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2 OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

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10 TRANSCRIPT OF PROCEEDINGS
11 PRESENTATION TO NUCLEAR WASTE TECHNICAL REVIEW
12 BOARD WASTE PACKAGE CONTAINERS

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15 LAWRENCE LIVERMORE NATIONAL LABORATORY
16 SHERATON HOTEL
17 PLEASANTON, CALIFORNIA

18

19 JANUARY 18, 1990

20 JANUARY 19, 1990

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2 NUCLEAR WASTE TECHNICAL REVIEW BOARD MEMBERS

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PRESENT

4 DR. DONALD LANGMUIR
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6 DR. D. WARNER NORTH
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8 DR. ELLIS D. VERNIK
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10 DR. DENNIS L. PRICE
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12 DR. MELVIN W. CARTER
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25 I N D E X O F P R E S E N T E R S 3

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5 Introduction by DR. DENNIS L. PRICE: 4

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

2 DR. PRICE: Welcome to the first meeting of
3 the Containers and Transportation Panel with Lawrence
4 Livermore National Laboratory. This is the first
5 panel meeting principally focused on the selection of
container
6 materials. Dr. Jardine will make comment on this
7 separately.

8 The meeting is being attended by panel members
Dr.
9 Carter, Dr. North and Dr. Vernik. Dr. North is yet
to
10 come. Also we expect Dr. Don Langmuir, a Board
member, to
11 be present a little later.

12 Our technical support is provided by Dr. Chu
and
13 Mr. McFarland. These are senior staff members of the
14 Board.

15 I would like to take this opportunity to ask
panel
16 members if on an occasion they wish to have an action
17 item, that they specify it as an action item very
clearly
18 and state their request very, very clearly and
19 specifically.

20 In addition, I would like to acknowledge the
21 presence of Mr. Voiland, a consultant to the Advisory

22 Committee on Nuclear Waste; Mr. Carl Johnson and his
23 associates from the State of Nevada; DOE
representatives,
24 including in part Mr. Stein, Dr. Isaacs; Messieurs
Delaney
25 and Hale from headquarters, as is Gertz and
Clonginger

and 1 from the Yucca Mountain projects office. (Mr. Gertz

2 Mr. Delaney were absent.)

Jardine. 3 Among the numerous attendees from Lawrence
4 Livermore Laboratory are Drs. Rams Spot and Les

and 5 The NRC staff are represented by Bunning and Ballard

for 6 other attendees, including personnel from the Center

7 Nuclear Waste Regulatory Analysis.

of 8 For the audience, the panel is in the
9 information-gathering stage of our effort. Because

10 this, presenters at this meeting may be questioned by
11 panel members and the NWTRB staff members also.

attendees, 12 If anyone has not yet signed the list of

at the 13 please do so at the break. That list should be out

14 table and you've had an opportunity to sign.

15 Transcripts will be made of the open meetings.

16 Mrs. Enerson of the Board staff can assist interested
17 parties in obtaining copies of the transcripts.

facilities 18 There will be a tour of the Laboratory

19 this afternoon. There will be closed meetings of the
20 panel Board members and staff at the end of the day.

21 At this time, I will turn the chairing of this
22 session over to Dr. Ellis Vernik.

23 DR. VERNIK: Thank you very much, Dr.
Price. It

24 is a pleasure to be here with you and thank you for
25 attending.

1 This is the first in a series of meetings on
the
2 engineer barrier system. We are developing plans to
3 receive separate briefings on host rock and waste
form
4 interactions. These meetings may well be held with
other
5 panels such as those concerned with structural
geology and
6 geoengineering, hydrology and geochemistry and the
Risk
7 Performance Analysis Panel.

8 A set of generalized questions has been
prepared
9 and circulated to DOE that outlined suggested lines
of
10 inquiry that the panel wishes to follow in these
meetings.
11 These questions are items that the panel and
eventually
12 the Board will address. These questions consider the
13 impact of possible modification of the current plans
for
14 emplacements.

15 Specifically, they ask, one, if shifting
additional
16 responsibility of the waste package from the host
rock for
17 the containment of isolation of wastes is an
advantageous
18 alternative.

19 And two, if in placing the waste under
conditions

the 20 that avoid the near-field temperature rising above

21 boiling point of water has a beneficial effect on

22 container life.

by 23 These questions are to be addressed separately

24 other panels from their respective viewpoints. It is

Board 25 hoped that within one to one and a half years, the

1 will be able to provide viable answers to these
questions.

2 With respect to the recently-announced
scheduled

3 changes in the development of the repository, we look
upon

4 them as offering the program an opportunity to
broaden and

5 deepen its database supporting the engineering
barrier

6 design. To do this, it may be desirable to expand
the

7 current program to consider both alternative
materials and

8 alternative designs for the waste package.

9 I wonder if any of the other members of the
panel

10 would have a comment that they would like to make in
a

11 preliminary way.

12 DR. CARTER: No.

13 DR. VERNIK: If not, I would like to turn
this

14 meeting over to you, Dr. Isaacs.

15 DR. ISAACS: Thank you very much. Good
morning.

16 On behalf of the Department of Energy, it is a
17 pleasure to be here to see you all again. It is a
very

18 important meeting.

19 I'm somewhat taken back by the popularity of
the

20 high level Waste Package Program. It is quite

being in 21 interesting. I'm sure it has nothing to do with
22 Pleasanton in January. I do understand that you are
panel 23 considering Camden, New Jersey in July for your next
24 meeting and we'll see if we get the same attendance.
year 25 On a more serious note, it has been about a

1 since the Board came into existence, so I think it is
2 worth reflecting just a couple of minutes, even
though
3 this is a panel meeting, that I believe the general
view
4 of the department, and certainly my personal view, is
that
5 the Board and the various panels have done a great
deal in
6 accomplishing a really remarkable amount in getting
7 organized and getting on with the actual work in this
8 first year.

9 I think we are quite comfortable with the fact
that
10 the Board has invested itself across the entire
program
11 and has had wide-ranging discussions and gotten
involved
12 in many of the key issues early on and I think that
it
13 shows already. I've said this from the very
beginning, as
14 soon as I started interacting with the Board, that it
is
15 quite clear that there is going to be a significant
16 benefit to the program, not only technically, but to
the
17 overall structure and credibility over the long term
to
18 the program by having you look at our program and its
key
19 issues.

20 I think it is fair to say that we are looking

21 forward to the Board's first report. We obviously
have
22 dealt with all the panels in a fairly open way and
have a
23 fairly good sense of what some of the key issues are
and
24 some of the key concerns. Nonetheless, that report
will
25 be taken to heart and certainly provide us with a
great,

1 great opportunity to sharpen some of our program
issues

2 that need to be addressed.

3 Today's discussion and tomorrow's, as you
4 mentioned, are focused for the Board on the Waste
Package

5 Program particularly the environment and the
Containers
6 Program.

7 We plan on talking about the waste package
8 environment, candidate materials that are under
9 consideration for use in the containers, the strategy
that

10 is being used currently to select the reference
container
11 material, the corrosion properties of the potential
12 candidate materials, and alternative materials and
13 concepts.

14 But I think it is also fair to say that nobody
15 believes, I think, that we have a corner on all the
16 information or knowledge that is necessary to be
17 successful in this program. It is a very demanding
issue.

18 I take to heart the comment that he just made as to
the
19 change in the program schedule and the opportunity to
20 broaden and deepen this program.

21 I think it is fair to say that there are a
number
22 of key issues about waste package performance and
overall

23 repository performance that need very serious looks.

24 Issues, for example, about the viability and

25 demonstration compliance and regulations as they
currently

targeting 1 exist, such as whether or not there is value in
very 2 the number of waste packages and a number of other
3 important issues.

one 4 I think the idea of expanding the program is
have 5 that we hope we will have a better sense of after we
have to 6 a chance to talk. Obviously, we in the department
year 7 realize and you have to realize, too, that an era of
will be 8 restricted budgets that the department is facing this
help 9 and next that priorities become important, and it
are in 10 valuable not only for the panel but for the Board to
hurt 11 shape both where they think some of the priorities
the 12 terms of resource applications and it also wouldn't
apply to 13 for you to take enough of a look at whether you think
words, 14 program scope, and therefore, the resources that
that we 15 this program are of the right magnitude. In other
16 whether we can get the job done with the resources
17 do have and to realize the budget realities in that
18 regard.

19 The agenda that we set up in this meeting was

got 20 developed directly in response to a letter that we
I'm 21 from Executive Director Coons on September 13, and
on 22 very hopeful that this process of early consultation
what we 23 setting the agenda early so we can concentrate on
want to 24 are interested in, I think, that is helpful and I
that 25 continue to encourage it and I have every expectation

1 your agenda here will meet your needs as well.

2 As the Board has asked, and I think is
appropriate,

3 the presentations will be made largely by the
specialists

4 who are actually doing this work. And in this case,
it is

5 predominantly people from the Lawrence Livermore Lab.

6 And without further ado, unless you have any
7 questions or comments that you would like to address
to

8 me, I plan on turning the meeting over at this point
to

9 Jack Hale who is the chief of Surface Facilities and
Waste

10 Package Branch from headquarters and who will make
some

11 further introductions.

12 DR. PRICE: Dr. Isaacs, I would mention that
Dr.

13 North and Dr. Langmuir, who we mentioned earlier, are
now

14 at the table.

15 DR. ISAACS: Thank have you much.

16 MR. HALE: At this time I would like to take
the

17 time to acknowledge several individuals who do play a
key

18 part in the Waste Package Program. I believe Ralph
Stein

19 has already been mentioned but Ralph is not with us
today.

20 He is the associate director of Systems Intergration

and

21 Regulations headquarter's office.

division

22 And we also have Leo Little who is the

Yucca

23 director for Engineering Development Division at the

Leo

24 Mountain Project. The Waste Package Program is under

25 Little.

1 We also have Max Blanchard with us today who
is the
2 division director at the Yucca Mountain Project
Office for
3 Regulatory Citing and Evaluation Division, and I
believe
4 Max is here. Yes, Max is here.

5 I have also with me Allen Bersch who works for
me
6 and he is the program manager for the Waste Package
7 Program.

8 I just would also like to express my
appreciation
9 to the Board for the opportunity to work with Dr.
Jack
10 Parry. I understand he is ill today, but I did have
a
11 number of interactions with Jack in developing an
agenda
12 which we hope will satisfy your needs, and I'm sorry
that
13 he wasn't able to be here today to realize the
benefits of
14 his work.

15 At this time I would like to introduce Michael
16 Cloninger at my right who is the chief of the Field
17 Engineering Branch at the Yucca Mountain Project. He
18 works for Leo Little and is directly responsible for
the
19 Waste Package Program. Michael Cloninger.

20 MR. CLONINGER: Thank you, Jack. I think
you'll

Barrier 21 find the Waste Package Program and the Engineer
technical 22 System Program to be one of the more interesting
23 challenges probably in the entire human history.
rests at 24 Technical responsibility for that program
direction 25 this point with Lawrence Livermore Lab under the

1 of Dr. Les Jardine.

2 Without further delay, I would like to turn it
over
3 to Les Jardine. Les.

4 MR. JARDINE: Good morning. I'll break the
rule
5 by standing up.

6 Mr. Chairman, members of the Board and members
of
7 the Container and Transportation Panel, I'm Dr.
Leslie Jay

8 Jardine and on behalf of Lawrence Livermore
Laboratory and

9 the Yucca Mountain Project staff, I want to thank you
for

10 the opportunity to discuss various aspects of the
11 technical and scientific programs being conducted by
12 Livermore as part of the Department of Energy high
level
13 waste program.

14 I've appeared before you today as the leader
of the

15 Lawrence Livermore National Laboratory Yucca Mountain
16 Project and I'm accompanied by members of the
Lawrence

17 Livermore Laboratory lawyers technical staff, ten of
whom

18 will be making technical presentations to you over
the

19 next two days that are in response to that September
13th

20 letter that was sent to the Department of Energy.

21 Today, day one, the staff will discuss their
22 technical activities involved in characterizing
near-field
23 environment in which the waste package is emplaced.
24 Tomorrow, on day two, the staff will discuss various
25 aspects of the container material studies that
Livermore

1 is involved in.

kind 2 By way of background, and before beginning a
set 3 of an introductory technical introduction, for me to
that 4 the stage, I want to take the time to say a minute
Department of 5 Lawrence Livermore National Laboratory is a
created in 6 Energy National Laboratory. It was originally
7 June of 1952 by Ernest Lawrence and the Atomic Energy
8 Commission.

University 9 The Laboratory today is operated by the
10 of California for the Department of Energy. It
occupies 11 approximately one square mile and is about 12 miles
due 12 east to your back side of this hotel.

13 The Laboratory currently employs a
multidiscipline 14 staff of 8,000 career employees and about 2,000
additional 15 multidiscipline contract people who are used to
supplement 16 this career lab work staff. The annual laboratory
budget 17 is about one billion dollars.

18 Lawrence Livermore National Laboratory is a
large 19 multiprogram Laboratory with major programs, which
include

20 nuclear weapons, design and testing, beam research,
laser

21 and magnetic fusion, energy, biomedical, and
environmental

22 research programs, among others.

23 In fiscal 1990, the Lawrence Livermore Yucca

24 Mountain Project, which is the project that the
speakers

25 are involved in, employ the equivalent to 70
full-time

'90 1 staff members in terms of our budget for the fiscal
2 year. In addition, we have about 40 to 50 additional
3 subcontract personnel at laboratories, other national
4 laboratories and universities.

5 The Yucca Mountain Project at Livermore
reports to 6 to Mr. Carl Gertz at DOE, YMPO, the project office.

7 I'm the technical project officer for Lawrence
Yucca 8 Livermore which is the major participant in the DOE
9 Mountain office. And I, as the TPO, am responsible
to the 10 Yucca Mountain Project for carrying out the assigned
work 11 scope according to the DOE guidance.

12 That Livermore work scope includes -- and I'll
get 13 a little more into that -- the characterization of
the 14 near-field waste package emplacement environment, and
this 15 includes the testing and modeling of the hydrology
and 16 reactive radionuclide transport and the altered
of 17 geochemistry due to these temperatures, perturbations
to 18 the emplaced waste, the rock fluid interactions due
tests 19 thermal and radiation effects, and the related field
the 20 that are appropriate to develop this information on

21 characterization of the near-field environment.

both 22 We also are involved in materials testing of

23 the potential waste container materials and the waste

geochemical 24 forms. We also have work scope that involves

25 modeling, performance assessments of the engineered

forms. 1 barrier system and the waste package and the waste

performed 2 There is also some engineering studies that are

at 3 as part of the whole waste package engineered program

4 Lawrence Livermore.

let me 5 So why don't you put up the first slide and

is 6 sort of say what I would like to do is I've made some
7 introductory-type remarks and what I would like to do

we 8 give you a flavor for the organizational summary that

picture 9 have at Livermore and move in to give you a real

10 about the waste package, as to how it relates to the
11 repositories, as it refers in any given version to
12 repositories. So the next slide, please.

the 13 Regarding the organizational aspects, this is

Gertz. 14 Yucca Mountain Project program office. As I said, at
15 Lawrence Livermore down here, it reports to Carl

have 16 There are three other laboratories and U.S.G.S. that

me go 17 scientific responsibilities for the program. So let

18 to the next slide.

has 19 The organization and use at Lawrence Livermore

box 20 this kind of structure where you can view this bottom

I, 21 across here as the technical and scientific program.
to me 22 as the Yucca Mountain Project leader, have reporting
is 23 resource, planning and control. What this represents
24 the planning and project control activities of our
planning, 25 project. So this is where we do our long-range

that 1 our networking and also our accounting of the costs
2 are incurred in doing the work.

side 3 On this side we have a project administration
4 which are records and documentation control. A very
and 5 important part of a project operation is controlling
technical 6 documenting and capturing all the scientific and
7 work.

Assurance 8 I don't want to leave out the Quality
9 Program either, which is the most important and at
the 10 highest and I want to make a few comments about that.

of 11 We at Lawrence Livermore were audited in June
the 12 last year and received several months later through
approval 13 review and approval process -- and it is not an
Lawrence 14 but an acceptance by the NRC and the DOE of the
15 Livermore QA program as fully qualified to do work.

quite 16 That was in June of last year, and we are
a 17 proud of that accomplishment and that is why we have
18 very strong project administration activity that
19 supplements that and will keep us on track.

20 In terms of the technical programs, there are

21 basically six technical areas represented by those
boxes.

22 Today the agenda will not talk about our activities
and

23 waste form modeling and testing and geochemical
modeling,

24 performance assessment or systems engineering and

25 engineering studies.

1 Those will be touched on but the agenda really
2 revolves around the near field environment modeling
and
3 testing which is today's topic and Dale Wilder, who
I'll
4 introduce later, will lead that discussion.

5 The topics that this technical group is
involved in
6 includes hydrology, geochemistry, mechanical
attributes,
7 G-tunnel tests and radiation interactions. These are
the
8 five bulletin topics that you'll be hearing about
later
9 this morning.

10 A second major technical area, which
represents
11 tomorrow's discussion, is container materials,
modeling
12 and testing technical area where Will Clarke is the
13 technical leader. Tomorrow's agenda will touch on
the
14 topics that were involved in material selection,
material
15 performance, corrosion properties and alternative
16 materials studies done to date.

17 Now, to set the background for the subsequent
18 speakers today and tomorrow, I want to put this up
and not
19 spend a lot of time on it but basically this is the
Yucca
20 Mountain site, the surface materials out here and the

21 access to the underground by ramp. The waste
packages

22 that we are going to be focusing our discussions on
are

23 the underground repository horizon in this area.

24 So let me have the next slide and make some

25 comments to put a little perspective in the back of
our

1 minds about some of the things that go on in this
2 repository, the annual throughput involved 3,000 tons
of
3 fuel each year, 400 MTU of the vitrified high level
waste
4 plant. And this is basically a 70,000 storage ton
5 capacity with mixtures of spent fuel and high level
waste.

6 These are the products, if you like, that we
have
7 to put into the underground repository horizon.
Depending
8 on the specific packaging configuration, this
translates
9 to over the life of the repository, somewhere between
25
10 to 30,000 spent fuel containers, or containers filled
up
11 with the spent fuel, and about an additional 14,000
12 containers of the vitrified high level waste that
13 corresponds to this level of capacity. That is the
14 quantity, if you like, of containers. Let's go onto
the
15 next slide.

16 Now, moving into this in a little more detail,
as
17 far as the repository horizon, the waste would come
down
18 from the ramp of the underground and find its way
through
19 tunnels and drifts to the emplacement drifts. And
then

up
20 the emplacement drifts -- and I'm going to blow this
21 and I'm not going to spend a lot of time -- but these
22 lines, these drawings, represent the emplacement
drifts.
23 Then we go to the next slide, and we are
moving
24 into the waste packages and the containers of the
waste
25 that we want to be emplaced.

