming out of it. There's also a lot
16 of rebar in there. Another part that we're actually
17 initiating this year is a study of biodegradation of cement.
18 This is kind of a high-angle view of a cooling tower.
19 Inside of this tower, we have severe corrosion of cement
20 going on that has to do with microbial activity.

21 What we want to know in the cement case is what are
22 the significant mechanisms and parameter that control the pH
23 of water in contact with cement over long periods of time.
24 And, just to kind of review the situation, the repository--

1 this is kind of an old design that you all might recognize--
2 but the idea is that in the SCP, at least, it calls for a
3 good bit of shotcrete on the walls here. So, that shotcrete
4 on the drift walls can actually experience a good bit of
5 elevated temperature. And, just to remind you that heat does
6 happen and it happens over a long period of time.

7 On the non-microbial side, we are conducting an
8 investigation in collaboration with Atomic Energy Limited of
9 Canada to get the thermodynamic parameters for phases that we
10 expect to be present in concrete at elevated temperatures.
11 Many of these parameters are either not known or are
12 estimated and the estimated values are fairly poor. This is
13 tobermorite (phonetic) here. One of the problems with
14 getting these values is--I don't know if you can see this,
15 but there's water in the structure. So, these structures are
16 expected to dehydrate with temperature. This can add to the
17 water that's available in the repository. But, it also means
18 that our measurements of thermodynamic parameters are awfully
19 difficult to come by.

20 In New Zealand, we expect to take the thermodynamic
21 parameters and apply them to a real situation. Here, we've
22 got a concrete drain channel with two compositions of water
23 coming through. One composition is precipitating silica
24 rather rapidly. You can see the grey in the water. That's

1 from silica armoring that's occurring. The top channel has
2 no silica precipitation at the moment. We'll be trying to
3 model and model the degradation of concrete in association
4 with this.

5 Now, when we model concrete, we usually expect the
6 pH to be rather elevated, around 10 or 11. So, it may be a
7 surprise, although since Dan's already mentioned it a little
8 bit this morning, may be a surprise to find that some water
9 in contact with concrete can have pHs that are down to 2 or
10 3. This is the case in the cooling tower in New Zealand. I
11 don't know if you can see all this icky green slime that's on
12 the walls here, but that's algae and there's all sorts of
13 microbial activity going on here and the pH of the water in
14 some parts of the walls is actually 3. This is the moat
15 outside the cooling tower. You can see a tidal line here and
16 you may be able to see that below the tide line, there's a
17 significant amount of corrosion going on. This is because
18 the microbes are producing a water that's very low pH and
19 it's actually eating away at the concrete. It's actually a
20 little bit more complicated than that because there's a
21 succession of three different kinds of colonies of microbes
22 that are required to get the pH value; from the pH of
23 concrete, about 10, down to the low pHs that actually corrode
24 the concrete.

1 We've emplaced some cores of material in this
2 tower. These are special formulations that have been
3 produced by looking at other cement formulations in use
4 presently at the ESF and other formulations that have
5 previously been studied for the purposes of Yucca Mountain.
6 These cores have been in place during the last shutdown.
7 That's the only time we can actually access this one area
8 where the temperature is quite elevated. We'll be pulling
9 the cores back out in two years when the next shutdown
10 occurs.

11 Just to remind you from Dan McCright's talk what
12 the implications are of pH, and that is pH is related to the
13 corrosion rate of metals. If we include cement in the design
14 and we assume that the pH is going to be relatively high and
15 we don't take into account that some of the water that comes
16 off of concretes could be much lower, we may be making a
17 little bit of a mistake.

18 So, in summary, we are well on our way to
19 understanding what the issues are that we need to address to
20 determine whether various--the chemical consequences of
21 having various materials introduced into the repository
22 environment are significant. There are significant
23 quantities of materials that may be used and they do have a
24 potential for modifying the water chemistry. But, we need to

1 understand for each material whether that--and, this depends
2 on the design constraints and what we want to design into the
3 repository--we'll know these effects are actually positive or
4 negative for the design. And, thirdly, the purpose of the
5 man-made materials task is to support design efforts and
6 actually determine which materials should be removed, which
7 could have unlimited use, which materials we need to get some
8 substitutions for, and what materials might be removed or
9 used in very limited quantities.

10 Thank you.

11 DR. MCKETTA: Thank you very much, Dr. Meike.

12 Now, since Annemarie's and Ken Jackson's talks are
13 in the same family, I'm going to suggest that we hold
14 questioning until after Kenneth finishes his talk. Then,
15 we'll have questions for both of you.

16 Kenneth is a research chemist in the Earth Science
17 Division at Livermore and is going to talk to us on the
18 hydrous pyrolysis of diesel fuel.

19 DR. JACKSON: Thank you. The experiments that I'd like
20 to talk to you about today are, I think, best considered in
21 terms of a baseline. By that, I mean that the results of
22 these experiments, I believe, should be considered to show
23 the chemical results of interactions at high temperature of
24 diesel fuel components in the absence of other materials that

1 would comprise part of the repository system. We've tried
2 really hard to look exactly at those reactions that occur in
3 the absence of various other reactive species and of various
4 catalytic surfaces.

5 To start off, I'd like to acknowledge the
6 contribution of my co-worker, Susan Carroll, with these
7 experiments. The basic idea of these experiments, as
8 Annemarie mentioned, was to look at the interaction of diesel
9 fuel components with liquid water as a function of
10 temperature and time. Now, these kinds of reactions,
11 generally known as hydrous pyrolysis reactions, are well-
12 known to occur in nature and, in nature, also well-known to
13 contribute significantly to various interactions among rock
14 mineral species with an aqueous solution containing the end
15 products of these kind of reactions.

16 Now, we know that at some point during construction
17 of the nuclear waste repository, a large amount of diesel
18 fuel will be introduced into the repository as fuel. It's
19 reasonable to assume that most of that fuel will be consumed
20 by burning it up and that during the construction, a large
21 amount of care will be taken to make sure that the repository
22 environment isn't polluted with spilled diesel fuel or other
23 hydrocarbon components, but it's also not impossible to
24 imagine scenarios where a certain amount of these

1 hydrocarbon-rich components might be left behind, sequestered
2 in the porous matrix of geologic materials or concrete
3 materials that comprise the repository surfaces.

4 We also know that temperature will rise during some
5 period of time following the emplacement of waste and that
6 there will be some period of time over which liquid water
7 will have the opportunity to interact with these residual
8 hydrocarbon phases and form whatever byproducts might occur
9 when these kind of reactions proceed.

10 It virtually is not yet possible on the basis of
11 well-established laboratory experiments to predict a priori
12 the results of these chemical reactions and so we've done the
13 next best thing which is to look at a series of experiments
14 designed to shed some light on these kind of reactions.

15 There are a number of interactions that go on among
16 hydrocarbon components as a function of temperature. And,
17 only a few of those reactions are really important in
18 determining how an aqueous solution in contact with the
19 reaction, products from these reactions might impact
20 seriously the rates or the extent of chemical reactions.

21 I've shown here an example of one of those kinds of
22 reactions that we might consider to be important. Now, this
23 is taken from some work by Siskin and Katritzky in 1991 where
24 they showed that such chemically complex components as

1 polyethylene terephthalate, which is basically the components
2 of the to date plastic Pepsi containers which we usually
3 think of as fairly inert, do undergo hydrous pyrolysis
4 reaction at modest to high temperatures like in this case,
5 200 degrees C, yielding compounds that are potentially
6 reactive in a geologic scenario. In this case, a
7 dicarboxylic acid and various alcohols and those reactions do
8 proceed at reasonably fast rates. Now, the kinds of products
9 that were formed in that reaction, namely the dicarboxylic
10 acids, are extremely reactive with respect to geologic
11 materials and I'd just like to show you a couple of quick
12 pictures taken from a paper by Ron Certum and Laura Crossey
13 (phonetic) that illustrate that point, I hope. This picture
14 is an SEM photograph of a feldspar surface that was used as a
15 reactant in these experiments where they exposed this
16 feldspar to a solution containing a dicarboxylic acid, in
17 this case oxalic acid. As you can see before the reaction
18 proceeded, the surfaces of this mineral were fairly pristine,
19 their cleavage and crystal faces were fairly pristine for
20 scale down here in the corners of the micron scale bar. If
21 allowed to react at 150 degrees with liquid water for a few
22 hours, the reaction products wouldn't look a whole lot
23 different than this. There would be a certain amount of
24 dissolution and a fair amount of--and, a possibility of a few

1 secondary minerals formed. However, if given the opportunity
2 to react with a dicarboxylic acid, those same mineral
3 surfaces look like this. And, there's an extreme amount of
4 dissolution. There's a large number of secondary minerals
5 formed and the important point is that both the extent and
6 the rate of reaction are accelerated by the presence of
7 dicarboxylic acids. That's the kind of thing that we'd be
8 looking for as run products in our experiments.

9 In addition, our interest in finding out whether
10 there are conditions evolving as a function of these
11 reactions that could be potentially viewed as corrosive or
12 reactive to the other parts of the system like the waste
13 canister or provide complexing ligands like the carboxylic
14 acids for enhancing the solubility of radionuclide species.

15 The experiments that we conducted were done in an
16 apparatus that's shown schematically in this diagram. I
17 don't want to spend too much time going over the details of
18 how this apparatus is set up. I just want to cover a few key
19 points. The reaction vessel in these experiments is a
20 Dickson type autoclave which is comprised of a moderate size
21 gold bag, thin-walled collapsible gold bag, which is filled
22 with a reaction mixture. This gold bag is capped by a
23 carefully passivated titanium head which contains in it a
24 sampling tool which allows us to sample the reaction mixture

1 at high temperature and pressure during the process of the
2 reaction several times repetitively. The idea is that the
3 sample tube extends up from the skull bag which is crushed to
4 eliminate any head space gas and so you only have the
5 specific reactants you want, in this case diesel fuel and
6 water, and extends up to a sampling system that allows you to
7 take repetitive samples at in situ conditions. We can go
8 over the details of that more later if you're interested.

9 The experimental conditions that comprise this
10 baseline study were two experiments. One was at 200 degrees
11 and 70 bars; the second one was at 315 degrees and 150 bars.
12 The temperatures were selected to give us a broad range of
13 kinetic response from the reaction of diesel fuel water. The
14 pressures were selected arbitrarily in order to insure that
15 we maintain the reaction products and the reactants in the
16 liquid phase rather--there would be two liquid phases, or
17 courses, rather than as a liquid plus gas phase which would
18 contemplate the interpretation and sampling of the
19 experiments.

20 In Experiment No. 1, the lower temperature one,
21 there was a roughly equal mixture of 50 grams of water and 50
22 grams of diesel fuel. In the higher temperature experiment,
23 there was a smaller amount of diesel fuel to water ratio
24 which was done so that we could take more aqueous samples

1 because that's the phase we were most interested in.

2 Diesel fuel is a very complex mixture of several
3 hydrocarbon phases as is, I hope, illustrated by this gas
4 chromatograph. You see the amplitude of the signal achieved
5 by the gas chromatogram which is proportional to the
6 concentration of the various components in the system as a
7 function of the time that is alluded from the gas
8 chromatogram. I labeled a few of what are the major peaks in
9 this system and, in further diesel fuel that we used, the
10 normal hydrocarbons between, oh, say, a carbon number of
11 about 10 and a carbon number of about 25 were the predominant
12 phases present in this diesel fuel. There's some variability
13 in diesel fuels. The broad hump in the baseline is
14 characteristic of mixtures of compounds containing a number
15 of various structural isomers of carbon containing compounds.
16 And, the minor peaks comprise a variety of other hydrocarbon
17 species, both aromatic and other alkanes containing various
18 function groups that would be important to the interpretation
19 of our experiments.

20 As I showed you on that slide from Sisken and
21 Katritzky, the kinds of compounds that we care about
22 particularly are those organic compounds containing an oxygen
23 or a sulphur functional group because those are the kinds of
24 bonds that break most easily during experiments involving

1 water and elevated temperature. Now, one thing we know from
2 previous experiments is that these major components of a
3 diesel fuel, the normal alkanes, are not very reactive at the
4 kinds of temperatures we would expect in a repository.

5 That, I think, is illustrated in this Arrhenius
6 plot which shows the cracking rates for normal hexadecane.
7 Now, these cracking rates are determined basically by
8 observing the rate of disappearance of normal hexadecane in a
9 series of experiments performed by a number of investigators
10 ranging from above 600, maybe almost 700 degrees, down to 300
11 degrees. And, one of the results of these sets of
12 experiments are that it's clear that normal alkanes disappear
13 at elevated temperature as a first order rate or their
14 disappearance can be described well by a first order rate
15 law. And, that, I hope, is illustrated in this next slide
16 which shows the match of that first order rate law to the
17 serial destruction of n-hexadecane as a function of time. On
18 the X axis is a logarithm of time; on the vertical axis is
19 the dimension of concentration relative to the starting
20 concentration of hexadecane.

21 And, as I think you'll agree, this first order rate
22 disappearance of hexadecane matches the data fairly well.
23 There's a slight disagreement at the lower temperature end of
24 the scale. If we neglect that difference at the lower

1 temperature end of the scale and extrapolate down to lower
2 temperatures, you can see that the normal hydrocarbon phases
3 are quite resistant to thermal degradation in or without the
4 presence of liquid water. These curves represent the
5 expected disappearance at 300, 250, 200, 150 degrees
6 Centigrade. Now, to give you some sort of a feel for these
7 axis, $\log_{10} t$ of hours isn't necessarily intuitive. The
8 intercept at this axis is about seven years, at this axis
9 about--or at this point, about 2,000 years. Here, we're
10 talking a million years, and out here, we're talking about
11 the age of the earth.

12 So, the bottom line is that you don't expect the
13 major components of diesel fuel to disappear during these
14 experiments. You expect them to vary almost undetectably as
15 a function of time and that's confirmed by the results of our
16 experiment where I've shown here that the normalized
17 concentration of various normal hydrocarbons here for decane,
18 dodecane, and tetradecane as a function of time are invariant
19 as a function of temperature. However, you would expect on
20 the basis of a number of analogies to natural systems and to
21 the results of other experiments that some components in the
22 system would be degraded at these temperatures during the
23 time period of our experiments which is on the order of three
24 months each.

1 Now, this plot, I think, illustrates that some of
2 these reactions are occurring. Here, I've plotted the
3 aqueous concentration of various components as a function of
4 time for the higher temperature experiment. The purple
5 triangles represent the sum of all the hydrocarbons generated
6 with a carbon number less than or equal to 5. They comprise
7 various components, but predominately it's methane and
8 ethane. These, based on other experiments, are what you
9 would expect to see.

10 There are a couple of points, though, that I would
11 like to make on this slide that could be important when
12 considering how these components will perform in a
13 repository. For example, the green squares here represent
14 the generation of hydrogen gas solubilized in the liquid
15 water fraction of the system and there, as you can see, is
16 something on the order of 5 millimole concentration of
17 hydrogen generated during this experiment.

18 You also see substantial amounts of some of other
19 products that represented oxidation of the components; the
20 hydrogen, of course, being the reduced sort of component in
21 the system. The generation also concomitantly of carbon
22 dioxide. Here, I've plotted both the carbon dioxide
23 generated from the lower temperature experiment that's found
24 in the diesel fuel fraction and in the liquid water fraction.

1 The summation of these two solubilities indicates something
2 on the order of 50 parts per million CO₂ in the system.

3 There's an impact on the pH of the system that's
4 derived from these kinds of reactions. Here, I've plotted
5 the pH as a function of time for the higher temperature
6 experiment. There's a clear outlier in the data, but as you
7 can see, although we started with the solution at a neutral
8 pH of 7, a relatively steady pH of around 5 evolves in these
9 systems.

10 There are also a number of hydrocarbon phases that
11 are present in the aqueous phase that might be considered
12 reactive. There are three curves on this and I'd just like
13 to concentrate for the moment on the red one which is the
14 appearance of acidic acid, one of the carboxylic acid
15 species, that you could anticipate might contribute to both
16 corrosion reactions and to the solubilization of radionuclide
17 species. The green curve up here probably represents various
18 benzene--toluene, ethyl benzene, and xylene components--that
19 are not separated well by that high pressure liquid
20 chromatography method.

21 Now, if we're generating product phases in this
22 system, we must be consuming some reactant phases. I've
23 already shown you that the normal alkanes are not considered
24 or not likely to be sources of reactants in this system.

1 There are, however, other things that you can see
2 disappearing during the course of our experiments that are
3 illustrated by this slide where I've plotted the normalized
4 concentration of orthoethyl phenol, one of the oxygen
5 containing compounds that I asserted earlier would be
6 reactive in our system as a function of time, and as you can
7 see, there's a clear decrease in the role of abundance of
8 orthoethyl phenol during the course of our experiments.

9 I think again I'd like to emphasize that this was
10 the first in a series, the first two in a series of
11 experiments and lead us to the following conclusions about
12 the behavior of diesel fuel in contact with water and in the
13 absence of specific catalytic surfaces. These conclusions
14 include that we believe most of the major hydrocarbon phases
15 will be very refractory in our system and we don't expect
16 them to react to any considerable degree without the
17 assistance of catalytic surfaces in the system. We do know
18 that there will be hydrous pyrolysis reactions involving some
19 of the diesel fuel components that we can expect to occur
20 over the time frame and in response to conditions that will
21 be found in the repository. These pyrolysis products could
22 be thought to influence the aqueous chemistry overall and the
23 result of these changing aqueous chemistry processes, such as
24 the lowering of pH or the contribution of complexing ligands

1 like acidic acid or sulfate, another compound I didn't
2 mention earlier, could be thought to be reactive to some
3 extent in the repository system. We also know that the
4 reaction of organic components is often responsible for
5 fluctuations in the redox chemistry of the system either
6 consuming available molecular oxygen or producing molecular
7 hydrogen which is also a very reactive species. In the
8 presence of catalytic materials, organic surfaces, or
9 microbiological activity, we can also presume that the
10 reaction rates for these compounds might be significantly
11 increased.

12 DR. MCKETTA: Kenneth, thank you.

13 And, now, we'll open the session to questions for
14 both Kenneth and Annemarie.

15 DR. CANTLON: In connection with the catalytic surfaces,
16 have you looked at some of the clay minerals which are being
17 explored as catalytic materials now for the petroleum
18 companies?

19 DR. JACKSON: Not in these experiments. I have looked
20 at the catalytic effects--let me say a couple things. We
21 believe that this system is very non-catalytic for the
22 presence--for organic compounds. That's based on other
23 experiments we've done in this same apparatus. Both with
24 pure hydrocarbon phases and with trace organic phases in

1 water. So, this, we believe, is acatalytic. I've looked at,
2 in other systems, the effect of the presence of smectite on
3 the decarboxylation and oxidation rate of aqueous acidic acid
4 and there may be some very slight effect on that system which
5 could be argued might not be representative of the system as
6 a whole. So, I agree that it's an important thing to look
7 at. It's not something we've looked at yet, but we do intend
8 in further experiments to look at the addition of shotcrete
9 sort of materials and the addition of the various components
10 of the tuff that might also catalyze it. Another thing,
11 along these same lines, is that you do expect in some places
12 metal surfaces and metal surfaces are well-known to catalyze
13 the decomposition reactions of organic compounds.

14 DR. CANTLON: And, of course, there are many cases where
15 microbial decomposition of these hydrocarbons is known. So,
16 you're going to have that process.

17 The other question that runs through my mind, while
18 there are many thousands of gallons of diesel fuel that will
19 be consumed in the operation, much of that will be pretty
20 heavily oxidized. So, the total materials coming out is
21 going to be a very much smaller amount. Another kind of
22 material that's going to be used in there are going to be
23 hydraulic fluids and sprays. Mists of broken hydraulic fuel
24 lines are going to be a problem. Now, I know there's an

1 attempt to try to fix the TBMs so that they will keep main
2 spills, but you're going to have hydraulic mist in there.
3 Are you looking at any of those compounds?

4 DR. JACKSON: We haven't looked at them yet. That
5 doesn't mean we don't consider them to be important. This is
6 just the system we chose to start with.

7 DR. MEIKE: That is part of our future plans. That's
8 part of our future plan.

9 DR. CANTLON: Thank you.

10 DR. MCKETTA: Any other questions from members of the
11 Board?

12 (No audible response.)

13 DR. MCKETTA: Staff?

14 (No audible response.)

15 DR. MCKETTA: We'll open it up to the audience. Will
16 you, please, come to the microphone?

17 DR. WALLACE: Yucca Mountain, of course, is an
18 unsaturated site. New Zealand or Wairakei, on the other
19 hand, is a liquid-dominated hydrothermal system. Has any
20 thought been given to or any studies been considered of
21 vapor-dominated hydrothermal systems, such as Logorello
22 (phonetic) that's been producing geothermal energy since the
23 1920s, or at Geysers for at least the same period of time as
24 New Zealand, as far as man-made materials or geochemical

1 modeling or hydrology?