1 Now blowing up one of these emplacement panels
2 where the drift is spaced not only 126 feet apart, if
you
3 look at a cross section through the emplacement
drift,
4 what you begin seeing is in the reference, SCP-CDR
design,
5 that the waste waters are alternating between the
spent
6 fuel container which is a little longer than the
defense
7 high level waste glass container and spent fuel
8 alternators.

9 Nominally, they are ten feet below the base of
the
10 drift and emplacement. The width of the drift is 16
feet,
11 and the standoff distance, you don't fill the spent
fuel
12 containers and the commingled configurations all the
way
13 out. Indeed, you stop somewhere, like, 85 feet short
of
14 an intersection of one of these drifts.

15 So the topics that we are talking about are
these
16 particular waste containers which are in boreholes in
the
17 emplacement drifts. Then go to the next slide.

18 Now, looking at a little more detail of what
those
19 waste containers look like, there are two types, as I

15.6 20 mentioned. Those containing spent fuel are nominally
the 21 feet tall and 26 to 28 inch diameter, depending on
how 22 configuration of the internals which is a function of
23 much is consolidated or whether it is intact.
centimeter 24 The wall thicknesses range between one
under 25 to three centimeters depending on the alloyd that is

1 consideration. The defense waste glass containers
are
2 slightly shorter at ten and three-quarters feet, and
that
3 is the outside.

4 And what is inside of the actual container for
the
5 defense high level waste glass is the pour canister
that
6 would come from the defense program, such as Savannah
7 River or two types of packages that we are going to
8 Hanford. So it is in a container that is normally
9 ten-feet high, 24-inch diameter and contains the
vitrified
10 high level waste glass.

11 So in most programs, the two types of packages
that
12 we are going to be emplacing and talking about in the
next
13 few days involve a container which contains spent
fuel
14 within its internal or a second type, slightly
shorter but
15 not the same diameter nominally, but which would
contain
16 the defense vitrified high level waste glass.

17 So if we can go to the next slide and blow
this up
18 one last time. One, in terms of whether a container,
be
19 it spent fuel or high level waste glass emplaced in a
20 borehole, what is it that we are looking at? And

this is

21 our reference configuration which is a vertical
22 configuration. And if this represents the drift
floor in

23 this cartoon form, nominally ten feet below the floor
is

24 where the drifting pintle would be on those
containers in

25 all of the configurations.

1 The borehole consists nominally of a hole, a
2 borehole into the rock. The reference concept uses a
3 liner which is a partial liner which comes down below
the
4 pintle. The idea and the concept is that it comes
down
5 far enough to get there to prevent other rock falling
or
6 other materials to come down to impede the ability
for a
7 retrieval of that container to come back with the
8 replacement machine and remove this container. So
the
9 current concept in the SCP-CDR is a partial liner.

10 Looking at other aspects of this, there is a
air
11 gap or space, if you like, between the container and
the
12 bore hole wall. And since the liner stops up there,
there
13 is a space between the container wall and the rock.

14 Now, the near-field environment encompasses
for
15 about nominally meters, 10 to 20 meters or so. It is
16 somewhat hard to define specifically the dimensions
of how
17 far the near-field environment is, but my perspective
is
18 where there are temperature gradients above the
ambient
19 perturbations due to the emplaced waste.

20 If you could go back to the earlier commingle

of

21 spacing, you realize that the spent fuel spacings are
22 about 15-foot centers and there is spent high level
waste
23 glass between them. So at least there is a raise in
the
24 near-field environment overlaps between different
wastes
25 and fuel containers and the emplaced waste glass.

1 Now, I think that is kind of what I wanted to
2 present here was a little bit of a overview to give
you a
3 picture of the underground repository configurations.
The
4 other speakers are not going to be doing this in
detail.
5 They are going to be focusing on the waste container
6 and/or the near-field environment.
7 As I said, today will be over the near-field
8 environment issue. The way that I've selected to run
the
9 program is to be fully responsive to your request and
to
10 get the real individuals doing the work up here
presenting
11 that. And the way I'm going to get there is to let
Dale
12 Wilder, who is the technical area leader for the
13 near-field environment testing and modeling technical
14 area, lead the discussion and be sort of the
moderator of
15 the technical work and the discussions today.
16 Tomorrow, we'll do it with Will Clarke who
will
17 lead the discussions of his people who are working
for
18 them directly and with actual scientists and
engineers,
19 but mostly scientists who are doing the technical
work.
20 That way, you'll be getting what I hope you want,

such as

21 people who are doing the work instead of figurehead
types

22 like myself or the managers.

23 So with this, I would like to introduce Dale
Wilder

24 who will lead the discussion for the rest of the day
in

25 terms of more agenda on the near-field environment.

1 DR. PRICE: I would like to make a procedure
2 point just to be clear about the way the Board might
3 interact with the presenters because I didn't make
such a
4 statement in my opening and perhaps I should.

5 I think if one of the Board members or panel
6 members has a question that they want to ask, they
7 probably will interrupt the speaker, not for the
purpose
8 of making it difficult for the speaker to proceed,
but
9 rather because it is on the mind at the time and it
is
10 just a little easier to work that way and it makes it
a
11 little more informal and we hope you understand this
kind
12 of procedure.

13 DR. CARTER: Let me ask you a couple of
questions
14 about things that I certainly as a Board member would
like
15 to hear addressed during the next two days. I'm not
16 necessarily looking for a specific answer at this
time.

17 One of those I'm very much interested now is
18 measurements, laboratory experiments and field tests.
In
19 other words, actual hands-on research or testing
versus
20 literature, computer simulations and so forth. And I
21 wonder if the speakers, if there is any question

about it,

22 would make it abundantly clear which of these
particular

23 areas, if I can divide them up that way, are being

24 **discussed. This is one of the things.

25 The other I'd like to ask is whether similar
or

1 parallel efforts are underway as far as this kind of
2 program mainly dealing with containers now, their
3 interaction with the media at Yucca Mountain, and I'm
4 particularly interested in if this is the case the
5 technical scientific interfaces between the Livermore
6 program and these other national efforts that may be
going
7 on.

8 Also the same would apply not only to such
national
9 efforts, but also those of an international nature.
10 Again, I'm interested in the working relationships of
the
11 scientific and technical level.

12 The third area I would like to hear addressed,
you
13 mentioned the facts that you'd received or Livermore
had
14 received approval, if you will, for their QA program.

I'm
15 quite interested on the realty nature of this, how
much of
16 the program effort again from the scientific
technical
17 standpoint goes into QA efforts.

18 I think this thing almost has a life of its
own or
19 a driver of its own and I'm sort of interested on a
20 national basis of finding out how much effort is
really
21 going into quality assurance. Is this 10 percent or

20

22 percent? I dare say in many cases it might be

23 considerably more than that.

24 So I would be interested in the perspective
now of

25 individuals doing the work as far as the QA
contributions

1 of either the helpfulness they are getting in that
area or
2 if it is an onerous responsibility, I would be
interested
3 in that as well.

4 So those are three things, and I hope that
I've
5 made them clear, that I would like to have addressed
6 during our next two days of meetings.

7 DR. JARDINE: Should I respond to any of
those?

8 DR. PRICE: Sure.

9 DR. CARTER: Be our guest.

10 dr. JARDINE: Well, we will be in varying
degrees

11 because in terms of whether something is a laboratory
or

12 field experiment versus theory, I think the
experimenters

13 will or the presenters will need to make that clear
and we

14 can do that.

15 But in terms of what is coming up on your
agenda,

16 on one extreme is Abe Ramirez with a total field

17 experiment in Nevada. And then some of the other

18 speakers, like Dr. Glassley, are a mixture of
Laboratory

19 experiments and some theory and we have some pure
theory

20 in the Nitao-Buscheck but I'll ask them when they
start

21 off to make it clear what it is, how much so you can
get

22 that, so the Board panel members can get that.

23 I think as we go through the program we'll
have to

24 address where the overlap occurs, if there is any.

25 Basically Lawrence Livermore Laboratory is
responsible for

1 the all of the near-field environment. And others
may
2 take exception to the statement that basically the
involved,
3 Livermore scope of work and responsibilities
ambient
4 where there is temperature deprevations above the
strong
5 field testing site. So in some sense, we have a
6 relationship of defining the near field to far field
and
7 interface and Los Alamos sits out in the far field
8 Sandia co-exists.

9 MR. CARTER: I presume that might be a fuzzy
line
10 in some cases.

11 MR. JARDINE: Yes, I think it is, because
how you
12 define this depends on the radionuclide driving
forces,
13 the temperature gradients, pressure gradients. There
is
14 overlap and more work has to be done in defining
and
15 interfaces to make sure that the pieces fit together
16 that all of them are being addressed.

17 On QA, that is something that is still being
-- I
18 guess I'm trying to extract what is the impact on the
19 scientific staff -- but I'm relatively new to
Livermore,
20 joining them last April, and I came in new to that

21 organization. They stopped in December and the staff
22 stopped the technical work and began the
implementation of
23 a QA program with help of supplemental labor and
outside
24 labor people experienced in nuclear quality assurance
25 programs.

28
1 What I found was an amazing workable system of
2 procedures and processes that were rather
straightforward
3 in the sense of allowing, you know, project control
type
4 things to be done. They got there by using the
outside
5 experienced nuclear people and the scientific people
6 working together with the scientific people writing
the
7 procedures but interacting very closely with the
8 experienced engineered types that knew the procedure
was
9 in the 6 to 10 page range as opposed to an order of
10 magnitude higher.

11 So the program at Livermore is implementable
in the
12 sense it doesn't tie yourself into knots and the QA
13 program, in a sense, looks like it can be done. The
14 difficulty, what happens is that it requires an
up-front
15 planning and commitments of all the work you are
going to
16 lay out in the scientific R & D process.

17 This is where it starts to get difficult in

our

all 18 research environment is how can you write down and do

19 your up-front planning which the QA program requires

between 20 because there is some connection in the process

where you 21 you have to do some scientific work and find out

has 22 are and go back and make a change, but your planning

23 to have a way to accommodate this.

24 So what we have been doing in the last year is

scientific 25 doing this up-front planning, of what is called

1 investigation plans or study plans, and then we write
2 lower-tiered activity plans which are more detailed
3 planning of the work and experiments that the
scientific
4 staffs are going to do.

5 Additionally, you have to write additional
6 technical procedures which might involve colleagues
in how
7 the experiments are conducted, and this translates to
a

8 lot of time to the staff. Not only are the
procedures in

9 place with this up-front planning but in getting all
of

10 the requirements in place before they are allowed to
11 proceed. And we use the word readiness review or
12 preparedness review to be allowed to start work.

13 And at this point, we have about 13 technical
14 activities that have been through the readiness
review in

15 order to start technical work that is under the fully
16 accepted QA program. And it translates to somewhat
of a

17 time delay on behalf of the staff to be out, to be
able to
18 be in a position to go forward with the work.

19 In terms of resources, it is hard to quantify
that

20 because the program was basically accepted in June.
The

21 planning is underway, and we have some technical

areas

22 that have worked that are being implemented now.

cost, 23 If I had to make a projection in terms of the

to get 24 there is no question it slows down because you have

How 25 the planning in place before you can start the work.

are
1 you quantify the dollar amounts or the time amounts
2 difficult and they will be changing. But if I had to
3 guess, they are in the 25 to 40 percent range for
this
4 year but I expect those to go down, not much. I
mean, the
5 range won't go down. The range will narrow.

6 DR. PRICE: What is 25 to 40? What is 25 to
40
7 percent?

8 DR. JARDINE: You mean in terms of dollars?

9 DR. PRICE: No. 25 to forty percent spent
in
10 readiness planning.

11 DR. CARTER: For quality assurance.

12 DR. PRICE: For quality assurance?

13 DR. JARDINE: Well, getting the up-front
planning
14 done before you go into the Laboratory or into the
field
15 or into your computer system to start doing what
might be
16 a technical product. There is a lot of up-front work
that
17 is needed. And once that is in place and you can
move
18 forward, it still will force a different way that the
work
19 is done by the scientist and the engineers in an R &
D
20 environment. I believe it can be done.

comment 21 There are some people that would make the
better 22 that there are still some scientists, some of the
this 23 ones, that will struggle harder to write down and do
rate 24 up-front planning. But we have a very good success
25 at Livermore because the staff wants to do this or is

1 willing to do this.

2 DR. CARTER: Well, my comments, I was not
only
3 interested in your views on this but I think I would
also
4 be interested in the views of the individuals that
are
5 involved in various aspects of the work, because
6 eventually we have to come to grips with the amount
of
7 resources that are going into QA and whether or not
this
8 is a balanced and reasonable kind of effort.

9 Obviously, this may take time with a lot of
people
10 working in the area. But I dare say a lot of them
are not
11 used to these kinds of procedures on a formal basis,
even
12 though they may have gone through quality assurance,
13 quality control in other ways.

14 But the question is is it really intergrated
into
15 the total program now on a working basis or is it
just an
16 appendage that you have to work with that is
completely
17 separate.

18 So we are have been much interested in this
of
19 intergration of QA. And like I say, also the amount
20 resources that go into it. Does it cause substantial

21 delays in getting the job done and other kinds of
22 pressures such as that.

23 DR. JARDINE: I think within Livermore we
are
24 very intergrated in the sense that our whole QA
program is
25 in place. It is just that it is difficult for a lot
of R

and
into
word
how
have the
you

1 & D types to make a decision and write down the plan
2 commitment to how they are going. What it translates
3 is a little bit of a delay. Maybe that is the wrong
4 for it but what is it that you are going to do, and
5 are you going to do it, and in the end you better
6 paperwork to show that you have done what you said
7 were going to do.

QA.
about to
which
into a

8 And that is one way to summarize the steps of
9 But I think we are getting there and we are just
10 begin implementation of our software QA program plan
11 was approved in December, and so we are now moving
12 newer era of trying to implement the software quality
13 assurance program requirements into the programs at
14 Livermore, and we are just now beginning that having
15 received approval in late December.

you
Are
vary

16 DR. PRICE: In your organizational charts,
17 presented six different technical areas or programs.
18 these about evenly described or does the distribution
19 with time?

time. 20 DR. JARDINE: I would say it varies with
balance, 21 But during fiscal '89 it represented a reasonable
systems 22 although the lighter areas might have been in the
the 23 engineering, engineering studies type activities and
are 24 performance assessment integration portion. And we
25 still adjusting for the fiscal '90 work scope.

1 Any other questions?

2 If not, then I would like to turn the program
for
3 the rest of the morning over to Dale Wilder, who I
4 mentioned is the technical area leader for the
near-field
5 environment modeling and testing technical area.
Dale.

6 MR. WILDER: I appreciate being able to
speak to
7 you this morning. I'll take just a few minutes to
give
8 you a little bit of background as to what it is you
are
9 going to be hearing in the environmental area.

10 A couple of things that I would like to point
out.
11 And that is that in terms of the waste package, the
12 environment that is of consideration is what we term
the
13 near-field environment. I would distinguish that
from the
14 the overall repository conditions because we are
going to
15 be concerned about that rock that interacts with the
16 package directly.

17 In defining near field, as Les pointed out, it
is
18 not always easy to define where the near field stops
and
19 the far field actually begins. But in defining that,
I

the 20 would point out that it is going to depend on what

21 process is that is of consideration.

22 For instance, if we are concerned about
different 23 temperatures, the near field may extend at a

24 scale than if we are talking about stress relief and
it 25 boreholes. And so we define near field based on what

1 is that we are looking at rather than some specific
2 geometry.

3 The other thing that I would like to point out
is
4 that for the discussions today, we are going to be
5 focusing on the environmental container material
6 interactions and, therefore, we are stressing this
7 thousand-year containment period. We certainly are
8 considering environmental conditions beyond the
thousand
9 years, but those have more to do with the interaction
with
10 the waste form than with the container materials.

11 And so today, you'll be hearing presentations
12 largely focused on the thousand-year containment
period.

13 The next slide shows the areas that we are
going to
14 be discussing today. Specifically, we are going to
be
15 looking at those issues of concern in terms of
interaction
16 between waste package container materials and the
17 environment, so we are going to be focusing on the
amount
18 and transport of water and water vapor that can
contact
19 the packaged materials, the composition of that
water, the
20 mechanical loading on the container, the thermal
21 conditions and the radiation-chemical effects.

22 I would like to point out that we are going to
be
23 using some terminology that I need to discuss to make
sure
24 that it is clear. Two specific terms that you'll
hear
25 repeatedly are "expected" and "bounding." When we
refer

1 to expected, we are talking about conditions that we
judge
2 are most likely to occur during the period of
interest, as
3 contrasted to bounding, which these are conditions
that we
4 judge to be beyond the expected values but still
within
5 possible ranges.

6 As an example, to maybe further clarify this,
let
7 me talk about matrix in the next slide, the matrix
8 saturation conditions as we currently understand them
at
9 Yucca Mountain. We expect 65 percent saturation. It
is
10 an unsaturated site but with approximately 65 percent
11 saturation with ranges that have been estimated right
now,
12 plus or minus 19 percent so it would be between 84
and 46
13 percent major saturation.

14 However, calculations that have been done
based on
15 at least one scenario for flux of one millimeter per
year
16 indicate that we may be able to expect as high as 95
17 percent saturation under those conditions if we use
the
18 characteristic curves as they will have been put
together
19 by Sandy in the Laboratory.

of the 20 Therefore, we are going to consider in terms
not 21 design envelope those conditions that are bounding,
spend a 22 just the expected conditions. So we are going to
23 fair amount of the morning talking about bounding
24 conditions, not just expected conditions.
as 25 The next slide will summarize the conditions

1 they exist. Call them either unchanged or ambient
2 conditions. In terms of hydrology, we expect an
3 unsaturated site with about 65 percent saturation.

4 The air that is in the remaining unfilled
void, we
5 do expect to be moist there, and our best estimate is
that
6 it will be an equilibrium with the water in the flow
and,
7 therefore, at 100 percent humidity.

8 There is going to be a very high matrix
suction
9 potential. And therefore, we do not anticipate
fracture
10 flow. Some estimates of fracture flow, if it is at
11 equilibrium with the matrix, is that we will not
initiate
12 practical until we get to about 95 percent
saturation.

13 In terms of water chemistry as we understand
it, it
14 is dilute bicarbonate water. We expect that the
vadose
15 water chemistry will be in equilibrium with the
Topopah
16 Springs Tuff. Now, I'm saying it is unknown. I
should
17 say actually it is not well understood at this point.

18 We certainly have got some samples available
of
19 water but not from the Topopah Springs repository
rising

20 rock.

21 You'll also hear discussions of J-13 well
water,

22 and that is representative of the water but it is not
an

23 equilibrium of Topopah Springs. Let me just point
out

24 that J-13 is a well that is completed over roughly a

25 40-mile wash where the water table is within the
Topopah

1 Springs unit.

2 The repository is in Topopah Springs well
above the
3 water table. So J-13 water is merely one of the
water
4 chemistries that we are considering, but we are not
going
5 to say that J-13 is representative necessarily of
what we
6 will come in contact with in waste packages.