2 DR. MEIKE: Yes. New Zealand was selected after review
3 of sites around the world for a number--based on a number of
4 criteria. We wanted to get an integrated site that would
5 integrate the interests of geochemistry, hydrology, and man-
6 made materials so we could start to test the code in various
7 ways that would actually integrate various parts of the
8 codes. I need to repeat something that's been emphasized
9 over and over again with respect to New Zealand and that is
10 that Wairakei is not Yucca Mountain and it never will be
11 Yucca Mountain. There are various parts of the Wairakei
12 system that are very important to test our code, but we don't
13 consider it an analog of Yucca Mountain. We consider it an
14 analog of some of the processes that we are interested in
15 testing.

16 DR. MCKETTA: Are there any other questions?

17 DR. DI BELLA: Dr. McKetta, you have one staffer slow on
18 the draw here. I've got a question for Annemarie Meike.
19 Design work is going on right now for the ESF, of course, and
20 conceptual design work is going on for the repository and for
21 the waste package also. The kind of work you're doing is
22 very important for them to make decisions even at the stage
23 of the data that you have right now. Tell me how you
24 communicate with those people? What sort of systems and

1 processes do you have set up to do that?

2 DR. MEIKE: There are a number of different ways that we
3 communicate. There are various people that get in touch with
4 me and say what about such and such a material, what about
5 such and such a material. Those are very specific kinds of
6 concerns that go on. And, from that, I get not only a sense
7 of what the specific design concern is at the point, but more
8 general ideas. I'm also watching the usage at the ESF and
9 this also gives me more general concerns so that I can kind
10 of try to second-guess where the direction of future concerns
11 might be and orient our experimental program towards that
12 kind of concern. In the other direction, as we produce
13 studies, we produce reports for the design people and, you
14 know, we hope that these reports are incorporated in their
15 design as they go along.

16 DR. MCKETTA: Any more Carl?

17 (No audible response.)

18 DR. MCKETTA: Any questions from the audience?

19 DR. DUQUETTE: Annemarie, you said you're looking at
20 different formulations of cements and concrete at the present
21 time. Are those advanced formulations or just formulations
22 of older concretes that have been around?

23 DR. MEIKE: There are a number of different things we're
24 looking at. When we can--and there are positive and negative

1 parts of any of these formulations we're looking at. One of
2 the formulations we need to look at is something that's
3 chemically very simple. This allows us to model the system
4 with our present capabilities. Not only that, we have to
5 look at the more complicated systems because, of course,
6 those are reality.

7 Super plastisizers are used, accelerants are used,
8 all sorts of additives are used. These things, we need to
9 keep track of. So, we take advantage of, for example,
10 Vicksburg and their great--the engineers down there have a
11 great library of cements used at various dams all over the
12 place. We're looking at cements in the various tunnels at
13 the NTS. All of these have well-recorded formulations.
14 Then, as we go back in time, we're less and less confident of
15 what the original formulation was, but we have better access
16 at long-term degradation. So, there are a few tradeoffs.
17 But, by combining all of these different kinds of cements, we
18 hope to get a good idea of what's going on over the long-
19 term.

20 DR. DUQUETTE: I would urge you to keep in close touch
21 with your corrosion people. --of concrete have come up and
22 bitten people rather badly by accelerating corrosion of metal
23 that's included in them.

24 DR. MCKETTA: Thank you, David.

1 One more question?

2 DR. CHADHURY: I don't really want to push the point too
3 much, but I've had some experience with geothermal systems
4 before getting involved in the nuclear waste area. I would
5 agree with the questioner from USGS that the Geysers and the
6 Logorello system seem to be better analogs because they're
7 vapor-dominated systems for the conditions at Yucca Mountain
8 compared to the Wairakei system in New Zealand. Another
9 advantage of the Geysers is it's only 100 miles north of
10 Lawrence Livermore rather than going around the world.

11 DR. MEIKE: Okay. Well, thank you for the opportunity
12 to address that in greater detail. One of the reasons we
13 chose Wairakei is that it's one of the three sites in the
14 world and that's including that one 10 miles north of here.
15 It's one of the three sites in the world that has such a long
16 well-documented chemical history associated with it. Another
17 one is in Japan and another one is in Iceland. The Japanese
18 site is very difficult to get access due to proprietary
19 problems. So, it was down to Iceland and Wairakei. Wairakei
20 has a much better representation of various chemical
21 compositions and mixing phenomenon. All of these things we
22 need to do to address our code. It also has some vapor-
23 dominated systems, especially when associated with man-made
24 materials. So, we think it's not the only site we want to

1 look at, but it's a good first start.

2 DR. MCKETTA: Thank you very much.

3 We're back on schedule again and I would like to
4 introduce our next speaker. We're very pleased to have as
5 our next speaker Dr. Penny Amy who really is a special guest.
6 She is a microbiologist and is a professor in the Department
7 of Biology at the University of Nevada, Las Vegas. And, as
8 we are all increasingly learning in the materials field,
9 metabolites from microbes can lead to serious corrosion
10 problems and I'm really looking forward to your talk.

11 Dr. Amy, please, begin when you're ready?

12 DR. AMY: Well, it's interesting to me that the last two
13 talks have basically described a microbial lunchroom and
14 everything that they would love to have.

15 I'd like to thank the Board for inviting me to talk
16 to you today about some of the work we've done in Rainier
17 Mesa in the subsurface microbiology. Rainier Mesa is a
18 structural analog to Yucca Mountain and, although most of our
19 work has been done in Rainier Mesa, we have recently
20 collected some samples from Yucca Mountain and I'll be
21 talking about those in a few minutes.

22 Microbes are known to be involved in many types of
23 corrosive processes including some of the ones that--all of
24 the ones I've listed here and others. Pitting, we've heard

1 about today. Hydrogen embrittlement, tubercle formation--
2 this isn't a form of tuberculosis; this is large masses of
3 metal deposits that form inside of pipes and clog them. And,
4 also, dissolution of structural materials, such as asphalt
5 and concrete.

6 We might ask the question why are microbes involved
7 in these processes, at all? And, there are a lot of reasons,
8 some of which are listed here. They are ubiquitous. It
9 isn't that long ago that the Subsurface Science Program was
10 begun in DOE support to look at microorganisms in the deep
11 subsurface. And, at that time, the basic belief was that
12 viable microorganisms would not be present in many locations
13 in the subsurface. And, we now know that every single site
14 that has been tested and every single depth from which a
15 sample can be taken contains viable culturable
16 microorganisms. So, they are literally everywhere and,
17 believe me, they are in Yucca Mountain.

18 Beijerenck was a famous microbiologist around the
19 turn of the century and made the statement, "Everything is
20 everywhere, nature selects." And, this is a perfect example
21 of this statement. Microorganisms of all kinds are present
22 in the subsurface at Yucca Mountain and Rainier Mesa. And,
23 the conditions that we give them will select for those
24 organisms that will survive and grow. They're very small.

1 They can penetrate pores, they can penetrate rock, they can
2 penetrate filters which are designed to retain them, and
3 many, many organisms can be found--you know, how many angels
4 can dance on the head of a pin or something? Well, microbes,
5 if you can even see a colony on an auger surface, there are
6 at least a million cells there. So, many metabolic types can
7 get together on a surface very easily and establish corrosive
8 process.

9 They are metabolically versatile. During the first
10 three million years of evolution of this earth, microbes were
11 the only things that were around and they basically evolved
12 all the metabolism that we currently have. We, as animals,
13 have stolen their metabolic processes and we use them; and,
14 likewise, for plants. So, microbes can literally do every
15 single metabolic process that there is.

16 They always can withstand fairly extreme
17 environmental conditions, say a pH range of 4 logs for
18 growth. But, some of them actually require extreme
19 conditions. We consider high temperature an extreme
20 condition; however, there's an entire class of microorganisms
21 called thermophiles that only grow at high temperature. And
22 then, I ask the question if microbial processes are
23 destructive to materials, what's the alternative? Well,
24 microorganisms' role on this earth is to be a degradative

1 organism, to degrade materials. They're involved in all the
2 steps of the major bio-, geo-, chemical cycles of elements
3 which means if they didn't do their job, all those elemental
4 cycles would stop. And, we ask microorganisms to degrade
5 materials for us all the time. We rely on that. If you
6 can't think of an example, think about the sewage treatment
7 plant or a sanitary landfill where we put materials in hopes
8 that microbes will degrade them. Unfortunately, in
9 microbially-influenced corrosion, what we do is we put
10 materials in the same kinds of environments and say don't
11 corrode them, don't degrade them. And so, they don't hear
12 us.

13 Some important groups that have been mentioned
14 earlier include the sulfate-reducing bacteria which can
15 produce hydrogen sulfide and consume hydrogen gas. One thing
16 I probably should take a moment to explain to you is there's
17 two basic modes of life and we're most familiar with them in
18 terms of plants and animals. The plants are called
19 autotrophs and they utilize carbon dioxide from the air to
20 build more biomass. All living things have to be made out of
21 carbon. So, they pull their carbon out of the air and they
22 get energy from light. That's what plants do. However,
23 bacteria are capable of doing some unique metabolisms where
24 rather than getting their energy from light, they get their

1 energy from oxidizing inorganic compounds. Then, the other
2 mode of life is the heterotrophs; those organisms which use
3 organic carbon. And, Annemarie put up the peanut butter and
4 jelly example; I usually say Big Mac and fries. But, it's
5 the same thing; it's organic carbon and most bacteria live on
6 organic carbon unless they're autotrophic. So, we have a
7 mixture here of organisms which are autotrophic and
8 heterotrophic.

9 Sulfite-reducing bacteria like to use simple
10 compounds like acetate and hydrogen when they grow under
11 anaerobic conditions and they reduce sulfite to hydrogen
12 sulfide; very unusual organisms, but very highly implicated
13 in microbially-influenced corrosion. Iron oxidizing bacteria
14 do just that. They take ferrous iron and oxidize it to
15 ferric iron causing rust. Polymer producing bacteria are
16 very common. These are just simply microorganisms that grow
17 as heterotrophs, they use organic carbon, and they produce a
18 sticky polysaccharide material that they excrete around their
19 cells. And, when they do that, that allows them to attach to
20 surfaces and grow biofilms and, without it basically,
21 microbially-influenced doesn't take place. Do I want to go
22 that far? I can't think of an instance where it takes place
23 in the absence of a biofilm.

24 Then, there are acid-producing bacteria, both

1 thiobacillus species which produce inorganic acids, sulfuric
2 acid that Dan McCright talked about earlier where they
3 oxidize sulfur to sulfuric acid. And, organic acids can be
4 produced by fermentive heterotrophic bacteria; small acids,
5 such as acetate, formic acid, et cetera.

6 Now, I mentioned how important these biofilms are
7 and I stole this figure from Gil Geesey's report to the
8 Nuclear Regulatory Commission on microbially-influenced
9 corrosion. What we see here is a conditioning film that
10 forms of organic molecules on any natural or introduced
11 surface. The organisms here are still planktonic, but they
12 begin to either settle or they are chemically attracted to
13 this conditioning film and they begin to produce exopolymer
14 material that allows them to stick to surfaces. And, as they
15 grow and produce micro-colonies on the surface, you get
16 differential aeration properties between the surface and the
17 biofilms and you also get chemical gradients that form and
18 this then begins the process of corrosion as electrons flow.

19 As the biofilm further develops, you can see that
20 you get complex consortia of microorganisms together in the
21 biofilm and they can synergistically interact with one
22 another by removing the metabolic products of their next-door
23 neighbor. The reactions are intensified. They can produce
24 nutrients which feed each other. We don't need to worry

1 about the bottom two. But, these biofilms are very important
2 and polymer producing bacteria are very common in all natural
3 environments.

4 Now, I'm going to switch gears a little bit and
5 talk about some of the research that we've done out at
6 Rainier Mesa. In an attempt to look at spatial
7 heterogeneity, the microorganisms in the subsurface, we have
8 sampled throughout the tunnel systems, B, P, G, and N and
9 published a manuscript on special heterogeneity of
10 microorganisms throughout the tunnel systems. We, secondly,
11 did an intense sampling regime in a 21 meter cubed section of
12 rock within N Tunnel and the boxes show where samples were
13 taken; 19 samples within this cube. The distances here are
14 .76 meters. And, we have published a manuscript on the
15 microbiology, spatial heterogeneity of the microbes within
16 this cube, as well as a correlation between the microbiology
17 and geochemical and geological parameters. So, a lot is
18 known about this particular section of rock. All these
19 publications are listed on the back of your packet if you're
20 interested in them.

21 Now, in the tunnel survey, we used Sample N-9 and
22 N-19 to add to our samples from B, P, and G tunnels and we
23 have compared organisms over a large scale. And, for spatial
24 heterogeneity, basically what we can say is the subsurface is

1 so heterogeneous in terms of cultural microorganisms and
2 metabolic types that it's as different a meter and a half
3 apart as it is 10 kilometers apart in Rainier Mesa. So, it's
4 very heterogeneous. We've found both Gram negative and Gram
5 positive bacteria. That probably doesn't mean very much to
6 you, but it does to a microbiologist. Actinomycetes or spore
7 formers and they're common in some of the samples and not
8 present, at all, in others, but we very, very seldom find
9 fungi which are not there due to surface contamination. We
10 enriched for autotrophs that would be capable of oxidizing
11 ammonium ion and sulfur and, although those enrichments were
12 negative, we found many, many, many kinds of heterotrophic
13 bacteria. And, they're related to Pseudomonas and
14 Arthrobacter, common soil organisms.

15 We also have done some work, a research project,
16 and published a paper on starvation-survival of some of these
17 isolates from the subsurface and I don't want to spend a lot
18 of time on this, but what we did is we formulated--like Dr.
19 Park did, we formulated an artificial pore water formulation
20 from the contents or the constituents for Well J-13 and we
21 starved some of our microorganisms from the subsurface in
22 this solution and we found that, although each of the
23 organisms shows its own pattern, in general, they survive
24 extremely well in just pore water without any kind of carbon,

1 nitrogen, sulfur, any kind of source that they would be able
2 to grow on. Sometimes, when we would put the microorganisms
3 in the same pore water solution with crushed rock, we would
4 find enhanced survival. So, there are things like surface
5 effects that we haven't even studied yet that may enhance the
6 survival of these organisms. It's becoming more and more
7 clear within the group of people who study subsurface
8 microbiology that these organisms have probably been in place
9 not only at this site, but in many other places for extremely
10 long periods of time, probably millions of years and they're
11 still viable.

12 Just one point from this graph, this is a figure
13 from the manuscript I just mentioned, and you can see that
14 although this is only tested for 100 days, there's no loss in
15 viability, whatsoever, of these microorganisms in pore water.
16 In this particular one, this organism lost quite a bit of
17 its viability and the point I'd like to make is that when we
18 start--this is a log scale over here. We start with more
19 than 10^8 of the eight cells per mill and we ended up with
20 slightly more than 10^5 viable cells per mill. And, even
21 though three logs of cell viability has been lost, we still
22 have a 10^5 cells per mill inoculum available for when carbon
23 is again available and these organisms can take off very
24 fast.

1 Now, sampling has been an interesting challenge in
2 the subsurface; sampling for microbiology, that is. There
3 have been a lot of drilling programs that have punched holes
4 into the earth and taken samples from very deep, but no one
5 can ever be sure that the microorganisms in them are not
6 contamination being brought from the surface or somewhere
7 along the vertical profile. So, the Subsurface Science
8 Program of the Department of Energy has spent a lot of time
9 to develop a low to no contamination drilling program using
10 filtered air and filtered argon as the drilling fluid. So,
11 some very sophisticated microbiological samples have been
12 taken throughout the country using this kind of system. They
13 provide a very extensive vertical profile about, you know,
14 this big, the size of a core, and three-dimensional spatial
15 studies cannot be done well on that kind of a scale.

16 So, we have taken another approach, the work at
17 UNLV, out at the Nevada Test Site. We have piggybacked onto
18 the mining operations in the tunnels and we go in and either
19 allow them to mine away large sections of rock for us and
20 then go in and hand sample or we simply go into the tunnel
21 systems, clear away all the debris on the surface and
22 carefully and aseptically hand mine into the walls themselves
23 to get samples. And, we think that this sort of mining
24 operation, hand sampling is the way to minimize perturbation

1 of the rock material itself when you're sampling for
2 microbiology and would recommend that for micro-samples in
3 Yucca Mountain which is totally analogous to the tunnel
4 systems in Rainier Mesa.

5 So, why would we want to minimize perturbation?
6 Well, it turns out that when you perturb samples simply by
7 removing rock from the tunnel walls and grinding it, the
8 microbial community totally changes. And, some parameters of
9 change are fairly consistent and they include an increase in
10 the number of culturable bacteria. We can get 10^2 to 10^4
11 greater bacterial counts simply by taking rock and grinding
12 it up and storing it for a little while at 4 degrees. 4
13 degrees C should be restrictive for the majority of the
14 organisms in this rock and yet they outgrow beautifully
15 probably because some of them lice and others grow off the
16 nutrient contents of their liced comrades. Besides outgrowth
17 of microorganisms, what we see as evidence for that is a loss
18 of diversity, just a few organisms are present in large
19 numbers and that's very common. But, as well as losing
20 diversity from a few weed species, we also find that if you
21 look carefully at the organisms that grow only at times zero
22 of sampling throughout a storage of rock experiment or
23 sampled only after a long period of time that all the way
24 along the storage process, new organisms are showing up.

1 And, what we believe to be true is that the storage, the
2 perturbation of grinding, whatever factors we're giving them,
3 maybe even putting them at 4 degrees, a cold shock, is
4 resuscitating some of these microorganisms. And, we probably
5 haven't seen all the diversity that's present yet.

6 Now, the change in these microbial communities
7 probably starts immediately upon sampling the rock, but we
8 can't get back to the lab and work up our samples in less
9 than six hours. And, I think that's just about a record in
10 subsurface microbiology, anyway, but six hours is it. We've
11 been able to document it in 24 hours, the community changes.

12 Now, we've recently taken some samples from Yucca
13 Mountain and Rainier Mesa. And the clay and water samples
14 here in Rainier Mesa were taken from a free-flowing fracture.
15 The rock was taken from several meters down tunnel from this
16 fracture and it's thought not to be influenced by that water.
17 And then, in Yucca Mountain, we sampled opposite walls of
18 the north ramp alcove and we took what we call--you may not
19 call this a QA sample--we call it a QA sample where we simply
20 went into the alcove and chipped the surface rock to
21 determine what the extent of the perturbation of mining, of
22 surface contamination, of diesel fumes and other gaseous
23 nutrients, and drying might have on the microorganisms on the
24 surface compared to those deeper in the rock. And, I'm

1 probably getting short on time. So, I'll just reiterate the
2 things that I mentioned before. If you look in this column,
3 we have the highest culturable counts here, we have the
4 lowest diversity, and this parameter called equitability is
5 the evenness of distribution of the colony types within the
6 community and we lose equitability when samples are
7 perturbed.

8 I'm going to jump down here to the polymer
9 producers. The more moist samples from Rainier Mesa seem to
10 support more polymer producers than we have seen in Yucca
11 Mountain; however, you notice that the perturbed sample
12 contains at least twice the percentage of EPS producers.
13 This has been well-documented that when microbial communities
14 are perturbed, they begin to produce microbes that synthesize
15 this exopolymer material. Oxidizers have been found in low
16 levels throughout this tuff system and sulfate-reducing
17 bacteria, the ones that produce hydrogen sulfide, have been
18 found in the rock at Rainier Mesa and I'll show you a picture
19 of those in a minute. But, these incubations are still in
20 the anaerobic chamber back home. So, we don't know yet if
21 we've successfully sampled the sulfate-reducing bacteria.

22 Here's what the tubes look like when you enrich for
23 some of these special kinds of organisms. This is the
24 sulfate-reducing medium and positive sulfate-reducing

1 bacteria in the tubes that have turned black. The reason why
2 it turns black is because the hydrogen sulfide reacts with
3 iron in the medium to form a black precipitate. Down here,
4 we have the iron oxidizing medium where we enrich for iron
5 oxidizing bacteria and here bacteria have grown in this
6 medium. It's extremely selective. The pH is about 3 to
7 start with and we put in the iron and the organisms turn it
8 into rust.

9 Okay. Organisms that are important in biofilm
10 formation are the exopolymer producers and these are just two
11 examples of what those look like and you can see this gooey,
12 starchy looking material all over those colonies. And, they
13 form this sticky material to be able to attach to surfaces.
14 When we took all the isolates from the YM sample in Yucca
15 Mountain, YC, and the QA sample, every single isolate was
16 tested on a variety of different nutrients to determine
17 whether or not the nutrients could stimulate the production
18 of exopolymer material. And, basically, the conclusion is
19 that 17.5% or so of the YM sample isolates are capable of
20 producing exopolymer given one or more of these nutrient
21 media. And, likewise, 30% of the YC and again lots of
22 polymer producers in the QA sample which has been perturbed.