7 If I can go back to the other slide. In terms
of
8 mechanical loading, we do not expect any hydrostatic
loads
9 obviously if it is an unsaturated site. And because
of
10 the air gap and the borehole design as currently
existing,
11 we are anticipating no lithostatic loads and no point
12 loads.

13 In terms of the expected conditions for
thermal, we
14 do recognize that there will be conductive, radiative
and
15 convective or latent heat transfer.

16 In terms of the bounding conditions, I'm sure
that
17 some of these numbers are familiar to you from the
SCP
18 site disposition plan, but in terms of the
performance
19 allocation that was made for the waste package,
taking

up 20 into account as five liters per year per borehole for

21 to five percent of the waste packages.

22 Now, this requires either a much higher than
23 expected flux or some sort of a high infiltration
pulse.

24 Just to put this into perspective, at a half a
millimeter

25 per year flux, which is currently our best estimate
or the

1 project's estimate of flux, you would have somewhat
less
2 than .3 liters per year if it was strictly matrix
flow.

3 Therefore, as I say, we would have to have
much
4 higher than expected flux for some sort of fractured
flow
5 to occur. We are also for design conditions
considering
6 the chemistry much more concentrated than expected
and
7 some of the testing that you'll hear discussed have
used
8 concentrations of 20 times J-13 water.

9 Some of the other work is looking at the
ranges of
10 chemistry that will bound the program.

11 In terms of loading, we have considered the
12 possibility based on the size of the borehole and the
13 fracture spacing of blocks up to 3,000 kilograms
being
14 possible to come into borehole. Of course, that
could
15 result in point loading.

16 We are also looking into the possibility that
17 sloughing might occur, which could provide some sort
of
18 bridging for partial application of lithostatic
loads.

19 In terms of the thermal, the two things that
we are

more
vapor
the

20 considering in terms of bounding is that there may be
21 liquid water present which would result in greater
22 transport and, therefore, influence on the thermal
23 gradients and also geologic variations in terms of
24 thermal productivity.

the

25 DR. CARTER: Let me ask you a question about

1 chemistry there. When you say chemistry more
concentrated
2 than expected, do you mean certain ions are more
highly
3 concentrated than other ions?

4 MR. WILDER: We are considering individual
ions
5 and we are also considering taking the chemistry of
the
6 water and essentially just evaporating it into a
7 concentration which is 20 times, in which case all of
the
8 ions will be more concentrated.

9 We are going through both approaches, and Bill
10 Glassley will be able to define that in some detail
in
11 terms of how we find that.

12 DR. CARTER: Thank you.

13 MR. WILDER: Now I would like to make some
points
14 about the waste package environment, and I've already
15 alluded to one of these, and that is that the
emplacement
16 environment is not going to be an ambient environment
17 because it is going to be perturbed by a number of
18 activities, one of which is construction activities.

19 Certainly in terms of once waste emplacement
takes
20 place, there will be perturbations and those
perturbations
21 will be changing with time. That is, the thermal,

time 22 radiation and chemical reactions are all functions of
23 themselves and, therefore, the perturbations will be
24 changing with time.
the 25 And once again, hold onto that slide and go to

1 next one.

2 Let me as an example look at the issue of the
3 quantity of water. Now what you are looking at are
4 computer calculations for vertical waste emplacement
based
5 on spent fuel activity about eight and a half years
out of
6 core. And as you can see, the isotherm does move out
with
7 time.

8 In this case, we are only looking through ten
years
9 of time but there are some things that are taking
place
10 and, therefore, the environment is going to be
changed or
11 churned with time.

12 When you first start, the boiling point
isotherm is
13 fairly close to the waste package and, therefore, the
14 vapor as it is driven off can certainly flow into the
bore
15 hole and it will flow out into the rock. As it
continues
16 to move, the vapor will preferentially start going
into
17 the rock more than into the borehole as your path
length
18 becomes longer. And we also will build-up the water
out
19 here in what we call the saturation halo, if we could
have

20 the next slide.

21 DR. LANGMUIR: Is this a 250 degrees Celsius
22 waste package that we are talking about?

waste 23 MR. WILDER: Roughly. It is 3400 kilowatts

Tom 24 package and the wall temperature -- I may have to ask

200 25 to help me with this -- but as I recall, it is about

1 degrees or 250 degrees through the borehole wall.
Okay.

2 If I can skip down.

3 Another way of looking at that same phenomena
that

4 I just went through is once again this is a computer
5 simulation but it is showing the distribution of
6 saturation with distance.

7 At 25 years after emplacement, you see that
there

8 is a dried-out zone and referred to that behind the
9 boiling point isotherm, and there is also a zone in
which

10 you'll have active drying occurring, a fairly narrow
zone.

11 Now in this particular case, I should point
out

12 that these are calculations done for horizontal
13 emplacement. However, the power density is very
similar

14 to 15-foot long, 15-foot spacing vertical bridge
15 emplacement. So what we are looking at can apply
also to

16 the vertical.

17 So what we are seeing is that there is an
active

18 dried zone and then there is this zone where the
19 saturation has actually been increased where you do
have

20 the condensation of the vapor taking place.

21 One of the points that I would call to your

22 attention is that the temperature in this zone is
23 elevated, so we are adding water to the rock at
elevated
24 temperatures, and this is going to be a very active
zone
25 for geochemical processes. And one of the things
that

rock
1 Bill Glassley will talk a great deal about is those
2 water interactions that will take place.

is
3 Now if I can go back to the other slide. It
4 going to be very important for us to understand the
5 ambient conditions in order to evaluate conditions.

because of
6 The final point that I will make is that
7 the changing conditions with time, it is not going to
be
8 possible to come up with a table or matrix containing
9 single value parameters for the environment. Rather,
what
10 the table will consist of are functional
relationships,
11 for instance, the saturation of the time, the
temperatures
12 at the time as we just looked at.

discuss
13 DR. LANGMUIR: Would you be prepared to
14 what might happen should you put 100 degree Celsius
waste
15 as opposed to 200 in the same kind of setting? What
would
16 that result in terms of the fluids in the system?

would
17 Now that might influence the chemistry. I
18 like to hear something of those possibilities.

all of
19 MR. WILDER: Okay. We've not gone through
20 the calculations for the colder waste. We are in the

give
this

21 process of doing that, but I'm not sure that I can
22 you all of the answers that you are looking for at
23 time.
24 I think that Bill will address some of the
25 temperature dependencies of the geochemistry. But in

1 terms of the hydrology, we are going through those
2 calculations right now for essentially a 20-year old
spent
3 fuel rather than an eight-year old, so I can't give
you
4 all of the specifics on that today.

5 I mentioned the change of conditions with
time.

6 This is an effort on my part to try to show this
7 pictorally. You've already seen the one distribution
and

8 I should have pointed out that the distribution that
I was
9 showing is conceptual.

10 We do not have yet sufficient numbers to
really say

11 that is the actual distribution of the expected Yucca
12 Mountain but I'm using it to illustrate what we are
going

13 to be looking at. So you've seen the ambient
condition

14 distribution with essentially 65 percent saturation.
We

15 anticipate due to ventilation -- and this is assuming
dry

16 drilling or dry mining techniques are used -- that
there

17 will be some drying of the rock in the near field.

18 What that drying is, I can't tell you
specifically,

19 but I'm trying to show that this distribution will

20 probably be broadened out and it will be essentially

dryer

21 rock. Certainly after emplacement, it is going to be

22 askewed toward the zero saturation in the near field.

23 Then as time goes on, it will eventually
return to

24 the ambient conditions, assuming that the flux
remains as

25 it is currently, and that all the conditions are the
same.

table
1 So when I said that there will not be a single value
2 of parameters, I think that this illustrates what I'm
those
3 saying. We'll have functional relationships and
4 functional relationships will themselves be changing
with
5 time.

6 DR. PRICE: Let me just ask on the ambient,
7 where you have the matrix saturation, in the other
slide,
8 I assumed a normal distribution in your bounding and
9 expected conditions were on three sigmas?

10 MR. WILDER: At this point it is really
11 conceptual but it would be essentially one sigma for
the
12 expected and the bounding. At this point I don't
have the
13 numerical number to give you, but I'm sure that it
would
14 be out at least two sigma.

15 Would you put that one back on? There was one
more
16 point to make. Because the dry conditions that we
are
17 expecting after emplacement up to some time between
300 to
18 maybe as much as 1,000 years, we are very concerned
about
19 evaluating the pulse flow in fractures.

20 Matrix flow is not much of an issue in terms
of

21 getting water into the waste package. So today you
are
22 going to hear a lot of focus on the fracture flow
versus
23 matrix flow.
24 Once again, going back to CODE 3 calculations.
As
25 you can see we are going to remain above the boiling

1 point. This is for the spent fuel case eight years
out of
2 reactor, 300 or 400 watt power output, for a
significant
3 portion of the containment time. As a matter of
fact, on
4 this calculation, it shows that we would not drop
below
5 the boiling point on the borehole wall itself until
after
6 a thousand years.

7 So that is why I say we are going to be
focusing on
8 those bounding conditions in which we could get flows
9 specifically to the fracture flow.

10 One final point that I would make before we
get
11 into the actual technical discussions on the next
slide is
12 that there are some scaled dependencies that we have
to
13 consider in the work. So I would like to review with
you
14 essentially three different types of tests that we
have
15 either already conducted or in the planning stages.

16 The short duration tests -- and by "short
duration"
17 I would say somewhere about the one to two-year time
18 frame, are usually overdriven. And we are looking at
19 either overdriving the temperatures or cooldown or
20 something in order to observe the processes that

would

21 normally take too long to observe.

22 We will be talking about one of these, the
G-tunnel

23 or prototype testing, certainly our lab testing. One
of

24 these is yet in the planning and that is the
Exploratory

25 Shaft Test No. 1. These tests help us to identify

1 physical processes and to provide parameter values as
well
2 as to test the models over limited conditions, and
those
3 conditions are limited because of the overdriving.
And
4 that does, therefore, give us some limited model
5 validation but certainly not total model validation.
6 We also have planned longer duration tests,
7 somewhere in the three to five-year time frame.
Although
8 depending on the schedule, they may be longer than
that.
9 These tests will usually be partially overdriven.
10 As an example of this partial overdriving in
our
11 Exploratory Shaft Test No. 2, we will be overdriving
the
12 heat but then cooling at the more typical rate so we
can
13 watch the cooldown. Whereas in Test No. 3, we will
be
14 heating at the more typical rate and then
accelerating the
15 cooldown.
16 These kinds of tests allow us to test models
over
17 more extended conditions. They certainly give us
extended
18 model validation. And it is during these tests that
we
19 plan to address the geochemical and geomechanical
aspects

20 which we've not yet incorporated into our field
testing.

21 And finally are what I call performance
22 confirmation tests. These are more representative of
the

23 actual ratings. And two types of performance
confirmation

24 tests that are currently planned, one is the No. 2
test in

25 the exploratory shaft has been identified as one in
which

1 we'll have long-term cooldown and that will allow us
to
2 validate the cooldown portions of the models because
if
3 you use the second test, the actual waste package
4 monitoring, you'll never get into the heating cycle
before
5 we run out of time.

6 And so in this test, we will be looking at the
7 actual heating over the 25 to 40 years that it takes
for
8 that heating to peak.

9 Now, I mentioned the fact we are going to be
10 looking at fracture flow. These once again are
11 calculations that were done for the vertical
emplacement
12 case, once again with that same eight-and-a-half-year
old
13 spent fuel.

14 The point is that we will be placing these
15 isotherms between drifts and, therefore, driving the
16 moisture vertically upward as well as downward. And
that
17 will allow us to have essentially a heat-driven
perching
18 condition in that this rock will be at elevated
19 saturations, possibly approaching 100 percent.

20 And if you have a fracture which then
intercepts a
21 waste package, we need to know what is the potential
for

22 water to flow down that fracture.

John 23 So the next presentation by Tom Buscheck and

impact 24 Nitao will focus on this mechanism in which you can

waste 25 the amount of water or water vapor that contacts the

about 1 package. And basically they are going to be talking
2 the interaction of flow into the matrix, specifically
flow 3 looking at conditions from which we can get fracture
4 and also looking at matrix dominated flow and the
role 5 that the fractures play in hindering or assisting
that 6 matrix flow in rock.

7 So I'll turn this over to to him.

like 8 DR. BUSCHECK: I'm Tom Buscheck and I would
9 to emphasize that my talk and John Nitao's talk are
really 10 one talk. And consequently, John will summarize both
of 11 our talks at the end of his talk and I'll just
provide a 12 transition.

getting 13 DR. VERNIK: I wonder if you would mind
14 the microphone a little closer to you.

not 15 DR. BUSCHECK: Because of time today we are
16 going to be possibly able to address all the aspects
of 17 the modeling work being conducted at Lawrence
Livermore 18 National Lab.

work 19 There are three primary areas that we view our

20 from. We have been undertaking code development
which is
21 taking the TOUGH Code from Lawrence Livermore
Laboratory
22 and substantially modifying it and enhancing its
23 performance and adding additional physical effects
that we
24 require in our model calculations, and we've
undergone
25 some partial modification of that code.

models 1 I have just mentioned some other types of
we 2 that we anticipate the need for in the future which
modeling 3 haven't currently developed. Our work in our
in 4 studies fall under nonisothermal modeling studies and
5 detailed fracture-matrix interaction numerical and
6 analytical modeling studies.

7 I would like to emphasize, based on a comment
involves 8 during Dale Wilder's talk, that while our work
is 9 numerical and analytical interaction, that our work
situ 10 done in close collaboration with laboratory and in
11 field experiments.

12 Up front, one of our primary purposes for
the 13 conducting a nonisothermal model study was to aid in
14 design of Laboratory and particularly in situ field
thermal 15 tests. We needed to know the extent to which the
needed 16 perturbations would occur in our experiment and we
to 17 to know the range of parameter values that we needed
18 measure.

and 19 So it was a very essential part of the design
20 the implementation of the G-tunnel experiment, which

Dave

21 Ramirez will be presenting later this morning.

into 22 Our nonisothermal modeling studies, I won't go

and 23 detail here, but the result of looking at Laboratory

24 field scale models along with mechanistic models and

relate 25 theoretical analysis of scaling laws all together

scale
and
and
1 in what I call intergrated parameters in situ field
2 models, able to present the results of one such model
3 compare those results with the in situ field tests
4 G-tunnel.

look at
5 We also concurrently are taking a detailed
6 fracture-matrix interaction, and have developed a
7 comprehensive theory which describes the primary
8 fracture-matrix interaction.

situ
specific
environmental
people
the
10 This work impacts our intergrated parameter in
11 field scale models and it also will impact case
12 scenario deliberations at a development of
13 parameters with which the waste package container
14 will need to work with in assessing performance of
15 waste package.

last
16 Move to the next slide. Could you show that
17 slide? Just keep in mind this slide here.

what
18 I'm going to show in somewhat detail what the
19 fracture, some of the fracture-matrix interaction of
20 is occurring within this zone here in the near field
environment of the waste package.

of

21 This is a conceptualization of how fractures
22 matrix blocks affect drying and wetting behavior
23 within the near field around the waste package. Heat
24 is radiated, while heat flow from waste package
25 primarily occurred as thermal radiation from the waste

1 package to the wall of the borehole. Also heat
2 conduction and convection play a role here.
3 Heat is then conducted into the fracture of rock
4 mass, and these represent idealizations of fractures.
5 As the temperature rises in matrix blocks,
evaporation 6 and then eventually boiling occurs. And because of
7 the fact that there was gas pressure gradient required
8 to drive the vapor out of the block, we get an
9 elevation of pressures as we move into the block to
consequently 10 an elevation of
11 the boiling conditions.
12 So as a result, boiling then subsequently
occurs 13 from its regularly released matrix block into the
14 center
15 of the matrix block. We found in the field and in
our 16 the
17 studies that fracture in the annular spaces within
18 waste package and the borehole wall exists ambient
19 pressures due to the fact that the hydrolic
productivity 20 of the fracture in the annular space is quite high.
21 So gas, then, or water vapor reaches these
19 fractures and is driven under gas pressure, including
20 buoyancy effects on the fracture network of the rock.
And
21 this vapor flow occurs until it reaches temperatures
which

the 22 are cool enough to cause condensation to occur along

23 walls of the fracture.

The 24 Then one of three things can possibly happen.

block. 25 water can be immediately imbibed into the matrix

1 It can also, if the saturation level, if the
imbibition is
2 not sufficient, the saturation levels may be obtained
high
3 enough to result in liquid mobility of water in the
4 fractures. For fractures oriented downward, this
results
5 in gravity drainage back towards the region of
boiling
6 where we get what I would call a gravity driven heat
pipe
7 effect.

8 In other fractures which are radiated away
from the
9 boiling zone, we can get net drainage of this
condensation
10 away from the boiling front. And then within the
rock
11 mass itself, water vapor will also be driven towards
the
12 condensation front, condense, and then water under
13 imbibition forces can be driven back towards the
boiling
14 region and possibly form some sort of heated pipe
effect,
15 though it may take some time for such heat pipes to
16 develop.

17 As I stated before, as the water is moved
along
18 fractures, it will be continually imbibing into the
matrix
19 blocks, developing that condensation "halo" that Dale

20 referred to earlier. Next slide, please.

up-front 21 Dave is going to present pretty much the

model as 22 preliminary validation picture of our integrated

23 compared to the G-tunnel experiments.

about 24 I just want to make a few conceptual comments

particularly 25 the results of our numerical studies, and

1 how these results impact future planning and testing.
We
2 find that the waste package geometry and
particularly the
3 heating rate of the waste package very strongly
effects
4 the near-field moisture movement and temperatures.
5 Particularily we found that through our
scaling law
6 analysis, that the drying rate is strongly dependent
on
7 the heating rate. And for radial flow, we found that
the
8 drying rate is dependent on the heating rate five
halves
9 power, which is very strongly superlinear.
10 What this implies is that -- well, in
G-tunnel, we
11 overdrove the rates but, in fact, the rates relative
to
12 the lower end nominally for waste packages were
13 overdriven by a factor of approximately three.
Applying
14 this relationship, we would require at least six
years to
15 conduct an experiment which was conducted roughly
over a
16 one-year period of time to reconduct the G-tunnel
17 experiment at the low and nominal rate.
18 The reason I mention that as an important
19 consideration is that later on this morning we are
going

20 to be hearing hydrothermal-geochemical coupling and
21 thermomechanical coupling in the near field. These
22 couplings can be substantially distorted for tests
which
23 are strongly thermally overdriven. And while the
24 thermally overdriven tests are important inasmuch as
we
25 have a relatively short period of time to thoroughly

important
at the

1 perturb a large volume of rock, it is still very
2 that we currently conduct tests which heat the rock
3 actual nominal rates that the waste package will be
4 heating in the environment.