23 So, what are the implications of what I have
24 presented to you to the Yucca Mountain Project? This was

1 really the hardest part to do. In terms of heterogeneity, we
2 know that there's a wide variety of microorganisms in the
3 subsurface. We know that microbially-influenced corrosion
4 microbes have been demonstrated in the subsurface, both at
5 Yucca Mountain and in Rainier Mesa. I haven't really talked
6 very much about C, but it does not appear as though we can
7 use the unimpacted geology or geochemistry to predict
8 microbial types or microbial numbers, at all. Those
9 correlations just don't happen. And, the natural rock
10 environment supports organisms capable of both survival and
11 growth when limiting nutrients or supplies. So, as soon as
12 you all start putting nutrients into the system, these
13 bacteria will take off.

14 So, survival? Well, we tested some of the
15 organisms in artificial pore water. We know that some
16 factors, such as surfaces, may be important in the survival
17 of these microbes. Typically, long-surviving, documented
18 organisms come from the marine environment which is a
19 continuously oligotrophic environment and the subsurface is
20 just like that. We think these organisms now may be
21 extremely old and even in the vadose samples that have been
22 taken throughout the country, as well as in the P, B, and G
23 tunnel systems and in Yucca Mountain, this low water content
24 rock certainly supports the survival of large communities of

1 microbes and, actually, if you give them very, very small
2 quantities of radioactive materials, they'll metabolize them
3 rapidly. So, their activities, even in the state of
4 concentration of water that they're in, they can be very
5 active if they're given a nutrient source.

6 We suspect in a recent publication in Applied
7 Environmental Microbiology supports the fact that desiccation
8 resistance of EPS may help these organisms in the survival
9 process. The exopolymer material absorbs water and is almost
10 impossible to dry. You almost can't freeze dry it. In fact,
11 people try to freeze dry it and they can't get it dry. So,
12 they have to store it in a freezer because fungi will grow on
13 the surface of it. So, it's an amazing material.

14 I guess my editorial note that even though the
15 radioactivity and the heat may sterilize areas around the
16 canisters for a period of time, those areas will be
17 recolonized when the conditions are met again for microbial
18 growth. It's analogous to a clear cut region of a forest.
19 You can clear cut a region, take out all the vegetation, but
20 the surrounding forest still serves as the new inoculum to
21 revegetate.

22 More implications. Sampling and perturbation. The
23 goal for sampling for microbiology, if analysis is going to
24 be done and I believe it will be, has to be to minimize the

1 impact of exogenous nutrients and microbial contamination.
2 Communities change when they're perturbed and this may have
3 implications for you in your backfilling process. As soon as
4 you take that rock and grind it up and just let it sit, the
5 microorganisms grow very, very rapidly. We don't know if
6 it's a reorganization of oxygen, of water, of nutrients. We
7 don't know what it is and it is under investigation by
8 various people across the country, but it isn't clear. It's
9 very hard to put a microelectrode in somewhere and figure out
10 if oxygen changes.

11 We know that after perturbation, there's more
12 exopolymer producers that are found. It turns out that the
13 organisms that come up after perturbation are more
14 metabolically versatile. They can grow on a larger number of
15 carbon sources and they also have a decreased generation
16 time. So, they grow faster.

17 So, in conclusion about sampling, I truly believe
18 that if you want to have characterization of Yucca Mountain
19 microbiology that the samples need to be obtained with
20 minimal perturbation, returned as fast as possible either to
21 a laboratory on-site or nearby, and I just happen to have
22 one. EPS--

23 DR. MCKETTA: One minute, Dr. Amy.

24 DR. AMY: Okay. EPS and biofilms are going to be very

1 important. There are now reports that show that EPS alone
2 can corrode surfaces. The bacteria don't even have to be
3 there. So, these are important factors when carbon is made
4 available.

5 And, transport, I haven't talked to you about
6 transport, but we've been doing some experiments in my
7 laboratory with intact cores from various depths in Rainier
8 Mesa and bacteria and water can move through fracture and
9 macropore movement.

10 And, I guess one last thing is that microbes don't
11 require like bulk water for growth and activity. They only
12 require a film of water. So, large quantities of water,
13 although it may be important in the chemical-corrosive
14 process, in a biologically-corrosive process, it only needs
15 to be a film. And, I already mentioned the vadose.

16 So, I'll let you read the rest. Future interests
17 that we have and, as you can imagine, no body of work, as
18 I've tried to quickly present to you, can be done without the
19 help of a number of people. These are my students at various
20 stages of their development and the bottom ones are
21 undergraduate students who have helped. And, again, on the
22 back page is a list of publications that we have on Rainier
23 Mesa.

24 DR. MCKETTA: Well, I want to thank all three of the

1 speakers for this last session; very, very interesting. I'd
2 like to open this for discussion and, Dr. Amy, as I told you
3 earlier, Dr. Cantlon is related to you through Wood's Hole
4 and I'm sure he's going to be the first one to ask a
5 question.

6 DR. AMY: Okay.

7 DR. MCKETTA: And, leave Wood's Hole out of it.

8 DR. CANTLON: All right. In your sampling in the
9 tunnels, have you noticed any kind of difference between a
10 drill and blast system as opposed to a TBM? One would think
11 with a drill and blast where you get a nitrogen charge into
12 the fissures that you would have altered the feed stock for
13 the system. Have you been able to sample anything that would
14 confirm that?

15 DR. AMY: We've never attempted to sample, to look at
16 that kind of impact. The studies that we've done on the
17 perturbation and storage were started as an accident, but
18 have turned out to be very important. When we first sampled
19 in tunnel about four years ago, we missed the count, the
20 viable count, on the microbes and so went back a week later
21 into these storage samples and played with them again and
22 found they were 10^4 more viable organisms. So, we initiated
23 this whole study. It would be very interesting to do some
24 experiments now on the subsurface with the goal of trying to

1 understand some of the processes that people have talked
2 about today. Of course, I've done all this for another
3 reason.

4 DR. CANTLON: All right.

5 DR. MCKETTA: It is now 4:20 and we're going to stop the
6 questioning at this time. We're going to take a brief 10
7 minute break and Dr. Cantlon will get at you very much later.
8 We'll take a brief 10 minute break to reorganize our table
9 up here. When we come back, I would like to have all of
10 today's speakers sit around the table for a roundtable
11 discussion. Dr. Dennis Price will moderate the panel.

12 In the meantime during the 10 minutes, will the
13 roundtable participants think about what you've heard today
14 and what you're liable to say. You can have any topic, any
15 topic is fair game. But, I would like to suggest several
16 rhetorical questions. One is on criticality control. Can we
17 analyze all the possible cases? Should we? Should the
18 regulation be changed or clarified? Two, how many years or
19 how many dollars will it take to obtain the data needed to
20 confirm corrosion models with reasonable assurance. And,
21 three, is there a tradeoff of zircaloy cladding as a barrier
22 versus a long-term extended dry thermal loading strategy and
23 so forth.

24 We have 10 minutes to get rearranged.

1 (Whereupon, a brief recess was taken.)

2 ROUNDTABLE DISCUSSION

3 DR. PRICE: Okay. At 4:30, our schedule calls for some
4 comments from the public before we begin the roundtable.

5 You'll note we don't have a round table, at all. It's more
6 in the shape of something else. That means those who are
7 sitting at the table have to be very flexible because this
8 calls for a roundtable.

9 But, before we get to the roundtable, we're going
10 to ask any of the members of the audience if they have any
11 comments about the proceedings of this day that they would
12 like to offer. Please, identify yourselves and your
13 affiliation and indeed your comments may be a stimulus to the
14 roundtable which will follow.

15 DR. INTERRANTE: My question is do you have a list of
16 unknowns, things you feel you would like to work on that you
17 don't have funds for and that sort of thing and some
18 acknowledgement of the unknown unknowns, as well? I'm just
19 wondering, you know, what proviso there might be for that
20 sort of thing and when you figure you might begin to tackle
21 those things? Is this something that comes up in the
22 confirmation period or--you know, when do you handle that
23 sort of thing?

24 DR. PRICE: Who wants to respond to that worm on a hook?

1 DR. STAHL: I'd be delighted to. I'd like to respond by
2 saying that we have a waste package implementation plan which
3 is a very detailed document. It was issued earlier this--
4 excuse me, a year ago, early I think January '93. It
5 describes, as I say, in great detail all of the things that
6 need to be done as we viewed them at that particular time.
7 We're now going through a modification because of the MPC and
8 other events, but we laid out what we thought was a
9 reasonable program. Now, we didn't attempt to provide a
10 schedule for those activities because that's funding-driven.
11 But, we do know what needs to be done and we hope that with
12 an expansion of the program and recognition of more work that
13 needs to be done that those things will be covered.

14 DR. INTERRANTE: Thank you, David. Well, the question I
15 have about your plan then would be in the plan do you spend
16 time thinking about all of the things that--or the large list
17 of things that might go in ways other than the anticipated
18 way, like technical problems that might be buried there that
19 some university professor might dream up if you gave him
20 enough time and money, but you're likely not to ever come out
21 with yourself straight away, you know? Do you see what I'm
22 getting at?

23 DR. STAHL: Sure. Again, I can respond. I think Dan
24 McCright will perhaps pick up on it.

1 We have an approach that uses the ASTM C1174
2 procedure. Basically, you look at service condition testing,
3 accelerated testing. You look at natural analogs and you
4 hope that you find--recognize all of the mechanisms that can
5 occur. Now, there's always some unknown unknowns and that's
6 why you have a performance confirmation program such that you
7 can pick up some of those.

8 DR. INTERRANTE: Thank you.

9 DR. PRICE: Any other comment? Oh, go ahead?

10 DR. CLARKE: Yeah, I'd like to comment to that also.
11 You know, almost everything that is of any significant step
12 or a milestone in the program as outlined in the waste
13 package plan and the waste package implementation plan is to
14 be formally peer reviewed. We did peer review the selection
15 criteria for materials a couple or a few years ago when I
16 first came on this thing. This was an independent group, a
17 chairman from EPRI who selected his own peer review panel
18 members, tried to represent a wide spectrum of the country.
19 A lot of the university types were on that peer review. They
20 obviously are going to be very critical. There is an intent
21 to do that at each significant step along the way. And,
22 also, we are recommended red team type review which are like
23 design reviews, data reviews, or whatever where these people
24 come in and critically review what you're doing and do

1 exactly what you just said; try to identify areas of concern
2 that maybe we have overlooked.

3 DR. PRICE: All right.

4 MR. WILLIAMS: I wanted to begin with a compliment. I
5 enjoyed the presentation this morning of the B&W Fuel Company
6 and the research reported by Kevin McCoy.

7 I wanted to inject into the record a reminder that
8 there is a key caveat that the creep rupture mechanism was
9 identified by PNL and by NRC. And, as we go to longer
10 periods of fuel storage and reliance upon clad integrity,
11 there are other mechanisms that deserve looking at. Now, to
12 some extent this is a commercial. I think EPRI and the
13 utility industry would profit from a joint program of
14 examining some of the high burnup fuel to determine the real
15 characteristics of the cladding. So, I would like to throw
16 both of those items onto the table and thank you.

17 DR. PRICE: All right. Any other comment or question?

18 MR. TIESENHAUSEN: I have a little question for
19 Annamarie. There was a lot of grout used in UZ-14 when they
20 hit water and I wonder if you're familiar with the
21 composition of the grout and if you were involved in the
22 selection?

23 DR. MEIKE: No, I wasn't involved with the selection.

24 MR. TIESENHAUSEN: Are you familiar with the

1 composition?

2 DR. MEIKE: Yes. I'm familiar with the composition of
3 it.

4 DR. PRICE: I think the next question is what is the
5 composition?

6 DR. MEIKE: It's got a lot of super plastisizer in it
7 and that was the interesting thing for us. In order to grout
8 something like that, you need to keep the cement as soft as
9 possible for a long period of time.

10 DR. CLARKE: I guess Bob Williams from EPRI made a
11 statement and we didn't answer it and I wasn't sure you were
12 demanding an answer, but there is one. Those obviously have
13 been in our plans for a long time. You're talking about a
14 fairly high-priced item, as you very well know. Right now,
15 we have essentially run out of specimens or samples at the
16 MCC at PNL and this has been an item that we are going to
17 attempt to resolve, have to resolve, in the near future. One
18 of the aspects of that, obviously, is to try to obtain the
19 high burnup material from around the country. We also have
20 engaged in negotiation, maybe negotiation is a good word, and
21 discussions with ENRISA (phonetic) from Spain who do have
22 some very high burnup material and, if we can successfully
23 get some of the studies that Ray Stout is doing under the
24 AECL program involved in that also, we have the opportunity

1 to share samples which they're very interested in and that
2 would give us some additional insight. And, that material,
3 as I recall, I think is BWR or--whatever it is, it's American
4 fuel. So, it's something that's going to come back to this
5 country anyway.

6 DR. PRICE: Any other comment?

7 (No audible response.)

8 DR. PRICE: All right. If not, before we begin on the
9 roundtable, I'd like to establish a couple of things. One,
10 I'm here on behalf of Ellis Verink who, as you know, his
11 voice--so, I am Charlie McCarthy. If he wants me to say
12 something, he's going to jot it down or do something so I can
13 say it for him and we've agreed to that. Also, I will try to
14 terminate the roundtable by 5:25 p.m. Some people have--if
15 we need to; maybe, we'll terminate it earlier. I don't know.
16 But, some people have planes to catch. So, we won't go
17 beyond the adjournment time that we show here.

18 When you speak, please give your name and keep--we
19 don't want any long speeches; so, less than five minutes
20 time. Although, I don't think that will really become an
21 issue. It's open to anything you want to talk about at this
22 point that you've heard.

23 Now, in order that we might do some housekeeping
24 here, I think, as we broke up, our very distinguished

1 previous moderator was going through some possible questions
2 you might want to consider, but it's open to anything. I'll
3 repeat those because I think we got to milling about before
4 we were ready to mill about.

5 The first was criticality control, a question about
6 that. Can we analyze all possible cases? Should we? Should
7 the regulations be changed or clarified? The second question
8 he mentioned was how many years and how many dollars will it
9 take to obtain the data--I expect someone is really going to
10 answer this--obtain the data needed to confirm corrosion
11 models with reasonable assurance? And then, the last one he
12 asked had to do with zircaloy cladding as a barrier versus
13 long-term extended dry thermal loading strategy. They're
14 just points to have in your mind for discussion. But,
15 really, I suspect some of you have things that are pressing
16 and you would like to discuss with one of your colleagues and
17 we're open and ready to do it.

18 MR. DOERING: Speaking to the criticality issue, one of
19 the questions, I guess, here is would it help if we would
20 change the regulations or clarify them. We are waiting for
21 the isolation phase to be more clarified. That would be a
22 great help to us understanding what is the goal of it. Being
23 an engineer, you'd like to have the requirements set down to
24 you so you can analyze it. With the systems we have in place

1 right now, with the Monte Carlo codes that we have, it's
2 pretty straight forward to analyze it. We are still working
3 on some of the isotopics throughout the time that we need to
4 evaluate. So, with that, we can go forward.

5 The .95, the 5% margin, there has been some talk
6 about dealing with that a little bit differently, but with
7 the conceptual design that we put together for the MPC and
8 the other activities, we can meet that within reasonable
9 cost. And, to really skinny that down to any further to 10
10 CFR 71 and 72 is still underneath review and better costing
11 of the MPCs, especially with the MPCs the vendors will
12 generate for us. And, each vendor's design will be reviewed
13 in accordance to that.

14 Does that essentially answer the question or have I
15 left something out?

16 DR. PRICE: Now, this is open for discussion. You heard
17 what he said. If you want to ask something more and the
18 purpose of the roundtable is to discuss, even to confront.
19 One thing about a roundtable, you're all facing each other.
20 So, all you can do is confront.

21 DR. CANTLON: Let me raise a question. As the decision
22 was made to move into the MPC, have there been any major
23 changes in the engineered barrier priorities and, if so, what
24 are they?

1 DR. STAHL: As you know, we have presented to the Board
2 previously a whole range of design concepts, but when you
3 take a look at them, you can see that they turn out to be
4 modifications of an MPC design. The differences are more in
5 detail than in the concept. For example, we have a multi-
6 barrier package. One has thinner walls, one has thicker
7 walls, for example, shielded versus non-shielded, metallic
8 versus ceramic. So, in essence, the MPC multi-barrier
9 package isn't very different from some of the concepts that
10 we were looking at before. And, also, as Tom mentioned, we
11 have some large packages and some smaller packages.

12 MR. DOERING: The MPC, the larger MPC, when we first
13 embarked on it, we had just got done doing initial evaluation
14 of the larger multi-barrier waste package and so it fell into
15 the sequence very nicely. There are areas that have changed.
16 Now instead of really looking at the materials and doing
17 long-term studies and seeing from sort of engineering out,
18 we're going to take a look at what the vendors do provide us
19 verification of those materials. It will essentially speed
20 the process up, the long-term corrosion, and put more
21 emphasis on that area. That's the thing that will really
22 change from our viewpoint.

23 DR. CANTLON: Well, I'll just expand it a little bit so
24 that you'll see where I'm a little puzzled. As I understand

1 it, in order to move at the schedule for delivering MPCs to
2 get the 1998 date, you're taking a fair amount of risk in a
3 number of dimensions because you don't really know what the
4 repository is going to look like, what the thermal regime is
5 going to look like, and so on. I guess, what I really wanted
6 to know is has that shifted your priorities a little bit from
7 the way you were moving before that set of decisions was made
8 just recently?

9 DR. HALSEY: To expand on Tom's response, many of the
10 issues that come along with the MPC, we were already
11 beginning to address for the large, robust multi-layer waste
12 package, the corrosion allowance materials, the multi-layer,
13 the larger waste packages in the in-drift emplacement which
14 got us into a lot of the thermal issues which come along with
15 the MPC. So, it's a two step process; one of looking at the
16 large waste package in an in-drift emplacement, and now with
17 the MPC decision, there are some new issues and some focusing
18 of issues. Some of the ones which are focused are we've been
19 told what, at least some of the fuel is going to want to
20 arrive in and that's an MPC. And that allows us to focus in
21 on those issues that come along with that kind of package.

22 Some of the new things; now, we're going to get a
23 waste form which comes in a package that was loaded at the
24 reactor. We need to worry about the internal environment,

1 the water that is left, did they get all of the water out at
2 the reactor? If we need a filler in there, is it compatible
3 with pool floor operations? Some of these types of things.
4 And, the ones that Tom was talking about now, the criticality
5 control, if you're indeed going to emplace an MPC into the
6 repository, the criticality control has to be there from the
7 beginning. It's not something that's put in with the waste
8 package overpack.

9 So, it's sort of a split decision. We've got some
10 issues focused down more and we've got some new ones that
11 we're just starting to assess. Does that--

12 DR. CANTLON: Yeah, that's really what I wanted to look
13 at.

14 DR. DI BELLA: Go ahead if you're going to answer the
15 same question because I have a slightly different one.

16 DR. O'CONNELL: To the same question and also to the
17 question of a tradeoff between cladding endurance and an
18 extended dry repository, when the intensified focus on multi-
19 purpose containers and, therefore, on possibly large
20 containers started, one of the immediate factors is the heat
21 transfer. Now, it is possible to meet a nice toasty area
22 heat loading and still keep the individual containers down
23 within a boundary that's within an acceptable envelope, but
24 that may be rather expensive either by going to somewhat

1 smaller containers with perhaps 10 BWR assemblies or to
2 extended heat transfer devices. So, there is some tradeoff
3 which also enters the multi-purpose container design. Now,
4 the first few multi-purpose containers, say the first 10
5 years of production, may not be as much of a concern as the
6 complete repository run because in the first ones, the fuel
7 will eventually be quite old.

8 DR. DI BELLA: I wanted to go back to our first speaker
9 of the day who mentioned that last month the MPC was
10 officially adopted as the reference design. I'd like a
11 clarification as to what that means and where does it leave
12 the SCP? Very specifically, I recall someone who we haven't
13 seen for a while with the initials CG telling the Board very
14 frequently that this SCP was a very sacred thing, that it had
15 been--it was required by law and it had been signed off by
16 the NRC and it couldn't be changed. So, part of my question
17 is, "Was the NRC involved in that decision to adopt the MPC
18 as a reference design?"

19 MR. SMITH: I do not know the answer to the question
20 about the NRC being involved, but as far as the MPC, it has
21 been incorporated into the entire requirements document
22 hierarchy of the program and has been baselined into them.

23 DR. DI BELLA: Where does that leave the old SCP,
24 borehole, thin-wall design? Is it in the picture, at all, as

1 one of the alternatives now or completely out the window? We
2 saw a picture of it at least once today.

3 MR. SMITH: That is an excellent question and we are
4 still working with that issue. That was, in fact, being
5 discussed earlier this week and that is still--David wants to
6 add something.

7 DR. STAHL: We will be doing other baseline changes to
8 bring forward a compatible design; for example, in-drift
9 emplacement rather than borehole emplacement. That's
10 something that we'll enhance or augment, the use of a multi-
11 purpose canister. So, the project is evolving, the design is
12 moving forward, and we'll be making a series of baseline
13 changes moving us away from the SCP design.