5 Consequently, based on the strong nonlinear
6 relationship, we find that we are going to be needing
7 long, long periods of time to appropriately thermally
8 pulse the rock in order to see the types of couplings
9 which will pertain to actual repository conditions.

the
In
in
over
and

10 Another point that needs to be made is that
11 fractured rock itself is a very heterogenous system.
12 fact, fracture spacing can vary quite widely. And
13 inasmuch as we are going to have to validate models
14 situ, it is going to be very important for us to
15 hydrothermally perturb a volume of rock which extends
16 the scale of heterogeneities, mainly to the fractures
17 matrix heterogeneity and the matrix properties.

rock
fact, is
it

18 In G-tunnel we perturbed about 1.4 meters of
19 with respect to saturation changes. And that, in
20 substantially smaller than the scales of the observed
21 heterogeneities, so that should be bore in mind when

testing 22 comes to planning future testing and the length of
next 23 that we reequire for adequate model validation. The
24 slide.
the 25 The focus of the rest of this talk, because of

fracture 1 importance on waste package performance of the
significant 2 matrix interaction, and as Dale stated, the
feel 3 amounts of liquid contacting the waste package, we
4 can only be facilitated through what we call
5 fracture-dominated flow.

of 6 Besides temperature affecting the performance
parameters is 7 the waste package, two other very important
waste 8 the quantity and chemistry of water contacting the
to be 9 packages Two of the important questions that need
from? 10 answered, first of all, is where can this water come

lenses 11 There is a possibility that low permeability
occurrence of 12 above the waste packages could result in the
the 13 perched water. The introduction of the drilling in
other 14 construction fluids and drilling fluids, and the
15 construction fluids will result in conditions being
16 than ambient at the time of emplacement.

be 17 Vapor condensation as we've shown earlier can
result 18 quite significant during the heating phase and can
19 in areas of full saturation around in areas of the

needs 20 repository. Also the variability of rainfall events

21 to be considered.

22 And another topic which I think we will be
23 receiving additional look in the future is the
seismic

24 pumping of the water table. And that fracture-matrix
25 interaction also affects our analysis of that
problem.

1 Then in order to understand the chemical evolution of
that
2 water as well as the quality, we need to know how it
is
3 getting there, whether it is a fracture-dominated
flow
4 system or matrix-dominated flow.

5 This will tell us if the residence time of
that
6 flow will affect quite a bit of that chemistry, as
well as
7 where it comes from will affect the chemistry of that
8 water, and it will also affect the flux of water
9 contacting the waste package. Next slide.

10 We have been addressing fracture-matrix
analytical
11 interaction with a combination of numerical
one. We
12 models. This process has been a very interesting
that
13 additionally conducted some numerical experiments
near
14 were done to scope out the impacts of drilling fluids
15 field, drilling fluids which would be used to put
the
16 instrument boreholes into the heater borehole from
17 G-tunnel experiment.

18 So from that work, we found some fundamental
19 theoretical relationships which, in turn, we then
looked
20 to analytical models to further understand. From our

21 analytical models, we then went back to our numerical
22 experiments to corroborate the applicability of the
23 analysis and it also brought up new problems that we
24 thought would be relevant to important questions of
waste
25 package performance, and I'll focus on the numerical

1 experiments in the next few minutes.

2 In this analysis we found that there are three
3 primary types of flow: Fracture-dominated flow and
4 matrix-dominated flow, the two that I've already
5 mentioned, and also a transitional fracture-matrix
6 dominated flow which occurs.

7 Through our analytical work we have developed
flow
8 criteria which tell us which type of flow, whether it
was
9 fracture matrix or transitional flow, is likely to
occur.

10 And John will describe that in the following talk.
Next
11 slide.

12 I have to quickly give an example. One of the
13 early samples that we looked at for
fracture-dominated
14 flow -- what we have here is a system of vertical
parallel
15 fractures which are uniformly spaced. We have a
fixed
16 pressure boundary condition at the top of these
fractures
17 which would pertain to a pond of water at a constant
18 depth.

19 These fractures have an aperture of $2b$ and a
20 spacing of $2a$. The matrix is initially less than 100
21 percent saturated, which in the case of this
particular
22 example of 65 percent, and due to the capillary

forces in

23 the matrix, the fractures are essentially drained to
water

24 under these ambient conditions.

25 Because of the periodicity of this problem, we
can

1 focus on a subcell problem utilizing the symmetry
down the
2 midplane of the fracture with symmetry down the
midplane
3 within the matrix block. And in this example we are
4 considering a 100 micron fracture or one with a 50
micron
5 half width and a .5 meter spacing.

6 We conducted this experiment for 48 hours with
a
7 fixed boundary pressure which would pertain to a
constant
8 head of drilling water in a borehole and could
pertain to
9 a variety of problems. On the left here we are
focusing
10 on saturation changes within the matrix block.

11 I would like to point out that the matrix
block,
12 that this is 1.5 centimeters. We actually go out 25
13 centimeters. But for the space, we are only showing
this
14 amount, so actually the midpoint of the matrix is
some
15 distance out here.

16 What we have is that the fracture that we saw
in
17 the previous slide, this is the midplane fracture.
This
18 is the distance into the matrix block away from the
19 fracture. And you see that we go down to 100 meters
in

20 this case, the vertical depth flow and infiltration
flow.

21 What we've plotted here is the mid-saturation
22 contour between 65 percent and the initial saturation
of

23 100 percent. So this is sort of like the mean
24 perturbations in the matrix with time. And we have
looked

25 at two-hour intervals going up to 48 hours along into
the

1 matrix block.

2 I would like to point out that this particular
3 problem is reference parameters for the repository
horizon
4 which we considered the best possible available data
to do
5 this analysis.

6 In this plot here what we are looking at is
the
7 liquid saturation level in the fracture with respect
to
8 vertical distance below the constant pressure
boundary
9 going from zero to 100 percent saturation. So this
is
10 showing the liquid pulse of water moving down the
fracture
11 in two-hour intervals.

12 Something that became very apparent early on
in
13 this study was that for this particular example, and
it is
14 fracture-dominated flow, we found that there is a
strong
15 amount of matrix interaction which we found resulted
in
16 the liquid front moving it at a two to the one-half
power.

17 Even though we are fracture dominated here,
18 conditions in the matrix have a very, very strong
19 influence on the movement of that liquid front down
the

20 fracture, so we should not be misled by talking about
21 fracture versus matrix flow. In fact, there is a
very
22 strong coupling in particular for a
fracture-dominated
23 situation.

24 DR. LANGMUIR: Can I ask a question?

25 DR. BUSCHECK: Yes.

lined
influence
1 DR. LANGMUIR: Supposing the fractures are
2 with secondary mineral phases. Is this going to
3 your movement into the bores?

look
to
4 DR. BUSCHECK: It will. We are starting to
5 at that type of problem. We don't have results today
6 show you but that is being considered.

7 DR. LANGMUIR: Isn't that a fairly realistic
8 condition to be expected?.

but
9 DR. BUSCHECK: It is. I won't speculate now
10 I'll show in the future what that impact will be.

11 Next slide.

12 If you look at what happens at the end of the
13 infiltration of that source, now after 48 hours we've
14 removed that source of water. This is the main
saturation

are
15 deprivation in the matrix at 48 hours. And now we
16 going to look at what happens to fracture flow once
that
17 infiltration source is removed. And these are 0, 2,
4,

18 and 24 hours after the removal of that source of
water.

19 What we find is that within the 24 hours, that
20 pulse of water in a fracture is essentially almost
21 completely imbibed in the matrix with a net result
that

22 the toe of the liquid front barely moved than it had
moved

23 in the 48-hour event.

24 The result here is showing us that when the
pulse

25 of water or the source of the pulse of water is
removed

1 that matrix imbibition will mitigate any subsequent
2 movement of flow down the fracture. Next slide.

3 We also found that the penetration depth
within
4 along the fracture is very strongly dependent on the
5 aperture which is seen here. We found for this
example
6 if we went from 100 micron down to 15 microne
fracture,
7 that only a two-fold difference in a fracture
aperture
8 resulted in an eight-fold difference in fracture
9 penetration depth.

10 John will show in his theoretical analysis why
that
11 is the case. But an important point to point out
here is
12 that fracture flow for these reference values is
quite
13 significant, 100 meters, and I think than points out
the
14 need for further study of this problem.

15 We conducted a parameter sensitivity study of
data
16 fracture-matrix flow and considered using repository
17 horizon. We found for fracture spacings that are
18 anticipated for the horizon, which remain yet to be
19 confirmed, that we found out most of these cases
result in
20 a "t" to the one-half power dependence.

21 What we are finding here along the normalized

won't 22 fracture penetration depth with log of time -- and I
23 describe what the normalized depth is but it is very
24 proportional to the actual depth. And this is a very
25 important observation which was made which aided

1 subsequent analysis or analytical work that John will
2 present. Next slide.

3 If we find, however, that if the repository
that
4 the fracture is substantially closer spaced than
we've
5 anticipated -- in this case the fractures are about
six
6 centimeters apart -- we find that, in fact, the flow
7 fields in the matrix blocks for two neighboring
fractures.

8 And again, this is a case where we have a
system of
9 uniform space vertical fractures. So that fracture
10 spacing is substantially reduced on the order of a
factor
11 of 10. We find that the saturation perturbations in
the
12 matrix interferes between neighboring fractures.

13 And, in fact, for this example, that it only
14 required three hours before the saturation fields and
15 neighboring fractures started to interfere with each
16 other. We found that as the saturation fields
interfered,
17 that the liquid front movement changed to a "t" to
the
18 one-half power dependent transition to a linear time
19 dependence.

20 We can see in the movement of the liquid pulse
down
21 down the fracture, that if we plotted these earlier

times,

22 we can see that they are changing "t" to the one-half
23 power. But in the transaction here, we transition to
a
24 linear time dependence which is much, much faster
than a
25 one-half power dependence.

An

1 Quickly we talked about matrix-dominated flow.

2 important outcome of our work is that we found that

3 contrary to what some may believe, fractures are not

4 capillary barriers to matrix-dominated flow.

5 What we have here is a fracture which is

orthogonal

6 to the direction of matrix-dominated flow or matrix

plot.

7 What these bridges here represent here is the fact

that

8 there are sparing contacts between neighboring matrix

9 blocks and we have modeled these contacts essentially

10 being where the fracture aperture goes to zero.

Again,

11 the matrix initial saturation is less than 100

percent or

12 55 percent and the fracture drained to water. And we

also

13 maintain a constant pressure boundary at the top of

the

14 boundary.

15 If we look at a subcell which occurs due to

the

16 periodicity of the problem, we get this particular

sub

17 element here. An important parameter is the length

of the

18 aperture, and this is the total length of that

periodic

19 subcell. And this ration, $l_{\text{sub a}}$ or $l_{\text{sub t}}$ is

an

20 important parameter to consider while viewing
21 matrix-dominated flow across these asperities.

22 Next slide. Here we are looking at from the
top of
23 the infiltration source itself going down into the
matrix
24 vertically. We are looking at various values of l
"sub a"
25 or l "sub t". It is 100 percent down to zero percent

1 which is virtually impossible, but we considered it
to
2 show what will happen if there was actually no
contact
3 between matrix blocks.

4 For 100 percent, we just get pure matrix
imbibition
5 into the matrix block and this is 1440 hours. We
find
6 that even for a very, very small value of one percent
7 contact area, which is this curve here, we find that
this
8 has a very small effect on retarding flow across the
9 fracture.

10 Even in the case where we have zero percent
11 contact, we actually can get flow across the fracture
due
12 to the fact that the vapor phase is also active in
13 addition to the liquid phase.

14 What happens is that we get relative humidity
15 gradients across the fracture which result in an
16 evaporation on the upstream side of the fracture and
17 condensation on the downstream side. Next slide.

18 Right now I would like to introduce John
Nitao. He
19 is going to emphasize the analytical studies that
were
20 done in conjunction with our numerical experiments
and
21 he'll also illustrate our flow criteria that were

22 developed.

23 DR. NITAO: My name is John Nitao and I'm a

24 hydrologist working in the Hydrology Department at
Yucca

25 Mountain Project at Lawrence Livermore. I would like
to

1 talk on the subject of fracture-matrix interaction,
2 continuing some of the discussion that Tom presented.

3 The emphasis of my talk is on some of the
4 analytical modeling that we've studied here in
conjunction
5 with the numerical modeling as an aid to experimental
and
6 field tests. Next slide, please.

7 This is the same graph that Tom showed. This
is
8 just to show the importance of fracture-matrix flow
for
9 the waste package environment. And whether the flow
comes
10 through the fracture or the matrix is important
because if
11 it goes through the matrix, then the geochemistry
would be
12 different than the fracture flow. And also with
matrix
13 flow, you would get less of the liquid flux onto the
waste
14 package than if you had fractured flow. The next
slide.

15 This is an outline of the work that we've done
in
16 local modeling. We've looked at a system of parallel
and
17 fractures and performed two dimensional simulations
groups
18 theoretical analysis, and we derived dimensionless
when
19 for fracture-matrix flow and found the criteria for

20 matrix-fracture flow occurs.

21 By deriving dimensionless groups, we can
reduce the

22 number of parameters that would be necessary for

23 experimental and field testing and also in our
computer

24 modeling that helps us to determine what range of

25 parameters are realistic parameters for Yucca
Mountain.

1 Hopefully it will be used for future computer models
in a
2 system analysis.

3 We've looked at both fracture-matrix dominated
flow
4 systems and found the approximate formulas predicting
the
5 travel of the water movement and found the expression
for
6 parameter dependence of various hydrological
parameters
7 environment and fracture-matrix based on flow
regimes.

8 We believe that a physical understanding is
9 necessary in order to have confidence in our computer
10 models and in the experimental work. And we've
compared
11 our analytical work with numerical solutions and have
12 pursued applications. Much of these areas are
continuing
13 development.

14 I believe we have really made significant
progress
15 in these but we are continuing in the effort of
16 determining the dimensionless groups in developing
more of
17 a theoretical understanding of hydrological physical
18 processes.

19 This is a similar slide to what Tom showed.
This
20 is the type of system that we are looking at. We
hope to

21 look at other types of systems in the future. We
have a
22 system of parallel fractures here with aperture 2b
and
23 spacing 2a. We are looking at this single cell here
in
24 our subsequent viewgraph.
25 Our analysis includes a few types of boundary

1 conditions, constant head value at the inlet to the
2 fracture which is corresponding to ponding at the
borehole
3 surface or at the drift floor. The other boundary
4 condition we look at is the constant flux into the
5 fracture which is correspondent to condensation of
water
6 vapor or seepage or surface infiltration.

7 Today we will just look at one aspect of our
8 analytical work, and that is to answer the question:
When
9 does fracture flow occur for the type of systems that
we
10 consider? We first determined dimensionless groups
for
11 flow in fracture-matrix systems and we found that
critical
12 values for dimensionless groups for fracture flow to
13 dominate.

14 An application of this or an outgrowth of this
is
15 to help to determine the range of parameters for
which the
16 equivalent continuum approximation is valid. The
17 equivalent continuum approximation is that there is
an
18 equilibrium between the matrix and the fractures.

19 This viewgraph illustrates the principle that
I'm
20 trying to illustrate today, which is that if the
inlet to

then 21 the fracture is much less than some critical flux,
of 22 we'll have basically matrix-dominated flow where most
instead 23 the movement in the water will occur in the matrix
24 of the fracture.
critical 25 If the inlet flux is much greater than the

and
1 flux, then most of the flow occurred in the fracture
2 the flow in the matrix will occur orthogonal to the
3 fracture. Next slide.

question
4 DR. LANGMUIR: Tom, can I raise the same
5 that I did earlier? How do you factor into the
modeling
6 effort, the real possibility of fracture of the
mineral
7 line? And therefore, you don't have continuity of
fluid
8 flow into the matrix.

show
9 DR. NITAO: The analysis, the results we
used
10 here do not take that into account, but the analysis
11 basically an imbibition of flux function between the
12 fracture and the matrix. Right now we are in the
planning
13 process of looking at simulations which will
basically
14 modify that function and put a low permeability
barrier
15 coating on the fracture phase. Those are simulations
that
16 we plan to do in the future.

17 DR. LANGMUIR: Thank you.

18 DR. NITAO: In the previous slide we had a
19 critical flux which we called a U^* and this new graph
20 shows a way that a motivation for what that U^* is.

the
a

21 We found from our analysis that the flow in
22 fracture, most likely the square root of what we call
23 fracture diffusivity times time, and this fracture we
24 found was related to the inlet flux times the half
25 fracture aperture, the porosity of the matrix, one

matrix 1 minus the initial saturation of the matrix and the
2 diffusivity constant.

of 3 The flow in the matrix goes as the square root
4 the matrix diffusivity times times time. If the
5 diffusivity in the fracture is much greater than the
6 diffusivity in the matrix, we'll have
fracture-dominated
7 flow. And vice versa, if it is much less, then we'll
we
8 have matrix dominated flow.

9 And basically by looking at these two
expressions
10 here, we obtained that our value of U^* down here is
this
11 expression here. Next slide.

12 These are computer simulations which confirm
this
13 theory. Here we have inlet flux is equal to
one-tenth the
14 critical flux and we find that the fractures here,
the
15 matrix here, these are liquid saturation contours
which
16 are the contours of constant moisture that is being
17 absorbed into the matrix. We find that the flow is
18 basically symmetrical and it is mainly in the matrix,
19 occurring mainly in the matrix.

20 At the equal to the critical flux we find that
the

flux 21 fracture flow is starting to increase. And when the
of 22 goes to 10 times the critical flux, we find that most
into 23 the flux is occurring in the fracture with the flux
I 24 the matrix occurring methodical to the fracture. And
25 notice that these are plotted at different times here

time 1 because in order to show that this is a much larger
flow 2 than this, which of course shows us that the fracture
3 occurs much faster.
expressions 4 And we found mathematical approximate
according to 5 for the movement of the flux in the fracture
6 these expressions here. Next graph.
7 This is a similar viewgraph. Here we have the
have 8 fracture is interfering with each other and here we
find 9 fractures of .2 meters apart from each other. We
10 similar other things, except that here because of the
that 11 interference with the neighboring fracture, we find
lines are 12 for matrix-dominated flow the saturation contour
matrix 13 basically perpendicular, which means that we have
fracture 14 equilibrium and continuing equilibrium between the
15 and the fracture. And at 10 times, we have a
16 flow occurring here. Next viewgraph.
water 17 Here we have a plot of the penetration of the
dimensional 18 into the fracture versus dimensional time,
19 penetration, and we found that for a
fracture-dominated

time is 20 flow, the dependence, linear dependence, for small

linearly 21 it looks like "t" to the one-half and goes both

22 when the fracture starts to interfere.

what we 23 The time at which it interferes is equal to

24 call lambda squared where the lambda is the initial

25 unsaturated matrix volume to fracture volume. And we

1 noticed that at three times the flow periods here and
at
2 Yucca Mountain we found that for a parameter's study,
that
3 it seems to occur mainly in flow reaching, too, so it
4 looks like "t" to the half power. Next.