14 DR. PRICE: Does this sort of mean that the other
15 alternatives, the dual, the single purpose, the universal as
16 compared to the MPC pretty well are at this point at least
17 not active participants? The decision right now is MPC, is
18 that right?

19 MR. DOERING: What re-baselining the system has done is
20 put the MPC in the front runner position that we are going to
21 evaluate that device first. Essentially, the universal
22 canister and the uncanistered fuel, essentially, coming to
23 the repository will not receive as much emphasis, but it
24 still will be carried at lower level until the MPC has been

1 fully developed.

2 MR. KUBO: Let me make some comments to clarify some
3 things. First, I think the specifications have been changed
4 at the program level. Let me be very clear. What it's
5 saying at the program level in our specification is that we
6 will include an MPC. The implementing instructions that went
7 to the project, both storage and transportation and to the
8 repository, was to implement changes in their documents or
9 their specifications to accommodate the change at the program
10 level. There's a second document that should be signed out
11 shortly by the Director which says the following: "There is a
12 decision to move forward to the design and certification of
13 the MPC, but not the implementation of the MPC until that
14 certification is achieved." So, there is not a decision to
15 deploy at this point. It is a decision to move forward to
16 see if we can achieve an MPC design that the NRC will accept.

17 Now, if, in fact, his instructions will require a
18 change to the SCP, then that will be the project's
19 responsibility to make that change. And, the Director has
20 asked the project to do those sorts of things in his
21 directive. In other words, he is saying look at your
22 program, here's what I'd like us to do. I'd like you now to
23 implement the changes in your portion of the program that are
24 necessary to accomplish this. That's the status of the

1 specifications at this point.

2 DR. DI BELLA: While Art is up there, is he able to
3 answer the question I asked about whether there was any NRC
4 involvement?

5 MR. KUBO: There is NRC involvement not in the decision
6 making process. I believe this is totally an internal DOE
7 process to make the decision. However, there have been a
8 number of interactions with the NRC that go to the licensing
9 issue and the certification issues that go with the MPC. For
10 example, I think the most important one that we have on the
11 front burner is burnup credit or criticality control. I
12 think they've had two meetings, the most recent one about a
13 month ago, in which they're discussing how they can--how
14 best, if possible at all, to incorporate burnup credit in the
15 design of the MPC.

16 Does that answer your question? What I'm trying to
17 say is the design of the MPC implementation into the program
18 is a DOE decision. They have coordinated with NRC to talk
19 about going to this, but I don't believe they asked NRC may
20 we do this.

21 DR. DI BELLA: I'm looking at it from the standpoint of
22 being a major change to the SCP. That's the question I'm
23 asking.

24 MR. KUBO: I believe that they're looking at this at

1 this moment and that they have to respond back. I have heard
2 and I can't confirm it, but I've heard--and I'll respond back
3 to the Board later and give you exactly what it is--that the
4 next report--I believe you have this every six months or
5 every year you have a report going out--that if something has
6 been changed, they normally transmit it through that. But,
7 I'll confirm that and respond back and get that information
8 back to you.

9 MR. DOERING: With the site characterization plan, it
10 was the advanced--not advanced conceptual design. It was the
11 earlier revision of that document, the third advanced
12 conceptual design now--this is the phase we're in right now.
13 It was always defined to re-baseline the system and we're
14 essentially taking the MPC and making it one of the major
15 attributes of the advanced conceptual design report that will
16 be baselined at the end of the advanced conceptual design.
17 So, the SCP stands where it is and essentially there will be
18 a new report issued, I believe, for the advanced conceptual
19 design. I think we're working for that from what I
20 understand from Dean Stucker and Bill Simecka has noted that
21 a new report will be issued not to change the SCP, but the
22 SCP is history now and we move forward. And, it was always
23 planned to do that.

24 DR. PRICE: All right. Any other topic or any other

1 thing someone wants to say?

2 MR. SANDIFER: I do want to make one comment about the
3 baseline change and also what it means. In this instant, as
4 I see it, DOE made a management decision to focus its
5 energies and efforts in a more single direction. It does not
6 imply that any alternatives have been cast aside permanently.
7 What it does mean is if we go further down the road and
8 mistakes are made, you have to backtrack if the risks are
9 reasonable and a decision has been made. So, that, to me as
10 an engineer, is what baseline is all about. We will focus in
11 this direction. Baselines are made to change, if you will.
12 When a need for a change comes along, you change it and
13 refocus in a different direction if that's appropriate.

14 DR. PRICE: Thank you.

15 DR. CANTLON: Yeah, following along the choice to go
16 into the MPC in terms of looking at it for possible
17 licensure, the strategy and the agreements with the utilities
18 is the utilities will queue on oldest fuel first basis, but
19 they aren't obligated to deliver their oldest fuel. If one
20 is trying to moderate the risk, does it make any difference
21 whether you agree to accept their hottest fuel as opposed to
22 the oldest fuel in terms of risk management for the system?

23 DR. STAHL: I can't address the question directly, but
24 let me state that DOE does negotiate with the utilities in

1 regard to acceptance under 10 CFR 961. And, the utilities,
2 at least to my understanding, that have the greatest need are
3 the ones that are or have been in operation the longest and
4 have the oldest fuel. So, those are the components that
5 we'll be presumed in the queue the soonest for the MPC. So,
6 we won't have to deal, I don't believe, with the hot, fresh
7 fuel problem for the MPC in the early stages. Certainly,
8 we're going to have to address that later and it will be
9 addressed.

10 DR. PRICE: But, won't the utility tend to just simply
11 take their fuel from the pool to give to the--

12 DR. STAHL: Well, it's the negotiation process and the
13 DOE can certainly work with the utilities and come to an
14 understanding of what fuel will be put into the MPC for
15 eventual acceptance into the civilian radioactive waste
16 management system. That's a headquarters' function. It's
17 not an MGDS function. The MGDS function is to dispose waste,
18 headquarters' function is to accept it. So, they have to
19 make those arrangements and then we will dispose of the fuel
20 at the appropriate time.

21 DR. PRICE: All right. Any other comment?

22 DR. CLARKE: Well, I've got two things I want to
23 address. One, I want to put to--I don't like the Board to
24 walk away with unsubstantiated or confusion on certain

1 issues. The one is--and, it's a very natural reaction to why
2 our Livermore people are going to New Zealand. Obviously,
3 the first thought that comes to mind is boondoggle. I can
4 only tell you that Russ Dyer and I are very avid fly
5 fishermen and that's one of the greatest fly fishing
6 countries in the world. So, any time you see us get on a
7 plane heading for there, you may be suspect. But, that, in
8 fact, is not the case. The New Zealand geothermal field
9 project was started in the international program and,
10 contrary to what southern Californians think, Calistoga is
11 not foreign soil. It was a choice, as Annemarie indicated,
12 between Japan, New Zealand, and the other site, Iceland.
13 And, it turned out to be the best.

14 The other thing is, in fact, it is cheaper to go to
15 New Zealand than it is to Calistoga. We are for the whole
16 amount of \$50,000--which, by the way, in a year and a half
17 they still haven't received from us because of institutional
18 issues and concerns, but they're sure that they will--got us,
19 I think, a quarter to a half of a scientist. We have 40
20 years of data. We have access to the facility. We can take
21 our experiments down there and bring them back. What we do
22 right now is send two technicians twice a year to New Zealand
23 for a week.

24 So, anyway, I want to just put that to rest. It is

1 not what it is on the surface. It's a very, very good site
2 scientifically. It's one of the best that we can get and
3 it's one of the cheapest that we can get and we're very
4 thrilled to be there.

5 The second thing gets back to one of the things
6 that I know is dear to Ellis' heart and that is the cost of
7 doing business, especially in the materials arena. Those
8 people that were at the waste package workshop two years ago
9 heard the same story repeated at the waste package workshop
10 that we had in September; one by the same person so you would
11 have expected Peter Andreason, but the other was
12 independently by Sam Basham two years ago and then more
13 recently by Dr. Michael Striker. And, that is that it costs
14 roughly \$5 million per year for five years to qualify a
15 single material for a nuclear application in this country.
16 We've heard it again. I'm going to repeat again, two years
17 in a row, we've heard it from four different people or three
18 different people now; \$5 million a year for five years. We
19 are operating at something in the neighborhood of less than a
20 million dollars. What I am saying is that an accurate number
21 to me is probably that, some \$5 million a year for some five
22 years to at least do an adequate job on the whole range of
23 materials, the whole range of applications, the whole range
24 of parameters that one is going to need to do to put us in a

1 position to, at least, feel somewhat comfortable walking into
2 a licensing arena five years from now.

3 DR. PRICE: Okay. Let me just pick up a thought here
4 and see what happens to it. When we open up the arena to
5 man-made materials, that almost could be anything. There's
6 no end to that. Any comment on that thought?

7 DR. CLARKE: Well, I'll give you the start and then Bill
8 looks like he wants to grab it out of my hands.

9 We went through this process at General Electric
10 many years ago in the boiling water reactor business and I'm
11 not that familiar with the PWR people, but I'm sure they did
12 the same thing. And, that's where you eventually, somewhere
13 down the road, formulated what was called a BWR Owner's
14 Handbook. What you do, essentially, is to list what is known
15 about all of the man-made type materials that could go into a
16 nuclear reactor and in this case into a repository, those
17 that are absolute no-nos for whatever reason or at least a
18 definition of what the risks and the hazards are by using
19 these kinds of materials. And, you're absolutely right, it
20 could be a very, very large list. In the repository,
21 perhaps, it won't be as big a one as there was in the nuclear
22 industry, but it is something that can be done with
23 literature surveys in some cases and in filling in the holes
24 by whatever engineering and scientific studies need to be

1 done to essentially fill in those holes on those that are
2 deemed to be the most critical.

3 There's always been a thought--again, I'll get back
4 to the New Zealand thing. This is an area that would be very
5 easy to make a scientific sandbox out of and study for the
6 next 20 years. We're going to attempt not to do that. If
7 you read Annemarie's study plan that is now being circulated
8 for approval, it's very specific in certain areas as to the
9 kind of things that are absolutely essential now, some that
10 can wait, some that are prioritized, or whatever. And, we
11 will do what we can. But, as you very well know, the project
12 is moving and in some cases it's after the fact and it's the
13 kind of thing as what is the best information we can give
14 them at the time. And, we're trying to put ourselves into a
15 position to be able to answer those questions when they're
16 asked and to try to stay ahead of the game which is going to
17 be very difficult at this point in time.