5 These flow periods can be entered physically
as the
6 first flow period dominated by inlet boundary
conditions
7 and the capillary condition in the fracture and
gravity.

8 The flow period II is dominated by the matrix
9 imbibition and gravity. Flow period III is when you
start
10 getting interference with the neighboring fractures.
Next
11 viewgraph.

12 Just as an application of our study, we looked
at
13 the problem where we have the borehole with the water
14 going into a fracture on this idealized fracture
here, and
15 we calculated how far it would go down.

16 Using nominal Yucca Mountain parameters, after
48
17 hours it would go down 20 meters using this
illustrated
18 calculation, and it would go 6.5 centimeters roughly
into
19 the matrix, and it will perturb the environment by 20
20 percent.

we
21 What motivated me to look at this problem is
22 were looking at defective drilling water on the near
field
23 environment or on the waste package, so here we were
24 looking at a borehole that was drilled with wet
drilling
25 and see what happened.

of the 1 And for this other case here, we used 1/40th
Mountain. 2 matrix diffusivity that is expected at Yucca
and go 3 And we found after 48 hours, it would go 140 meters
four 4 one centimeter into the rock and perturb the rock by
5 percent. Next.
talk, 6 Just to begin to conclude both Tom and my
doing 7 this summarizes some of the work that we have been
8 in the hydrology area.
we 9 In terms of code development and verification,
Code. 10 have developed and partially verified the V-TOUGH
at 11 And our nonisothermal modeling studies where we look
key 12 thermal perturbations, we've identified some of the
waste 13 mechanisms of heat and flow fluid flow around the
we've 14 packages. And through the G-tunnel experiments,
15 partially validated a model.
analyzed 16 In fracture-matrix interaction, we have
then 17 the interaction of the fracture and matrix flow and
fracture 18 identified major flow regimes and developed the

19 and matrix flow criteria.

20 Pete will go into case specific scenario
evaluation

21 by using numerical analytical models which were
validated

22 through field and laboratory experiments in order to

23 identify conditions for which liquid flow to the
waste

24 package is possible.

25 DR. NORTH: Before we go on to that, I would
like

1 to ask you a specific question in regard to specific
2 scenario evaluation. Let's just take one. For
example,
3 Ghost Dance Fault. There is a large fracture with
that B
4 cubed relationship that was discussed earlier.

5 DR. NITAO: Yes.

6 DR. NORTH: Have you looked at that as a
case?
7 How much water could get down through Ghost Dance
Fault
8 into the repository and how does that fit into your
9 modeling framework?

10 DR. NITAO: That is something that we would
like
11 to look at.

12 DR. NORTH: Have you done it?

13 DR. NITAO: No, we haven't done it yet.

14 DR. NORTH: Thank you.

15 DR. NITAO: Our nonisothermal environment
will
16 involve long-term field testing and determining more
of
17 these scaling laws for drying and condensed flux.

18 And by using some of these scaling laws in our
19 testing, we hoped to develop integrated parameter
models
20 which would allow us to model larger systems than we
are
21 able to model now and develop dual porosity models,
since

to 22 the only other alternative to dual porosity models is

23 use discrete fracture modeling and that would require

24 considerable computer costs.

modeling 25 In our fracture matrix flow modeling, this

1 work is relatively recent work that we've done, so we
2 haven't been able to apply it to future problems yet.
But
3 we need to also develop an experimental confirmation
of
4 our theory before we feel confident in applying it.
And
5 we need to also extend the work from some of the
idealized
6 systems that we are looking at to multi- dimensional
7 fractures and fracture systems and use this different
8 mechanics to develop dual porosity network models.
9 DR. VERNIK: Are there any questions that
need
10 to be discussed? I suggest that we take a
fifteen-minute
11 break.
12 MR. WILDER: I wonder if we could follow up
on
13 the comments relative to the Ghost Dance Fault, and I
14 think this is an example of the intergration that
Carter
15 was talking about.
16 The evaluation of the water being down at
Ghost
17 Dance Fault is really being done by U.S.G.S. but we
are
18 having to look at that ourselves to satisfy ourselves
that
19 in terms of the way it is impacting us, it is not
going to
20 have an impact.

21 One of the things that is specified in the
site
22 characterization plan is that we will not emplace
waste in
23 a known fault. So we won't be in the immediate
vicinity
24 of Ghost Dance Fault but we are certainly going to
25 interact with the U.S.G.S. to understand that the
water

Fault 1 appraisals that they have for going down Ghost Dance
2 are not going to impact the waste package.
3 So there is a lot of intergration between us
and 4 the U.S.G.S. on that.
5 DR. NORTH: It seems to me that this is an
issue 6 that we should get on with. I found it very
persuasive to 7 go down an end tunnel a few months ago and watch what
I 8 was told to be the order of 10 gallons a minute
coming out 9 of a big crack.
10 How much of those are there in the proposed
Yucca 11 Mountain area? And how does this modeling study
12 contribute to be an understanding of how we might go
about 13 looking for them? I mean, Ghost Dance Fault is one
where 14 we know there is a potential problem and then there
may be 15 some others that we haven't found yet.
16 I would like to see some case specific
scenarios 17 run potentially as a way of getting on with the
18 performance assessment and finding out what kinds of
19 things do we need to know.
20 For example, can we rule out that medium-sized

21 fractures and small fractures are essentially
unimportant?

22 We had an extensive discussion with some people from
the

23 Bureau of Reclamation in December on the importance
of

24 small and medium-sized fractures in relation to

25 tunnel-boring machines.

1 So I would like to see this exercise taken to
some
2 bottom lines where we can conclude what issues are
going
3 to be most important to performance assessment and
which
4 issues we can bound out because we have strong
indications
5 that they are not important.

6 MR. WILDER: Some of the work that Tom and
John
7 have been doing to address that issue is that they
found
8 that beyond certain aperture, it doesn't matter how
much
9 wider the aperture is. And we are trying to get a
handle
10 on that and when we get those result --

11 DR. NORTH: Can we get those results?

12 MR. WILDER: I think we can, and I think it
is
13 already contained in some of the literature that is
14 available.

15 DR. BUSCHECK: In the fracture sensitivity
study
16 we considered, we considered a thousand micron
fracture
17 and we can even go larger than that. So, in fact, we
do
18 have some data which may contain more closer with
Ghost
19 Dance Fault but it would not require a large amount
of

20 work to address that directly.

21 DR. ISAACS: We'll take your comment under
22 advice. My decision is that other parts of the
program
23 are probably more oriented to addressing that issue.
24 Maybe what we ought to do is see if we want to put it
on
25 the agenda for the March meeting presentation.

1 DR. PRICE: Were you just requesting some
2 information as an action item?

3 DR. NORTH: Let's make it a generic interest
in
4 seeing this kind of exercise go further, and I don't
5 really feel it is appropriate to make it to these
specific
6 individuals, but rather the program as a whole.

7 DR. PRICE: I mean, there was an indication
of
8 some data in there and you said can we get that data.
Did
9 you want to make that particular request as an action
10 item?

11 DR. NORTH: I think we'll leave it to DOE to
12 interpret what it is that they can give us in this
area.

13 DR. VERNIK: Why don't we reconvene in
fifteen
14 minutes.

15 (Whereupon, a recess was then
taken.)

16 MR. WILDER: We would like to continue on.
We
17 might ask for a little bit of feedback from those in
the
18 back. One thing is that the laser pointer batteries
wore
19 out on us. We have new batteries in it, but we are
also
20 going to try maybe just a manual pointer, and so I
would

one 21 like to get some feedback later on today as to which
22 is working better.
of 23 We also moved the microphone over and because
the 24 using the manual pointer, there may be a problem with
working 25 microphone, so be sure to let us know if it is

1 okay.

2 We are now going to be moving onto the issue
of
3 composition of water and water vapor, essentially the
4 geochemical interactions by Dr. Bill Glassley. As I
5 mentioned earlier, he will be focusing on the rock
water
6 interactions. Bill.

7 DR. GLASSLEY: As Dale said, my name is Bill
8 Glassley and I'm the task leader for waste package
9 environment geochemistry and mineralogy.

10 The responsibility or effort that this task
has is
11 to define what the geochemical environment is within
what
12 waste packages will exist. In particular we are
13 interested in generating information that will be
used for
14 the evaluation of candidate container materials. We
are
15 interested in generating information that will be
used in
16 establishing a source term, and finally we have to
provide
17 information that will satisfy regulations,
particularly
18 those contained in 10CFR 60.135a.

19 The organization of this presentation will be
as
20 follows. It will first describe very briefly the
ambient

21 conditions that we expect in the environment,
emphasizing

22 in particular water chemistry.

23 Following that, I'll describe the perturb

24 conditions that we think we are going to have to deal

25 with, concerned primarily with the types of
processes.

1 And then I'll discuss some of the work that we are
doing
2 trying to evaluate the consequences of these
processes for
3 the waste package environment geochemistry. I'll
then
4 describe some of our modeling activities and
summarize
5 briefly what we have accomplished to date.
6 As far as the ambient conditions are
concerned,
7 most of them were described by Dale Wilder but to
8 emphasize those things that are particularly
important to
9 us, the site is unsaturated and it has a range of
possible
10 saturations but the fact that it is unsaturated is
11 critical to what we are doing.
12 We believe it is slightly oxidizing with an
13 atmosphere that is dominated by air and we believe
that
14 the vadose water composition in the Topopah Springs
tuff
15 probably approaches that or probably approaches
16 equilibrium with Topopah Springs tuff.
17 However, it has yet to be established whether
or
18 not the water composition or known water composition
is,
19 in fact, an equivalent with Topopah Springs tuff, and
that
20 is one of the issues that has to be dealt with in the

21 future.

22 As far as water chemistry is concerned, we
have to

23 deal with two different issues: One is what the pore

24 water chemistry will be in the immediate vicinity of
waste

25 packages. We need to understand what the chemistry
of

Those 1 water could be that would contact waste containers.
2 are not necessarily the same thing because of the
3 possibility of fracture flows and high flux
conditions.

4 Shown in this figure in this column is the
5 composition or compositional ranges for particular
6 elements in J-13 water. As you can see, the ranges,
7 although limited are not for some elements,
particularly
8 small. There is quite some variation in some
9 constituents.

10 However, it remains if you look carefully at
the
11 composition a very dilute solution. However, in
12 comparison with other waters that have been obtained
from
13 the extraction processes, particularly that Al Yang
has
14 employed, for samples that have been obtained from
shallow
15 wells or relatively shallow wells in the vicinity of
Yucca
16 Mountain, those pore waters, extracted pore waters,
have
17 composition that overlap with to some extent J-13 but
18 nevertheless can be significantly different.

19 If you look in particular at silica, chloride
and
20 sulfate, for example, there are wide ranges and very
21 different compositions compared to J 13.

the 22 Our concern, therefore, is to establish how
possible 23 chemical environment will behave for the entire
slide. 24 range of conditions we could see out there. Next
most 25 The approach that we've taken, therefore, and

determine 1 of our efforts recently has been to describe or
2 what the range of ground water composition is in the
3 vicinity of Yucca Mountain and use those as bounding
4 conditions for our experimental work and modeling
5 activities.

which 6 As an example of what we've done, this figure
7 has as a vertical axis oxidation state, horizontal
figure 8 axis, the pH, we've examined or plotted on this
9 all of the waters that have been obtained from all of
the 10 wells in the vicinity of Yucca Mountain.

are 11 They all fall within the shaded region. They
12 bounded by conditions in which the pH ranges from
about 13 6.8 to about 10 and oxidation conditions of about
minus 14 200 millivolt to about 400 millivolts.. That covers
a 15 very large range.

of 16 Most of the ground waters fall in the vicinity
17 the lower left-hand corner where the pHs are
relatively 18 neutral and the oxidation state is near neutral to
19 slightly reducing, but they can be somewhat oxidizing
as 20 well.

21 DR. LANGMUIR: Bill, don't these waters
basically

22 contain measurable dissolved oxygen?

23 DR. GLASSLEY: Yes. And the problem is what
the

24 significance of that measured oxygen is. As you
know,

25 measuring Eh state of any ground water is a very,
very

the 1 difficult problem. What we've done is simply taken
2 measured potentials that have been reported in the
3 literature and plotted them here.

rather 4 DR. LANGMUIR: These are measured values
5 than theoretical values?

6 DR. GLASSLEY: That is right. These are all
7 measured values.

them 8 DR. LANGMUIR: So when you start comparing
9 to theoretical diagrams, they may or may not be
10 meaningful?

11 DR. GLASSLEY: That is correct. This is the
12 approach we are taking in establishing what the
ambient 13 water temperature used in the environment is.

14 Now what I want to talk about is the work we
are 15 doing to look at the conditions that could pertain to
once 16 the system has been perturbed. There are a variety
of 17 things that we want to deal with here. Next slide.

18 One of the problems that we must address is
the 19 behavior of radionuclides at elevated temperature for
that 20 scenario in which water enters a container, dissolves
the 21 materials, leaves the container and energy

That

18 work is in progress. It will not be described in
this
19 particular meeting but it essentially is the
technical
20 area involved in waste form testing.

21 We also need to understand sorption and
transport
22 characteristics of the near field and put that
information

23 into computer codes that will be used to make our
24 long-term predictions and calculations, and that work
has
25 been in progress. Once we have information that is

adequate to conduct modeling and to guide
experimental
1 activities, those activities will be undertaken to
look at
2 radionuclide behavior.

3 DR. LANGMUIR: Bill, are you going to be
talking
4 about the codes in which you put these parameters?

5 DR. GLASSLEY: Most of the work of modeling
and
6 numerical simulations we will be doing at least at
this

7 point will probably employ EQ3-6 which will have in
it the
8 capability to incorporate absorption processes, ion
9 exchange, solid pollution and exchange processes that
10 would occur in the presence of the radionuclides.

11 DR. LANGMUIR: Are you talking about an
updated

13 EQ3-6?

14 DR. GLASSLEY: Yes.

15 DR. LANGMUIR: That would handle triple
layer and
16 constant capacity models and that sort of thing?

17 DR. GLASSLEY: That is certainly our
18 consideration now.

19 DR. LANGMUIR: What is the time scale on
those
20 possibilities now?

21 DR. GLASSLEY: That depends on budgeting.

22 DR. LANGMUIR: How far along are they now?

23 DR. GLASSLEY: The solution exchange models
are
24 in progress now and are being developed. That is
well on
25 the way to being incorporated into the code.
Adsorption

1 processes are being delayed right now. We expect to
use
2 some of the information generated by Los Alamos in
their
3 work in incorporating that into the code, but that
has
4 been delayed.

5 DR. LANGMUIR: Have they looked at just
simply
6 taking the very effective working portions of MINTEQ
which
7 can do sorption models and form them into EQ3-6?

8 DR. GLASSLEY: There are a variety of points
that
9 are being considered. No decision has been made yet

about

10 which approach would be the one to incorporate into
the

11 code at this point.

12 The conditions that we have to be concerned
with in

13 the environment, once a waste package is emplaced,
involve

14 a variety of things. But to summarize them briefly,
the

15 environment is going to experience a thermal peak
that

16 could be as high as 240 degrees centigrade in the

17 immediate vicinity of the waste package. That
thermal

18 peak will probably occur within 40 years of
emplacement

19 and that will be followed by an extensive period of

20 cooldown which could go on for thousands of years.

21 We know that vaporization of water will occur
and a
22 within the immediate vicinity of the waste package

23 saturation "halo" or something similar to that will

24 develop at some distance from the borehole wall.
These

25 are considerations that Dale discussed earlier.

86

1 Eventually the possibilities exist that that
2 saturation "halo" will migrate back toward the
container
3 as cooldown occurs.

4 We know that reaction products as a result of
5 radiolysis will interact with the rock and will be in
the

to 6 independent vicinity of waste packages, and we need
they 7 understand what those radiolysis products are, how
in the 8 will interact, what their chemical products will be
9 environment.

10 And finally, we have to be concerned with the
of 11 presence of man-made materials. There are a variety
be 12 things that could be emplaced in the drifts or will
behind 13 emplaced probably and things that could be left
14 including human biological waste.

15 All of these need to be incorporated into our
what 16 considerations of establishing for various scenarios
17 the chemistry of the environment will be.

18 To conduct the long-term modeling when
considering 19 all of these attributes, there are a variety of
know 20 assumptions that we have to make. First of all, we
terms 21 we are dealing with a system that although in human
very 22 is going to be long-lived, in fact, geologically is a
23 short time period.

24 We must assume that although equilibrium may
be 25 approached, it probably will not be attained. We,
1 therefore, have to be concerned with the kinetics of

the

2 reaction in the environment.

3 The thermal stability of minerals is extremely
4 important and the range of temperatures that can
exist in

5 the environment obviously will be broad. We,
therefore,
6 need to understand what the thermal stability of
minerals,

7 particularly the secondary minerals, will be in the
8 environment and we need to understand the effects of
solid

9 solution on that stability of a particular mineral we
are
10 concerned with.

11 Finally, we must assume that there will be
some
12 interaction of pore water with man-made materials.

It is
13 difficult to imagine scenarios where that will not
occur.

14 We, therefore, have to have sufficient information to
15 incorporate those effects in our modeling capability.

16 Next slide.

17 Now what I want to do is talk about the work
that

18 we are doing in establishing, first, the reaction
kinetics

19 and our effort in determining essentially rates at
which

20 equilibrium will be approached. And then I'll talk
about

21 the numerical simulations that we have been doing in
this

22 area.

23 In this figure, I've taken examples of rock
water
Kevin
24 interaction experiments that have been conducted by
25 Knauss & Associates. They have been looking at the
tuff,
have
this
samples
us
26 interaction of water with pieces of Topopah Springs
27 either wafers or crushed fragments of rock. They
28 been emplaced in the action vessel and cooked up in
29 case to 150 degrees centigrade and through time,
30 of the solution have been extracted and this provides
31 with a means of understanding reaction progress.

32 The top four figures are on the vertical
access
horizontal
33 concentration of the indicated element. The
34 access on all figures is time and the bottom figures
35 represents pH.

36 What is important here is to recognize a
couple of
37 things. First, in all cases some steady state is
38 certainly approached in the reaction progress, but
the
39 steady state is not always the same. There may be
40 substantial scatter. Particularly if you look at
sodium,
41 you can see substantial variation from one experiment
to

17 the other.

18 In conducting model simulations and numerical
19 simulations of these models, it is imperative that we
can
20 in most cases reproduce what we see in these
experiments
21 but that is not true for all cases. There are
variations
22 that occur, reflecting the fact that starting
materials
23 are not always the same and it is not possible to
24 completely characterize everything that is there.

25 The second thing is that reaction kinetics is
89
1 important and there has been a paucity of data on the
ways
2 in which it can be represented which are ultimately
the
3 controls on reaction progress.

4 So we've established an experimental and
laboratory
5 effort to define this thermal stability of mineral
phases
6 as a function of chemistry of the environment and a
7 program to look at the dissolution of particular
mineral
8 phases. And I want to briefly go through what that
work
9 has shown us.

10 As far as the thermal stability of minerals is
11 concerned, as I've mentioned, we are dealing with a
wide
12 range of temperatures, as because of these values, we
need

13 to establish composition isotherms and internally
14 consistent highly accurate thermodynamic properties
and
15 mineral phases that we are concerned with.

16 We've then attempted to or plan to compare the
17 results of laboratory experiments at variable
temperature
18 and water chemistry with our numerical simulations to
see
19 the extent to which those results similar.

20 Once we've done that, it is possible to define
21 stability fields of the particular mineral phase that
we
22 are concerned with as a function of the temperature
and
23 composition.

24 DR. LANGMUIR: Bill?

25 DR. GLASSLEY: Yes.

1 DR. LANGMUIR: How about thermal gradient
studies
2 where you are looking at changes of thermal
composition?
3 Are there some studies published in that area? Are

you
4 going to be dealing with that sort of thing?

5 DR. GLASSLEY: You mean thermal gradient
across a
6 mineral grain?

7 DR. LANGMUIR: Across a meter or two or
three,
8 that sort of thing, as you would expect near a
catalyst.

9 DR. GLASSLEY: One of the things that we

10 ultimately expect to be able to do is describe how
the
11 chemistry of the water will change as it is moving to
the
12 thermal field. And, in fact, one of the modeling
13 activities that is taking place right now is a
combined
14 transport chemistry, a combined hydrology-chemistry
code
15 which will look at the transport of water across the
16 thermal gradient and establish what the actual
thermal
17 gradient will be in that kind of environment.

18 Does that answer your question?

19 DR. LANGMUIR: Yes.

20 DR. GLASSLEY: I want to show you a
particular

21 example to show you the direction our work has gone.
Next

22 slide.

23 This is a figure that shows the stability
fields of

24 a wide range of minerals in the system,
CaO-Al₂O₃-SiO₂-H₂O

25 at 100 degrees centigrade as a function of two
different

91
1 composition parameters. The log activity of silicon
is on

2 the bottom of the figure and the log activity of
calcium

3 is over the activity square of hydrogen on the
vertical

4 axis.

I
this
dashed
To
line, the
when we
indicated
some
occurs in
the
able
work
that
25

5 Originally when this figure was done -- well,
6 should describe first some of the important points of
7 figure. That line separates the phase fields. The
8 line labeled "quartz" shows where quartz is stable.
9 the left of that line "quartz," the solution would be
10 under saturated in quartz. To the right of that
11 solution is super saturated into quartz.
12 As an example of a problem that we ran into
13 were conducting our initial modeling activities,
14 Clinoptilolite, which is indicated by the field
15 as C-l-i-n-o-p, overlapped with the quartz line.
16 Clinoptilolite and quartz have never been reported in
17 nature before. Therefore, clearly, there had to be
18 discrepancy between the thermodynamic properties of
19 clinophyllite and the way clinophyllite actually
20 nature.
21 We undertook a very extensive reevaluation of
22 thermodynamic properties of clinophyllite. We were
23 to identify the particular problem in the original
24 that came up with the thermodynamic properties of
25 phase. We determined those thermodynamic properties

of

is

does

those

through

are

a

undertaken

that are

dissolution

ones

as

as

1 that phase. We generated a figure and the figure now

2 consistent with what is seen in nature.

3 Clinoptilolite does not exist with quartz. It

4 exist with mordenite and cristobalite. And both of

5 boundaries, although not plotted there, pass right

6 the clinoptilolite field.

7 That is the kind of work we are trying to do,

8 trying to establish what the thermodynamic properties

9 and thermostability is of the various mineral phases.

10 Next slide, please.

11 As I mentioned before, reaction kinetics are

12 extremely important in determining the rate at which

13 system is going to approach equilibrium. We've

14 an experimental program to determine both dissolution

15 kinetics and precipitation kinetics of the phases

16 of concern to us.

17 The ones we have looked at so far for

18 are indicated as well as precipitation kinetics. The

19 indicated by astrix are phases that occur in the rock

20 it exists now and they are also phases that can occur

21 secondary reaction products.

22 The conditions that we have been looking at in
23 determining dissolution precipitation processes and
24 kinetics, the pH range is 2-12 and the temperature is
25 to 240 degrees centigrade.

93

1 I want to show you an example of the kind of
2 results that we've obtained and describe very briefly
3 significance of those results. Next slide.

4 This is a figure that shows the dissolution
5 quartz indicated by the solid symbols and the rate at
6 which silica is removed from heulandite on the open
7 symbols. Vertical axis is log rate in moles per
8 centimeter per second and the horizontal axis is

9 These experiments were conducted at 25 degrees C.

10 What is important in this figure is that the
11 dissolution rate of quartz and the rate of silica
12 for heulandite at high pH's are virtually identical.

13 one were going to take modeling, using those two
14 and try to come up with the chemistry, which solution
15 one used or dissolution rate one used wouldn't make
16 difference in the results.

17 However, at low pH's the difference in

25

the

rate of

square

pH.

removal

If

phases

rate

much

dissolution

18 rate is substantial. In fact, the difference between
19 quartz and heulandite at a pH of 2 is more than 10
orders
20 of magnitude. Any modeling activity that would be
21 undertaken at low pH's that did not take this kind of
22 difference into account would be in substantial
error.

23 We are now trying to incorporate this kind of
24 information in our modeling activities. However, the
25 amount of dissolution data under these kinds of
conditions

1 is very limited. Much work needs to be done to
establish
2 this. We are in the preliminary stages. We are in
the
3 preliminary stages of incorporating it into our
models.

4 What I want to talk now briefly about is what
our
5 bodily efforts have been up to this point but which
have
6 not taken into account the kind of dissolution
behavior
7 that we've seen so far, at least not quantitatively.

8 Going back to this figure of the range of
water
9 chemistry, what we've done is to try to compute how
water
10 chemistry will change as a function of temperature
when it
11 interacts with the rock for a wide range of
conditions in
12 order to bound what we believe will be the chemistry
of

9 minerals that are stable at the end of the reaction
10 process.

11 What is important to note here is that the
minerals
12 that occur during the early stages of reaction into
two
13 different waters are very different. But by the time
one
14 reaches reaction completion, the minerals are
virtually
15 identical. What you are seeing is believing, the
fact
16 that the rock is dominated by the nature of the
chemistry
17 of the system.

18 Look at the next slide, please.

19 You see how the water responses changes in
20 minerology. For both solutions, the pH 7 and pH 10
21 solution, the pH's remain about where they started
out
22 during the early phases of the reaction progress; but
by
23 the time equilibrium is obtained, the solution is
24 virtually the same pH.

25 J-13 water, for comparison, is shown here.

You can

96

1 see it essentially falls within the bound except for
this
2 one data point here during the modeling progress and
3 eventually reaches the same state.

4 What that emphasizes is at least if the system
5 obtains equilibrium, the rock is going to dominate

the

6 chemistry of the solution and we can obtain probably
7 pretty good, very near bounds on what the water
chemistry
8 will be. But for those systems which have not
obtained
9 equilibrium which are still undergoing reaction
progress,
10 there is a wide range of possible conditions that the
11 waste container will experience if water contacts it,
and
12 it is that range of conditions that we need to
establish
13 and are in the process of establishing.

14 DR. LANGMUIR: Bill, you need to do it one
more
15 time. My comment earlier was that you were plotting
16 measured Eh's and using those measured Eh's which are
not
17 at equilibrium.

18 DR. GLASSLEY: That is right.
19 Along with some thermodynamic data values
here, the
20 minerals and the equilibrium Eh would really be on
that
21 water boundary with oxygen present at the top of your
22 figure. So one of your bounding conditions for
23 calculation should be Eh-pH condition at the water
24 boundary with oxygen. Even though it is not
measured, it
25 is the theoretical value.

1 DR. GLASSLEY: Absolutely.

your 2 DR. LANGSMUIR: And that should be one of
3 boundary calculations.

All 4 DR. GLASSLEY: I don't disagree with you.
we've 5 I'm presenting here is a range of computations that
has 6 conducted. The one you are talking about is one that
is 7 been conducted. In fact, as I remember, it certainly
8 included in the matrix of conditions that we need to
9 define and we are in the process of doing that.

going 10 The problem is, and it is a problem that is
operating. 11 to exist probably as long as this project is

12 What is, in fact, the Eh-pH of the water that is out
before, is 13 there. And what we have to do, as I mentioned

14 simply define the possible ranges both reducing and
15 oxydizing, and let those be the bounding conditions.

And 16 define those in such a way that we can be certain
that 17 whatever the water will be that will contact the
container

18 will be within that range of bounding conditions.
That

19 way, we will at least have a good characterization of
the 20 pH conditions in the environment.

unsaturated 21 DR. LANGMUIR: Chances are with this

22 condition, that as long as you can measure oxygen,
your pH

23 is probably up at the top of that the whole time.

24 DR. GLASSLEY: Absolutely.

25 DR. LANGMUIR: So that really is it.

1 DR. GLASSLEY: That is probably true but we
can't

2 prove it, which is the reason why we have to
establish

3 bounds rather than take a single value. Next.

4 In summary, the work that we have been doing
has

5 emphasized reaction rate work, trying to establish
the

6 kinetics of reactions that can occur, emphasizing

7 water-rock interaction and dissolution precipitation

8 processes.

9 We are working on generating sufficient
information

10 so that we can define precisely the thermal stability
of

11 minerals, taking into account taking both the

12 thermodynamic properties of the minerals and the
solid

13 solution behavior. We need to characterize the
effect of

14 man-made materials and how those affect the
environment

15 and that work is planned.

16 Modeling is proceeding as data is available to
us

17 and data are available to us. But one of the things
that

18 will be a very important activity in the future is
19 validating those model calculations and those
numerical
20 simulations.

21 Much of the work in the next years will
involve
22 developing strategies and carrying out those
strategies
23 for validating our numerical simulations for the long
term
24 behavior to the environment.

25 Any questions?

99

1 DR. LANGMUIR: One last chemical-type
question.

2 As you are aware, there have been a number of papers
3 published in the last five years or so which have
looked
4 at the effect of thermal gradients around each source
on
5 the geochemical process and hydrology. And one of
the
6 most important aspects of what you are getting into
or
7 what the program is looking at or should be looking
at
8 certainly is to what extent do these reactions alter
9 hydrological properties of the adjacent blocks.

10 DR. GLASSLEY: Absolutely.

11 DR. LANGMUIR: And in many cases, of
course,
12 they've shown that they seal up the porosity in the
13 source rock and that sort of thing. This is a very
14 important interplay between the geochemistry and

hydrology

15 that should be addressed and I'm wondering if your
group
16 is doing this or what group in the program is doing
this
17 kind of work.

18 DR. GLASSLEY: We realize that probably the
most
19 important part of conducting numerical simulations
for
20 this environment will involve a couple flow and
transport
21 code.

22 There is in existence now a modified version
of
23 EQ3-6 looking at flow regimes, and they try to
establish
24 how rock fluid interaction will change the
hydrological
25 properties of the flow pathways.

100
1 Mineral precipitation will influence fracture
will
2 roughness. It will change fracture aperture and
The
3 change pore sizes and influence all of these things.
4 code is in the early stages of accomplishing this.

5 Ultimately, what we expect to do and what our
plan
6 is to intergrate the EQ3-6 kind of approach with the
have
7 hydrological kinds of computations that Tom and John
provide
8 been doing in a much larger code package that will
9 the kind of information that we talked about: How

6 of things.

7 That is an area that we are looking at very
8 actively and we have an experimental program that
9 addresses that. It also is tied to the hydrological
work

10 that Tom and John are doing. And many of the
experiments

11 that Wunan, Lin & Daily have done have been guided by
the

12 numerical simulations that John and Tom have carried
out.

13 So there is a very strong coupling there and
much

14 communication in establishing what the behavior of
that

15 kind of system is.

16 DR. NORTH: Could you tell us a little bit
more

17 about the effects of man-made materials? What it is
that

18 you are worried about? What investigations do you
plan?

19 There are several things that you listed, and
I'm

20 wondering if you could translate these into, for
example,

21 the Eh-pH regime. What kind of excursions might be
22 possible given that some things were done in the

course of

23 repository operations like leaving some human garbage
24 around. Is that a serious problem and what might be
the

25 implications to the overall program in terms of
dealing

1 with it?

2 DR. GLASSLEY: We think that potentially it
is a
3 very serious problem. We know that based on
experiments
4 that have been conducted so far, it generates waters
that
5 have very high pHs of 9 and a half or greater. In
fact,
6 the lowest pH of water coming out of cement has a pH
of 9
7 and a half and pH's of 12 are not uncommon. That
kind of
8 pH can have a dramatic effect on the performance of
the
9 container material.

10 It can also have a very important effect on
how
11 fuel, spent fuel or rock waste forms, dissolve. We
are
12 planning an activity or a task area that looks at
nothing
13 but the kinds of man-made materials that will exist
in
14 that environment to establish what the interactions
will
15 be.

16 The approach that we plan on taking is first
going
17 through the lists of materials that have been
developed
18 for what will be in the repository, establish on the
basis
19 of some reconnaissance work and literature surveys
which

20 of those materials probably would be the most
reactive.

21 Then establish a laboratory program and numerical
22 simulations program to determine the effects of those
23 materials on water chemistry.

24 Then when that is done, try to conduct some
25 validation exercises and numerical simulations to see
what

103
1 the long-term consequence of having that material in
the
2 repository would be and how it would interact with
the
3 rock that would be in there.

4 Most of the work that we've done so far is
5 collecting information. We've been in contact with a
6 variety of laboratories that are doing work primarily
in

7 concrete because that is where most of the
information is

8 going to lead. There is a lot of work yet to be done
in

9 human biological waste, volume, composition, impacts
on

10 water chemistry. A lot of work needs to be done on
11 paints, solvents of any kind, drilling fluids that
could

12 be used. It would be a very extensive program that
would

13 require many years of long-term experiments.

14 DR. NORTH: It is the many years of
long-term

15 experiments that concerns me. What I would love to
see at

16 this point, and we'll make this a specific data
request,

17 is one, a plan for carrying out the investigation
with

18 respect to these man-made materials or human
biological

19 wastes. And instead of back-of-the-envelope
calculations,

20 the effect of where should we work?

21 You've mentioned the Portland cement issue,
human

22 biological waste issue. You didn't go into that.
What

23 are the implications? Is it possible to fix this
rather

24 easily, like we require everybody in the repository
to use

25 port-a-potties, or not throw their lunch somewhere or
are

104
1 we talking about having to design a new kind of
cement

2 that doesn't exist?

3 DR. GLASSLEY: Well, the task that I was
talking

4 about, man-made materials task, would have as its
primary

5 goal establishing precisely the kind of guidelines
that

6 you are talking about.

7 DR. NORTH: I'm worried about can we have
those

8 insights in the next six months or so as opposed to
ten

9 years after the research is finished? It seems to me
the

10 that the implications for the program are
sufficiently

11 important so that it would be hopeful to get a first
cut

12 at these issues very soon.

13 DR. GLASSLEY: I would agree with you.

14 DR. NORTH: Second question, this relates to
a

15 paper of yours dated October 1, 1986 which I had as
part

16 of my reading before coming into this meeting.

17 DR. GLASSLEY: Could you tell me the title
of

18 that?

19 DR. NORTH: It is entitled "Reference Waste
20 Package Environment Report," and I'm looking at it in
the

21 discussion of thermal effects on rock physical
properties.

22 And it discusses cristobalite and a particular phase
23 transition from alpha to beta, and notes this phase
24 transition results in a volume increase of about five
25 percent, referencing Helgeson, et al, 1978.

105
1 It then goes on to conclude at the end of this
2 discussion and I quote:

3 "The alpha to beta cristobalite
transition

4 temperature falls within the temperature
5 range expected for the near-field waste
6 package environment during the period
7 immediately following emplacement. The

8 effect of the associated volume change
on the

9 waste package environment has yet to be
10 established."

11 I'm particularly interested in the last
sentence.

12 What research has been done on the issue of the
associated

13 volume change on the waste package environment? And
if we

14 haven't made any progress since 1986, why haven't we?

15 DR. GLASSLEY: Two responses to that.
First, the

16 work has continued and there was a paper that
occurred at

17 the most recent MRS meeting that dealt with some of
the

18 work that has been done by Dr. Annemarie Meike and
myself

19 looking at the phase transition alpha to beta
cristobalite

20 in the presence of vapor phase, It was a HVEM study,

21 trying to understand how that transition takes place
and

22 what it really means.

23 There is also work that is being planned in
Steve

24 Blair's task, which he'll describe later on today,
that

25 concerns how volume changes really influence the

1 development of cracked growth, possibly the formation
of

2 microcracks.

3 Ultimately those may have an impact on water

change 4 chemistry and water flow pathways because it could

5 the permability pathways of matrix.

is 6 Those are all concerns that still exist. Work

7 in progress to evaluate those particularly in Steve's

by any 8 area. It is not something that has been terminated

9 means.

structural 10 DR. NORTH: How about the physical and

this 11 implications of five-percent volume increase from

talking 12 mineral? Are we talking about spalling or are we

13 about mechanical loads on the containers potentially?

with. 14 DR. GLASSLEY: Those are precisely the
15 considerations that Steve is involved in dealing

those 16 DR. NORTH: Good. So he is going to answer

17 questions?

18 (Laughter)

19 DR. GLASSLEY: Any other questions?

you 20 DR. CARTER: Yes. I have a couple. One,

is to 21 mentioned one of your most important task functions

process 22 generate source times. How far along has that

23 gotten?

the 24 Have you taken a worse case, a release of all

of 25 radionuclides that might be there over short periods
some 1 time? Have you ranked the radionuclides? Is there
2 things that you are most concerned about?
waste 3 DR. GLASSLEY: There is a technical area,
currently 4 form performance, waste form behavior that is
a 5 headed up by Ray Stout that has been looking at the
6 interaction of waste forms with various waters under
things 7 wide range of conditions to establish what kinds of
they've 8 could come out. There is a vast literature that
9 generated. The work is extensive and that work is
10 continuing.
of 11 What we need to know to establish the behavior
how 12 those materials once they get out of the container is
because 13 those materials interact with corrosion products
products 14 those solutions will be in contact with corrosion
15 before they get to the packaged environment.
it is 16 That information has yet to be generated and
it is 17 something that is expected to be available to us but
do the 18 not available yet. Once that is there, then we can
19 kinds of studies necessary to determine the behavior

of

20 those elements once they are in the waste package
21 environment.

being

22 So at this point, the basic information is
23 generated by the waste form materials people
determining

24 what the water chemistry would be in the waste
container.