18 DR. HALSEY: The whole area of man-made materials, you
19 have to divide it into several different bins or types of
20 problems. We're starting the ESF construction and some of
21 the near-term questions are "Is there anything that we
22 obviously shouldn't be using down there?" Let's not do
23 something stupid and then find out about it later. And,
24 that's hard to come to grips with on a very short time frame,

1 but part of it is then looking at the alternatives and making
2 a judgment as to which one you think you're better off with.

3 I don't know, Annemarie may want to address some of
4 these. When you discuss grout, they say, well, we don't have
5 to use grout; we could use a polymer epoxy. Well, you go
6 back and think about that for not very long and say use the
7 grout if it's between those two.

8 Those are short-term activities and you're not
9 getting definitive answers. What you're getting is a
10 judgment and you're going to have to live with that judgment
11 in the future. And, all of those don't turn into long
12 research projects. A few of them, you're going to say, "Hey,
13 we need to know more about this and how it interacts with the
14 engineered system and the natural system." And, you go off
15 and you do a research project to find out how bad is it,
16 sometimes after the fact.

17 Then, there's the other category that you are going
18 to have to do some extensive research on. When we go from a
19 borehole emplaced waste package which has a partially lined
20 borehole in the drift floor of the conceptual design so the
21 only thing between the waste form and the rock is one
22 centimeter of stainless steel and one inch of air, you don't
23 worry a whole lot about the transport properties through the
24 man-made materials. You've got one inch of corroded

1 stainless steel when it comes to transport.

2 Contrast that to a MPC sitting in an in-drift
3 emplacement with perhaps 10 inches of concrete underneath it,
4 steel supports for the emplacement drift, several inches of
5 shotcrete, it's inside perhaps one inch of Incoloy and 10
6 inches of carbon steel. Now, you have a great deal of man-
7 made material between your waste form and your rock. The
8 transport through that, through corroded steel or cast iron
9 into concrete and grout, through that material and then on in
10 to the rock, yes, you're going to have to study that. And,
11 you're not going to study it for a little while and say we
12 understand it well enough. That now becomes a major
13 characterization project if you're indeed going to emplace
14 your waste that way. So, you need to separate the man-made
15 materials into different bins.

16 Annemarie?

17 DR. MEIKE: Thanks, Bill and Bill. Because of their
18 comments, I won't have to make mine so extensive.

19 As Bill Halsey mentioned, there are two kinds of
20 issues and we will become more focused on in our activities
21 as we move along. Some issues are design-specific and some
22 are not design-specific. There are a lot of materials that
23 are a part and parcel of every single mining operation right
24 now that we can go ahead on. And we can expect that, unless

1 we restrict the usage of these materials, they will be used
2 in the repository. Now, as Bill Halsey also mentioned, we
3 want to be able to discuss what the substitutable materials
4 are in these cases.

5 Also, as Bill Clarke mentioned, we do want to
6 develop this handbook of materials to use, and not to use,
7 and perhaps materials that will create certain environments.
8 And, to produce that kind of report, we need to look at two
9 kinds of things. One is "What is the significant process
10 over a long period of time or processes over a long period of
11 time that are involved?" And, two, "What are bounding
12 conditions on this various material? What are the maxes and
13 mins that are involved in the chemical processes that we're
14 interested in?" So, those two questions really do focus our
15 research. And, it's not that big of sandbox once you get
16 down to it.

17 Thanks.

18 MR. WALLACE: It seems that my comments might have been
19 misinterpreted. The question I have is "Is a liquid-
20 dominated hydrothermal system a good model for a vapor-
21 dominated--or is a vapor-dominated hydrothermal system a
22 better model for an extended dry repository at Yucca
23 Mountain?" I don't give a damn how cheap it is. If it's not
24 the right model, it's not going to give you full value.

1 That's what I was trying to bring up.

2 DR. CLARKE: Annemarie is going to answer your question.

3 It wasn't you I was referring to.

4 MR. WALLACE: Okay. They have been using, I'm sure,
5 man-made materials both at Geysers and Logorello and, if
6 there's a question of access, I can assure there's a large
7 volume of information and access to sites that are available
8 for your consideration.

9 DR. MEIKE: That's great, that's wonderful, and I think
10 eventually we may take them up on the vapor-dominated systems
11 and try to look at our code in those ways. Right now, the
12 questions that we need to ask are very well answered by
13 specific chemical systems in Wairakei. We need to test the
14 code in the water-dominated systems at this moment in time.
15 The vapor-dominated systems come next.

16 Thanks.

17 DR. PRICE: I didn't expect all this discussion on
18 Wairakei here, whatever--however you say it.

19 Go ahead, Bill?

20 DR. HALSEY: The studies were not initiated to
21 understand the hydrology primarily. Even a vapor-dominated
22 hydrothermal system isn't a real good analog for Yucca
23 Mountain because the heat fluxes are orders of magnitude
24 different. The evolution of the system is much different.

1 The initial purpose for these analog studies was aqueous
2 geochemistry. We do have aqueous geochemistry modeling in
3 the program and looking at aqueous geochemistry at various
4 time evolutions in a geothermal system is a better analog
5 than is a hydrothermal system--than is a hydro--it's better
6 for the geochemistry than it is for the hydrology. So, we're
7 in an aqueous system because we're trying to examine aqueous
8 geochemistry models, not the hydrology.

9 DR. PRICE: Okay. Anybody want to pick up something
10 closer to home like J-13?

11 DR. McCRIGHT: I'd like to pick up something and this is
12 a question directed towards Professor Amy. And, that is that
13 we talked a lot about microbiological attack on irons and
14 steels, but some of the other metals that we're considering,
15 copper and nickel-based and titanium-based materials, from
16 your knowledge, do any of these appear to be--I'll say the
17 word--immune to microbiological attack or like in the example
18 of copper which is very useful for being toxic to at least
19 higher organisms and we see it works very well protecting
20 against--under barnacle attack and so on. Is there any
21 aspiration of looking at some of the other metals as being
22 either very, very highly resistant to microbiological attack
23 or, in fact, immune, as best we understand the word "immune"?

24 DR. AMY: I'm going to pass the buck and say that a

1 report has been prepared for the NRC on microbially-
2 influenced corrosion that addresses the potential corrosion
3 of each of those kinds of materials. And, I can get you a
4 copy.

5 DR. McCRIGHT: Okay. You prepared the report?

6 DR. AMY: I did not prepare it. Gil Geesey at Montana
7 State University, Center for Biofilm Engineering.

8 DR. McCRIGHT: Thank you.

9 DR. DUQUETTE: I was involved with preparing a similar
10 report for the chemical process industry about 10 years ago.
11 And, in that report, we found some definite evidence of
12 microbial attack of copper specifically, even though it's
13 normally toxic. Apparently, the biofilm that comes down
14 effectively blocks the toxicity of the copper. We could find
15 no instances, however, of either nickel-based alloys or
16 titanium being attacked by microbes. Now, titanium has only
17 been around for about 45 years, really, as a commercial
18 material. If we wait long enough, we'll probably find
19 something that eats it, but at the present time, the nickel-
20 based alloys and the titanium alloys seem to be relatively
21 immune to microbial corrosion even with large populations of
22 microbes being attached to them. But, copper, surprisingly,
23 not only suffers from them, but there's at least one recorded
24 instance of some bacteria that apparently produced ammonia

1 and caused stress-corrosion cracking of some brasses.

2 DR. PRICE: Is there any comfort in the fact that they
3 might not presently attack something, but they're so adaptive
4 that--

5 DR. AMY: What it takes for an organism or a cell to
6 become adaptive is to grow and go through many generations.
7 And, that's not what we're seeing. In the subsurface, these
8 things are relatively inactive. So, my best guess would be
9 that, as Beijerenck said, "everything is everywhere, nature
10 selects". And, what you will do is, as you put different
11 things in there and produce different conditions, you will
12 simply select for the organisms that were already there, but
13 which can live in this new environment.

14 DR. PRICE: Okay. We're running short on time. So,
15 those of you who want to use it, please do.

16 DR. CRAGNOLINO: I can offer a comment regarding these
17 precisely. One is an important consideration. I think it's
18 the Energy's requirement. You mentioned very well that they
19 have--that there is not too much--water, but it seems that
20 one of the important considerations is--could be a
21 significant difference in between the condition--corrosion--
22 that release--with respect of materials that are corrosion
23 resistant where you don't have such an ability for
24 --and this is something that has to be really explored as a

1 very important issue.

2 MR. WILLIAMS: You can always get in trouble by trying
3 to be light-hearted, but I'd like to inject the thought in
4 this microbiology-induced corrosion arena. That we need to
5 look at all of these things from the perspective of their
6 effect on nuclide migration. We looked at the seismic
7 tectonic issue from that perspective and decided we weren't
8 quite as worried about earthquakes as we thought. Now,
9 sitting here today just brainstorming and wondering, oh,
10 shit, "Is mic going to sink us, maybe mic is going to help
11 us. Maybe, it's going to enhance the case and maybe we
12 should be looking at whether these microbes are going to glob
13 onto the minor amount of effluent that comes out of this
14 place and sticks it to the rock with these EPS's".

15 DR. AMY: There's actually a fair amount of work being
16 done to look at the absorption of metals onto bacterial
17 surfaces and interaction with metals. Microbes work
18 beautifully with metals because, of course, they're involved
19 in those elemental cycles and they do those biological
20 conversions. But, EPS and cell wall constituents do bind up
21 ions very nicely and it just depends upon which organism,
22 which ion, and you know, the conditions as to whether or not
23 they attach or are transported.

24 DR. MEIKE: Just one further comment on those. Those

1 are also some of the sources of colloids that we need to
2 worry about because if they detach from the surface, they are
3 indeed colloids.

4 DR. JACKSON: I just wanted to address a previous
5 question about nickel-based alloys and their susceptibility
6 to corrosion enhanced by microbiological sort of sources.
7 There's some data that's stemmed from experiments that I've
8 done that are as yet unpublished about looking at microbial
9 degradation of solvents in an experimental apparatus that was
10 composed of nickel 200. And, in those experiments, there was
11 some fairly clear evidence based on potentiometric
12 measurements that the introduction of the microorganisms into
13 the device enhanced the rate of corrosion of nickel 200 in
14 that experiment.

15 DR. PRICE: Well, thank you very much, participants.
16 We've come to the end. I think we did do a scatter of topics
17 as we talked down at the end, all except J-13. I appreciate
18 very much your participation and, Ellis, do you want to try
19 to say anything toward the end here or just say thanks a lot?

20 DR. VERINK: Thank you.

21 DR. PRICE: Thanks a lot.

22 (Whereupon, at 5:30 p.m., the meeting was concluded.)