25 The next step is to determine what the water
chemistry

1 will be as it leaves the container and then we'll
take it

2 and play with it in the waste package environment.

in

3 MR. CARTER: You are eventually going to get
4 the loop but you are not there yet?

5 DR. GLASSLEY: Yes.

to

6 DR. CARTER: What about considerations given
7 the differences between high level waste in a
repository,
8 used fuel elements in the repository, and any
particular
9 mixes of those two waste forms?

10 DR. GLASSLEY: Mixed waste?

and

11 DR. CARTER: Mixes between high level waste
12 used fuel elements. I presume the source terms are
13 different for those two waste forms.

that

14 DR. GLASSLEY: What we'll do and our
15 consideration is to take the spectrum of solutions

16 the people involved in the waste form interactions
17 technical area generate and deal with each of those
in our
18 evaluation of how they behave in the package
environment.

19 We don't expect to have just one solution of
20 chemistry or one type of solution that we are going
to
21 deal with. We have to cover the entire spectrum. So
22 anything that we'll deal with, I mean, it would cover
the
23 range of things that you are talking about.

24 DR. CARTER: I think that the only thing
that
25 we've heard today so far, if I'm not mistaken, has
dealt
109
1 with used fuel elements and not with high level waste
per
2 se.

3 DR. GLASSLEY: We are dealing with spent
fuel,
4 processed fuel, glass.

5 DR. CARTER: Well, when I say used fuel
elements
6 I'm talking about spent fuel but not processed fuel
in the
7 alloy.

8 DR. GLASSLEY: You mean glass?

9 DR. CARTER: Yes.

10 DR. GLASSLEY: We fully expect to deal with
that
11 as well. We are by no means ignoring that. It makes
a

12 significant compliment with the material in the
13 repository. It is something that we have to deal
with.
14 And everything that we have been doing has been done
under
15 the assumption that we are going to have to deal both
with
16 the glass waste form and spent fuel.

17 There has been no distinction made between the
18 necessity of dealing with either of those.

19 DR. CARTER: But at the moment you are
dealing
20 with essentially spent fuel?

21 DR. GLASSLEY: No.

22 DR. CARTER: And your temperature
generations and
23 so forth are related to that. Is there a possibility
that
24 you could have mixes of these materials as far as
waste
25 forms?

110
1 DR. GLASSLEY: Sure. We've said that.

2 DR. CARTER: And this would affect all of
the
3 things, I think, that you are going to be interested
in
4 studying.

5 DR. GLASSLEY: Absolutely. It will affect
both
6 the chemistry and solutions and the temperature that
will
7 exist around the waste packages. All of those issues
are

And 8 part of the efforts that Livermore is undertaking.
9 although we've talked primarily about extreme cases,
that 10 particularly high temperatures, the 240 degrees,
11 essentially is the maximum.

high 12 There is going to be, because of this mixed
conditions 13 level waste issue, a variety of temperature
conditions 14 that we have to consider, including temperature
probably 15 around processed waste forms where the heat will
much 16 be much less intense and the radiation field will be
17 less intense than it would be around spent fuel.

we are 18 All of those are considered in the work that
fuel, 19 doing. The presentations may have emphasized spent
there 20 but that doesn't mean it was not meant to imply that
21 was no work being done in glass work form at all.

terms 22 DR. CARTER: I guess a related question in
23 of potential release of radionuclides, are you more
me ask 24 concerned with spent fuel or high level waste? Let
25 the question that way.

111
will be 1 DR. GLASSLEY: I think for most of the
2 radionuclides of concern, the main source for them

3 spent fuel.

4 DR. CARTER: But not to the exclusion of the
5 glass?

6 DR. GLASSLEY: Absolutely not, no.

7 DR. JARDINE: Dr. Carter, I might mention
that we
8 have a whole other technical area that is equal or in
big
9 as size as the near-field environment that deals
10 specifically with waste form testing, and there is an
11 extensive series of activities, including other
national
12 laboratories, doing glass waste form testing. It is
not
13 something that we've put together today but it could
14 certainly be done in the future.

15 DR. CARTER: Well, what flagged my interest
was
16 the fact that he put up the things that he is
particularly
17 interested in as far as important task functions.
And if
18 I'm not mistaken, one of them was generation of task
forms
19 and the other was satisfying regulatory requirements.
So
20 that is the reason for the question.

21 DR. GLASSLEY: And I would respond that we
are
22 dealing with all of the waste that could exist in the
23 repository.

24 DR. CARTER: I guess in a way everybody is

25 dealing with those particular questions.

112

1 DR. GLASSLEY: Yes.

discuss 2 DR. CARTER: But you are not prepared to
3 those?

4 DR. GLASSLEY: No.

what 5 DR. ISAACS: There is still an issue out of
6 will go into the repository. It is a consideration
of 7 greater than Class C waste, for example, that we
haven't 8 talked about. And the important terms there would be
to 9 find out the kinds of issues we might have to
consider.

to 10 There would be yet another challenge should we have
11 start considering accepting that kind of waste of
12 repositories.

the 13 DR. GLASSLEY: If that becomes present in
14 repositories, then the man-made materials task is
greatly 15 expanded because chemical interactions with those
other 16 materials would have to be considered as well.

the 17 MR. WILDER: We are now going to move onto
18 mechanical loading conditions on the container
materials.

19 And the areas that we are going to try to focus on a
20 little bit are the impacts on the hydrology and

could be 21 specifically looking at what some of the impacts
22 on the air gap.

23 Also, looking at geochemistry impacts, and
24 specifically Steve will talk a little bit about some
of
25 the mechanisms whereby increased surface area might
be

1 available for rock-water interaction. 113 And finally,
the
2 loading conditions including the block failures of
sand
3 and creep. Now I'll turn the mike over at this time
to
4 Steve Blair.

5 MR. BLAIR: Good morning. Today I want to
talk
6 to you about work that we have planned to do on the
7 mechanical attributes, to study the mechanical
attributes
8 of the waste package environment.

9 I want to mention that this work is in the
planning
10 phase. We have not completed any tests to date.
We've
11 completed a study plan and that study plan has gone
to DOE
12 for review and it is presently back at headquarters.
We
13 expect to be getting the viewed copies and comments
back
14 and we'll incorporate that and resubmit the study
plan.

15 In this talk, I'll first review some of the

package 16 effects, the thermomechanical effects of the waste
of 17 emplacement, and then I'll discuss specific aspects
look 18 elements in our study plan. In particular, I want to
then 19 at borehole stability, modeling and validation, and
20 I'll give a brief summary.

rock 21 I will not be discussing tests to look at the
22 properties or fracture properties. Thermomechanical
all, 23 effects of the waste package emplacement -- first of
borehole 24 I want to mention that just the excavation of the
stress 25 for where the package will go will increase the

114
1 along the borehole. Increasing the temperature,
2 increasing of the stress, the moisture, the strength,
3 creep rate, and as discussed earlier, may cause phase
4 transformations in the formation. Decreasing the
the 5 temperature during the cooldown phase will decrease
6 stress and also change the moisture distribution.

I've 7 As far as stress around the borehole here,
the 8 shown schematically what stress would look like in
be 9 uniaxial stress field. Actually, the formation would
when 10 more complicated than this but this slide illustrates
11 you put a hole into a rock mass or any infinite

medium,

12 the stress concentrations are on the borehole.

radii,

13 So you can see that within a few borehole

back

14 right next to the borehole, the stress will increase
15 dramatically within a few borehole radii it bores
16 down to the ambient levels.

as

17 Here I'm using the same slide that Dale shows,

plotted

18 far as the temperature is along the borehole, and

water

19 temperature boreholes calculated for pressurized

that

20 reactor. What I want to point out on this slide is

high

21 very near the borehole, the same area where we have

for

22 stress concentrations, we also have high temperatures

23 a long time.

so

24 That is in the areas of one borehole diameter,

25 we can have temperatures over 100 degrees C for

1 considerable length of time up to a thousand years.

would

2 Here we show schematically how the moisture

3 be distributed around the borehole, and this is just
4 depicting some of the results from G-tunnel which Abe
5 will discuss in more detail in the following talk.

around

6 We see that the moisture is, first of all,

7 the borehole. There is a dry zone. There would be a

8 saturation "halo", and then saturation back to
ambient

9 conditions as we move away from the borehole.

10 Now, the majority of this talk is going to
discuss

11 some issues that we think are appropriate as far as
12 boreholes stability. Over the time periods of the
13 repository, mechanism such as subcritical crack
growth or

14 creep may affect the borehole wall. Our purpose is
to

15 increase confidence in the estimates of the amount
and

16 type of mechanical loading on the waste package by
looking

17 at these phenomena.

18 There are several mechanisms that could affect
the

19 borehole wall. In the study plan, we specifically
address

20 three of those and in this talk I'm going to
concentrate

21 on spalling and block movement. Spalling would have
the

22 effect of wicking water onto the container in loading
the

23 container. Block movement would also wick water onto
the

24 container and cause point loading on the container.

25 I'll not talk about creep today but if the
116
1 formation were to increase, it would reduce the air
gap

2 and also bring loads onto the container.

3 As far as spalling, the rate of subcritical
crack
4 growth increases with increasing temperature and
stress in
5 rock. Spalling may occur due to the growth of
cracks
6 near the borehole by this mechanism.

7 Over long times that we have available in the
8 repository, this could become significant. We plan
to
9 study this using laboratory studies, a series of lab
tests
10 and then through some numerical models.

11 I want to note that the work to date in both
effect
12 G-tunnel and Climax has not shown evidence of this
mechanism
13 in other short-term tests, but we feel that this
14 should be examined.

15 Just to orient you to the slide that follows
this,
16 I want to show schematically the log of crack
velocity
17 versus stress intensity. This is for rock. And we
see
18 that as we increase temperature and increase the
vapor
19 pressure, that the crack velocity increases at a
given
20 stress intensity.

21 Now here we are looking at some data for
granite
22 and what we see are data for cracked velocity at 20
23 degrees C, 100 degrees C, 200 degrees C and then 300

24 degrees C. And what we see then is that as you
increase
25 to 100 degrees C, you actually may get a decrease in
1 velocity. But then as you go above 100 degrees C,
the
2 subcritical factor increases. We also see that as
you
3 increase the relative humidity or the vapor pressure,
that
4 the crack velocity also increases.

5 Now, for the repository conditions, we expect
to
6 have stress intensities down in this range. And also
I
7 want to point out that even at a crack growth rate as
slow
8 as 10^{-9} meters per second, that would
give us
9 a growth rate of one meter in 30 years. We don't
need to
10 grow the cracks a meter long, but we have plenty of
time
11 to grow cracks even small distances. Next slide,
please.

12 As far as mechanisms that may be responsible
for
13 some of these phenomena, some work has been done on
the
14 subcritical crack growth in glass and we see that at
the
15 cracked tip, this represents a cracked tip on a
molecular
16 scale. Due to the size of the water molecules, you
get
17 down to the cracked tip and form bonds.

14 these stresses here and another here. And at later
stages
15 of failure, given on the next slide, we see that
these
16 cracks are then coalesced to form a piece of borehole
wall
17 that then spalls into the borehole.

18 Now, the idea of this study, the aspect of
this
19 particular study plan, then, would be to investigate
this
20 phenomena in tuff. First we look at the relation of
21 cracked velocity, density, temperature and the
potential
22 of water vapor pressure. We look at the stress along
the
23 borehole and look at the mechanism by which boreholes
24 actually fail in tuff.

25 This work has been done on limestone and there
has
119
1 also been some similar work done in sandstone. Work
of
2 this kind today has not been done in tuff, so we
don't
3 really know what the mechanism failures around the
4 borehole are.

5 We also planned some tests to look at block
6 stability around the borehole. These blocks would be
7 formed by sets of fractures that would intersect and
form
8 blocks that could move into the borehole at long
times.

9 First thing we would do is, using the

distribution

10 of fractures, identify the blocks and shapes. Then
we
11 would do a kinematic stability analysis to identify
key
12 blocks that may move in to conduct stability analysis
for
13 selected key blocks.

14 Now, this type of analysis is well established
and
15 we would use existing codes, and we wouldn't initiate
this
16 particular work until the ESF becomes available.

17 As far as modeling and validation of this
work, we
18 feel that we need to develop models for time
dependence,
19 temperature dependence, also looking at the effects
of
20 radiation. And then as I discussed before, the
effect of
21 mineral phase transformations.

22 Cristobalite occurs in very small grain size
in the
23 ground mass of the Topopah Springs tuff. Now at the
24 temperatures of the repository, it may undergo this
phase
25 transformation at the tuff or microcracks under the
120
1 conditions then of the high stress and increased
2 temperature flow. Not high stress, but the elevated
3 stress condition and increased temperatures, these
4 microcracks may then grow and lead to changes in the
5 physical and mechanical properties.

6 As far as once we develop these conceptual
models,
7 we'll evaluate the existing codes and incorporate
those
8 potential models into FEFFLAP or SANCHO. HEFF is
another
9 code that is available. The Block Stability code
that is
10 available now is called BSTAB3D.

11 We also plan on a series of larger laboratory
12 tests. As far as the modeling validation, we've
tried to
13 simulate these laboratory tests as part of the
modeling
14 validation.

15 In summary, the purpose of this task is to
16 characterize the mechanical behavior of the waste
package
17 environment. We are looking at time dependent and
18 temperature-dependent mechanisms and the work is
presently
19 in the planning phase.

20 Any questions?

21 DR. NORTH: Do you want to expand on your
22 comments with regard to Cristobalite as to how
serious a
23 problem it might be? Is there anything further
beyond
24 what was stated on this problem in 1986 in terms of
our
25 understanding the implications for the program?

121

1 MR. BLAIR: There have been some thermal

2 measurements done and they show that Cristobalite
might
3 not just be the only culprit mineral here. There
actually
4 are a couple of other minerals here that give us
5 significant thorough disadvantage. As far as what
that
6 will do, as far as the general stress levels and
localized
7 stress levels, the calculations have not been made.
8 We looked at some SEM as far as identifying
how
9 much Cristobalite there is and where it is located
but we
10 haven't really gone beyond that as far as this.

11 DR. NORTH: Do we have any sense of how much
this
12 problem is reduced if we go with lower levels of
thermal
13 loading from the fuel, with taking fuel that has been
aged
14 for a longer period as opposed to the reference
design?

15 MR. BLAIR: The work to date shows that
thermal
16 expansion is actually significant at temperatures
just
17 above 100 degrees C. It starts to go up to 200
degrees C.
18 It is fairly significant.

19 So if you are looking at waste much below 100
20 degrees C, then it would probably not be a problem.
But
21 at temperatures much above that, I think we would
have to

22 look at it.

level
23 DR. NORTH: There are no insights at the
24 that looks like you have a potential for serious
25 microcracks and spalling block formation, et cetera,
when
1 you get up above 200, but at 150 it should be much
less.

150.
2 MR. BLAIR: I think it would be much less at
3 I think at 225 we can certainly say that we would
probably
4 have the problem. We don't have a lot of hard data
to
5 back that up.

6 DR. NORTH: How long is it going to take us
to
7 get that data?

8 MR. BLAIR: I think if we can get the rock
and
9 get the study plan through, then we can start looking
at
10 some of the effects of this, as far as the cracked
growth
11 rate, as a function of fractured toughness or as a
12 function of stress intensity.

13 Hopefully, we could start those tests in
another
14 year, but right now we are in the paperwork phase of
the
15 study as far as getting it moving.

would
16 DR. NORTH: Given what you've described, I

is a 17 like to put a request to the Program. Suppose there
18 problem here. Suppose there is a potential for
19 considerable degree of fracturing in the replacement
20 boreholes? What do you do about it? What is the
21 contingency plan?

up? 22 MR. WILDER: Can I make a comment to follow

which 23 First off, there are some engineering design things

the 24 are under consideration. For instance, fully line

borehole 25 replacement hole to prevent the spalling into the

123

1 would be one approach.

progress in 2 The other thing is that we've made some

3 terms of understanding the physical process, the

things. 4 geochemistry kinds of things, mineralogy kinds of

on the 5 And there are studies that indicated that depending

amorphous 6 amount of water present, we may go through an

significant 7 stage. And if we do that, we have some fairly

structure 8 problems because obviously it doesn't have any

9 to give it strength.

But in 10 So it is not that we haven't made progress.

are 11 terms of the actual mechanical attributes at work, we

12 very much in the planning stage.

13 In fact, there was a question that was asked
14 earlier about the impacts in terms of just starting
work
15 versus the QA. We have to make sure that we have the
16 study plan approved and in place before we can start
this
17 work.

18 We do envision that within a year we would
have the
19 mechanical attributes portions of it done. But in
terms
20 of the minerology, that work is progressing.

21 DR. NORTH: One of my favorite things is
the
22 need for contingency plans, and this seems like a
very
23 good example of where it is needed. The very concern
that
24 I have is what we just heard back to the
geochemistry.

25 For example, I think if you have to line these
boreholes,
1 are you going to do this with cement? And what does
this
2 imply for the pH-Eh regime?

3 Are we talking about pH's of 9 to 12? And
what are
4 the implications that may have for all the analysis
that
5 we are doing for the geochemistry? So there are
kinds of
6 interaction that need to be explored.

7 My concern is that I don't see that that has
been

8 done. And maybe you do it a very crude
9 back-of-the-envelope level to try to understand how
10 serious the problem is and can you fix it easily or
is it
11 going to be very hard, because when you try to fix
it, you
12 cause some other kind of problem over here that you
then
13 have to deal with.

14 So I'll put my plea on the record. Do the
figure
15 contingency planning. Lay out these scenarios and
16 out what you are going to do if you have a problem.
And
17 how immediate it is therefore, depending on the
difficulty
18 of doing that contingency response to get this kind
of
19 data early as opposed to doing the research on a very
20 leisurely time scale.

21 DR. PRICE: What is the maximum temperature
that
22 you have plans to look at for this?

23 MR. BLAIR: We were looking at plans up to
250 C.

24 DR. PRICE: What perplexes me a little bit
is
25 that the temperature profile that you showed looked
like

1 it as 190 something, and then I've heard ¹²⁵ 232, 242,
243,
2 250.

3 Why is there such a wide range of estimates as

to

4 the maximum temperature?

5 MR. WILDER: Let me respond to part of that
6 because I think some of the comments were during my
7 presentation.

8 Part of the variations is in terms of what you
9 assume the fuel age and the fuel mix to be and so
forth.

10 And so some of the higher values that I use were the
11 bounding conditions, very young spent fuel, probably
12 unrealistic at this point because many of our
calculations
13 were based on Code 3 exercises, taking half-year-old
fuel.

14 And of course with scheduled controls and so forth,
it is
15 very unlikely that we are going to be dealing with
16 temperatures that high.

17 The other thing is some of the temperatures
that we
18 were reporting, I think, were in response to what are
the
19 temperatures on the container itself. They are
pretty
20 close to the same as the borehole wall temperatures.
21 There is a slight variation.

22 I think the differences that you are seeing
depends
23 on the assumptions that you make as far as what the
24 emplaced waste is, how old it is, what the mix is,
what
25 the configuration is, what the configuration is

inside the

126

1 container. So I think the worst case is 250 to 250

2 degrees, the worst.

3 DR. PRICE: Thank you.

4 DR. VERNIK: Thank you.

5 MR. WILDER: We are now ready to move onto a
6 study that was done at G-tunnel. This is a field
scale

7 study. It doesn't fit one of the five interaction
8 bulletins because it really incorporates all of what
we
9 have been talking about.

10 But this was specifically a field skill test
of the
11 hydrologic and thermal response, and so we were
testing
12 the hydrothermal models, measurement techniques and
13 procedures.

14 I should point out that it was a horizontal
15 orientation. The intention was that we would
continue the
16 prototype testing in the vertical mode. Later on
when we
17 had a greater extent of welded tuff available -- at
the
18 time, the welded tuff that we had available was not
19 sufficient vertical depth to be able to do a vertical
20 prototype test.

21 And secondly, with the limited resources that
we
22 had at the time, we were not able to do everything
that we

which 23 wanted to in terms of the geochemistry and so forth,
started 24 a reference orientation we felt justified. So we
will be 25 with the horizontal and this is the work that Abe

127

1 responding to.
work Abe 2 Three things, I think, that are key to the
3 will report. One is that it did provide the
understanding 4 of physical processes that go on. It gave us an
5 opportunity to compare the numerical and analytical
codes 6 and models for -- well, I'm calling it a generic
tuff. It 7 is not the repository horizon tuff but it is a welded
tuff 8 with similar mechanical attributes.

9 And finally, it did allow us to look at the
10 instrumentation measurement techniques and evaluate
them.
11 So now I'll then turn the mike over to Abe Ramirez.

Abelardo 12 MR. RAMIREZ: Good morning. My name is
13 Ramirez and I want to tell you about the fuel tests
that 14 were done at the G-tunnel.

15 At the present moment, we will give you a
snapshot 16 of our interpretations but we reserve our right to
change 17 our interpretations as time progresses and we
continue to

18 uncover more interesting information.

19 I would like to say that what I'll do is give
you a
20 brief introduction of what we did during that test,
and
21 lead right into the summary, guiding you through the
key
22 observations that we have made. And then as time
allows,
23 show you some of the supporting evidence that drives
those
24 conclusions as you'll see.

25 The purpose of the G-tunnel test primarily was
to

128
1 evaluate our ability to characterize the near-field
2 environment. This kind of testing has not been done
3 before, so one of our concerns was do we have the
tools
4 and understanding needed to properly characterize the
near
5 field environment.

6 So that was the main objective of prototype
testing
7 was to give us the ability to decide whether we are
ready
8 or not to do this kind of testing.

9 We were concerned about whether we had the
right
10 kind of measurement techniques available to us. We
also
11 wanted to provide in situ data that would allow us to
and
12 evaluate the applicability of our conceptual models

13 also provide data that would challenge the
predictions

14 from the numerical code, the code that Tom described
15 earlier.

16 We also wanted the opportunity to develop what
17 quality assurance procedures and try them under the
18 realistic conditions, see if we can have workable
19 procedures and control the work in the field. Next
slide.

20 The rock was perturbed by a heating and
cooling
21 cycle. What you see on the left here is the heater
power

22 schedule used. You see the vertical axis here, power
23 shown in kilowatts. And on the horizontal axis, you
see
24 time and date from start of heating.

25 You see the figure of 128 days. We heated the
rock

1 at maximum power and the maximum power applied was
3.3

2 kilowatts. Now the heat loading rate for this test
was

3 about two and a half to three times that of an actual
4 spent fuel waste package. The reason for the
overdriving

5 condition is that we have a limited amount of time in
6 which to conduct the test.

7 We wanted to create a regional boiling that
8 incorporates several practices within that period of
time,

9 and the only way to do that was to provide the rock
with a

10 lot more heat than what a true waste package could
11 actually provide.

12 We were shooting to create a boiling region
13 diameter of approximately 1.4 meters so that it would
14 include within this boiling region several fractures.

The

15 fractures facing in this location is about .3 meters.

16 The heater was on for 195 days and the cooling
17 ramp, after we heated at maximum power, we then
started
18 decreasing the power gradually over a period of 68
days to
19 try to simulate a cooldown condition somewhat akin to
a

20 true cooldown situation in the repository, of course.

In

21 the repository, the cooldown will occur over a period
of
22 centuries and here we are making it happen in 68
days, so
23 really accelerated. Next slide.

24 This is the plan view of the test region.
Here we

25 show the heater. The heater was about 3 meters long.

It

130
1 was emplacing a 12-inch borehole. You can see that
we
2 have 12 boreholes which monitors the response of the
rock
3 during the test. We had boreholes that came in at
about
4 right angles to the heater and were concentrated near
the

5 center of the heater. We also had boreholes that
came in
6 axially to the heater. Next slide.

7 These are the kinds of measurements that were
made
8 during the test. We measured temperature throughout
the
9 rock which was approximately 120 thermocouples used.
We
10 measured changes in moisture content using a couple
of
11 physical methods, dielectric, neutron logging and
gamma
12 density logging.

13 We monitored steam pressure during the test,
matrix
14 pore pressures using psychrometers, microwave
resonant
15 circuits, capacitance sensors. We used rock
permeability
16 testing of the heater borehole before we started
heating,
17 completed the heating cycle and then we turned to the
18 heater wall and we checked the measurements to see if
the
19 rock permeability would change so that we could
decide
20 whether microfracturing occurred which would enhance
21 permeability.

22 We also did fracture mapping and also
atmospheric
23 pressure. Okay.

24 I'm going now into the summaries of the key
points.

25 We think that the primary contribution of the test is
that
131
1 it has allowed us to evaluate our conceptual models
and
2 point out areas where we have problems and point out
areas
3 where we are doing all right.
4 We know that if this cartoon is intended to
5 illustrate the situation that we had around the
heater,
6 this is the heater inside a 12-inch borehole. We
know
7 that we created a dry region around the heater and
the
8 drying increases toward the heater inwards as we
expected.
9 We know that we created a saturation "halo"
10 immediately adjacent to the dry region and that this
11 saturation "halo" as time progresses moves out
basically
12 as the dry region forced it out and increased.
13 The radius of the dry region matched the
prediction
14 of about .6 or .7 meters, or in other words, 1.4
meters
15 diameter as I initially indicated. Fractures have a
16 measurable effect on the drying condensation front.
In
17 the drying front, we know that the drying front tends
to
18 extend more where the fractures are present. We
think our
19 data shows that. The rewetting process when the
20 temperature starts dropping and when water,

therefore, can

21 start coming back into this dry region, apparently
22 happened primarily where the fractures were, so the
23 fractures had a dominant control on the rewetting
24 processes.

25 The measured temperatures were close to our
fractures 1 predicted temperatures, and we observed that the
the 2 had a slight cooling effect on the temperatures in
3 regions where boiling occurred. Next slide.

4 We also had some surprises. The rock below
the 5 heater dried faster as the temperatures increased.
We

6 think the reason for this is that we had some
calculations 7 gravity-driven flow. And when the scoping
such a 8 tests were performed, the problem was performed in
9 way so that gravity was not a factor, so the
predictions 10 did not account for gravity-driven flow.

11 We also had increased fractures below the
heater 12 and as compared to the region above the heater. And
it is 13 also probably drying faster.

14 The rock above the heater rewetted faster as
the 15 temperatures started dropping. Again, we think that
this 16 is an indication of gravity-driven flow of the

saturation

17 "halo" overlying the heater region contributing
water,
18 similar to the dry zone above the heater, so that
that
19 route of flow would tend to move the water away from
the
20 dry region below the heater.

21 The "halo" of increased saturation differs
from
22 predictions. That is, this saturation "halo". We
think
23 that there are two likely reasons for this
descrepancy.

24 No. 1, we know that the TOUGH Code that Tom used only
had
25 the drying factors incorporated into it. It did not
have
133
1 the wetting correctors incorporated into it because
this
2 data is not available at the moment . That would
tend to
3 overpredict the magnitude of the saturation level.

4 We also know that when we started the test,
the
5 ambient conditions for the rock were very close to
full
6 saturation, so there was only a very small delta to
be
7 filled in the bore space with water. And, of course,
you
8 cannot go beyond 100 percent saturation, so we
probably
9 reached 100 percent saturation very early in the
test.

draining 10 And once we reached that point, the water started

11 away and we could not build-up much of the saturation
12 level.

13 We also saw slight increases in the rock
14 permeability as measured by the gas permeability
15 measurements.

you a 16 In terms of the instrumentation, I can give
17 brief overview. We did find that we had several
problems.

We 18 We found that some of the instruments corroded badly.

that we 19 also found that some of the calibration processes

needed to 20 thought were adequate were indeed inadequate and

giving 21 be revised and we had some of the instrumentation

understood. 22 inconsistent results and this is still not

23 Next slide.

changes of 24 Now I would like to show you some of the

like 25 moisture content measured during the test. I would

134

1 to describe to you some of the results. We have the

2 heater going into the page. We have three container

3 boreholes that cross the heater at about its
midpoint, and

4 I would like to include all the data from all three

5 boreholes into one plot. The way to do that was to

6 calculate the radial distances to each measurement

point

7 for all the measured values and then show them
together.

8 Next slide.

9 This is the changes in moisture content
measuring

10 functional radial distance 70 days after the start of
11 heating. This is about midway through the maximum
power

12 phase of heating of the test. The white access shows
13 changes in moisture content. The zero change is
shown by

14 this dark line, meaning that the rock is still
ambient,

15 near ambient conditions plus along the line.

16 We can see something quite interesting; that
is,

17 that the rock below the heater shown in the little
circles

18 is drying at a much faster rate than the rock above
the

19 heater shown by the triangles within the boiling
region,

20 which at this point in time extends maybe .6 or .7
meters

21 into the rock mass.

22 As I said before, we think that this moving
flow is

23 moving moisture away from the bottom portion of the
heater

24 at a faster rate than for the rock above.

25 If we take some of the same data tests and
blow it

1 up so that you can see some of the detail or some of

the

2 information shown here, we see we also see evidence
3 formation of a saturation "halo," in that some of the
4 changes in the moisture content are above ambient
5 conditions as shown by the positive change here. So

that

6 it shows that indeed a saturation "halo" formed.

Next

7 slide.

8 Now, this is a snap showing time of moisture
9 content changes the last day that we took data. So

we've

10 gone through the full heating and cooling cycle. We

have

11 allowed the rock to recover for 100 days after the

heater

12 was turned off, and now we want to see how the rock
13 rewetted, where the rock was gaining water.

primarily

14 We see that the rock is gaining water

15 above the heater compared to the rock below the
heater.

16 The rock below the heater, in fact, has gained
relatively

17 little water, where the rock above the heater shown
in the

18 triangle is rebounding at a faster rate. And as I
said

19 during the completion slide, that this is probably
20 evidence for a gravity flow bringing water from a
21 saturation "halo" above the heat. Next slide.

22 We've also seen evidence that fractures
control the

the 23 rate of rewetting. Again, the heater is going into
talking 24 page. The same three boreholes that we have been
map 25 about are shown in here. I've added the fractures

136
lines. 1 along each of the boreholes shown by these dark

objective of 2 You can see the dark lines in here also. The
3 this line is to show that the rewetting is occurring
4 primarily where the fractures are.

in 5 The graph that I'm showing, I show the changes
changes 6 saturation along this borehole, in NE-2A, and the
which 7 are calculated relative to the velocity of heating
8 should have been the maximum drying that occurred.

the 9 So we want to see where water is returning in
see in 10 rock relative to the last day of heating. What we
11 the heating is that the changes, the increase of
12 saturation, are occurring only where the fractures
are.

13 Next slide.

the 14 We think that the explanation for this is that
more 15 fractures are helping the rewetting process in one or
16 ways. No. 1, it allows humid air that is in
equilibrium

17 with water to force the water to move freely. You'll

come

18 into the dry region and then because of the suction
19 pressures in the rock, the rock can pull humidity out
of
20 the air and condense it and make it part of the pore
21 water.

22 It also allows for a possibility of gripping
off of
23 saturated regions above the heater to occur and bring
some
24 of those drips into the region and again, that would
also
25 again be brought inside of the formation.

137
1 The other possible mechanism to be playing a
role
2 here is that the humid air along the fracture can
move --
3 the humidity in the air can move into the formation
by a
4 process of binary diffusion quite easily. Once there
is a
5 strip of increased saturation, you still can have
binary
6 diffusion move past that strip of saturation and move
into
7 drier portions of the rock and help increase its
moisture
8 content. Next slide.

9 The predicted and measured radial profiles are
10 different. Here is the predicted moisture content
profile
11 profile. Here is the measured moisture content
terms
12 for the same time during the test. We see that in

and 13 of radial distance of the dried region, the predicted

14 measured values are quite close to each other.

of 15 Where the difference comes is in the magnitude

saturation 16 the saturation level "halo." Here we have the

17 "halo" is overly predicted compared to the measured

to 18 values. And as I said before, we think that this has

19 do with the fact that, No. 1, we started the test at

2, we 20 almost full saturation or very close to it. And No.

21 also know that the code would not predict the results

22 anyway because we have only drying factors occurring

23 incorporated into the code. Next slide.

24 I would like to show you now some of the

25 temperature results that we have. The little symbols
138

The 1 shown in space are the location of the thermocouples.

is a 2 heater is going into the page again as before. This

3 flow of temperatures showing all of the measured

4 temperatures two and a half months after we started

full-powered 5 heating, so this is about halfway through the

6 heating cycle.

log 7 We are plotting the temperatures at a natural

this 8 of radial distance and what we find is that over in

9 region, most of the temperatures are plotting along a

10 straight line. And what that means is that the heat
11 transfer mechanism is conducting as we would expect.

above
12 We also see that as we move into the region
13 the boiling point isotherms, this is significantly be
14 formed relative to a straight line. If you were just
to
15 project that straight line, you would see there are
16 several points that plot below a stright line
projection.

17 After examining the data, you see that that area
18 corresponded to regions where fractures were. And
what we
19 think was happening in this situation is that the
20 fractures are allowing the steam to escape easier
from the
21 matrix.

22 In doing so, it removes some of the energy
23 available to the system of those locations and takes
it
24 away and that creates a cooling effect. Just in the
order
25 of a few degrees, however.

borehole
1 We also see that one of the boreholes,
2 TC2, plotted quite a bit cooler than all the other
3 boreholes, indicating that there is substantial
thermal
4 heterogeneities of thermal conductivity within the
rock
5 mass. Next slide.

6 Now I would like to show you some temperature

7 information for thermocouples 87, 88 and 89 that you
can

8 see are below and to the side of the heater.
Thermocouple

9 87 shown in the square is shown by this upper profile
and

10 this is a typical time temperature history.

11 We see that the temperatures increase fast up
as

12 the heater is turned on. As we are seeing the
boiling

13 point isotherm, we see a little dip, as predicted by
the

14 calculations and continue to increase. And then we
start

15 the rundown as they decrease. In fact, most of the

16 thermocouples that were monitored had this kind of

17 response. Two of them, however, had a very different

18 response and these are thermocouples 88 and 89.

19 Notice that the temperature increased quickly
here

20 and then began to rollover. Then all of a sudden the
rate

21 of temperature increase picked up again similarly
over

22 here and began to rollover. And then the rate
increased

23 again and then they pegged both at about 97 degrees
C,

24 which is the boiling point of water for this
elevation.

25 We think, referring to the next slide, that
the

2 follows: We have the heater going into the page. We
know
3 we created a region of dry rot. Within this region
we
4 have rigorous boiling. We created high gas pore
5 pressures. We drove some of those gas pore pressures
6 outwards and that steam was condensed when the
7 temperatures were cooled, raising the saturation
"halo."
8 Now, the the predictories are going to be
9 different, however. For example, for steam traveling
10 upwards and condensing, if the rock was fully
saturated,
11 then gravity-driven flow would tend to move the
condensed
12 water back into the boiling region and create some
sort of
13 a reflux mechanism that would tend to stablize the
push of
14 the driving upward.
15 If you go to this side, you would see that the
16 steam would flow outwards from there. For the region
of a
17 full saturation then, rather steam flow would tend to
move
18 the water tangential to the margins of the dry
region.
19 And for the region below the heater, we see that the
steam
20 flow would bring water to this location and then
condense
21 it and then rather the steam flow would take that
water

22 away.

23 We think that for the two thermocouples that I
24 showed you earlier, they were located in this region,
but

25 what we were seeing was the shedding of condensate
water

1 just below boiling reaching that condition at some
point

2 during the test. Next slide.

3 The predicted and measured temperatures are
very

4 close and here we can see the predicted temperatures
are

5 shown in the close where that compared with P2 and P3
6 temperatures that they are within a few degrees of
each

7 other. Next slide.

8 We also saw that the heating changed the air
9 permeability near the heater wall. The preheat
values,

10 this is gas permeability. Note the logorythmic
scale, and

11 this is, therefore, on the heater borehole. The
location

12 of the heater element is shown by this dark line
here.

13 The preheat values are shown by the open
squares in

14 here. The post heat values are shown by the closed
15 diamonds. I've also plotted fractures mapped along
the

16 heater borehole by this dark line.

17 What we see is that where the rock got
hottest,

largest 18 that is near the middle of the heater, we saw the
other 19 percent increase in gas permeability as compared to
increase in 20 regions away that only saw very small percent
21 permeability.

and 22 Now, we think that while this is interesting
23 important to note, in terms of the performance of the
24 hydrologic system at this location, this is really a
dominate 25 relatively small change because really what will

142
1 saturated flow conditions in this case would be this
this 2 region of high permeability here. And even though
below 3 increase is still two or three orders of magnitudes
4 some of the higher regions of naturally-occurring
5 permeability.

6 I believe that that is the last one. Any
7 questions?

8 Thank you very much.

late 9 DR. PRICE: We are running just a little bit
10 here.

the 11 MR. WILDER: I think they are talking about
12 schedule outside right now.

concluded at 13 (Whereupon the hearing was

14 12:30 p.m. and continued to January 19, 1990)

15

16 JANUARY 19, 1990

9:00 A.M.

17

CONTINUED PROCEEDINGS

18

19

DR. VERINK: Good morning. I'd like to make

a

20 few comments about the laboratory tour yesterday.

21

Review

The members of the Nuclear Waste Technical

22 Board, and particularly the panels on Containers and

23 Transportation greatly appreciate the courtesy
extended to

24 us during the tour of Lawrence Livermore yesterday.

25

This certainly is a national resource in both
143

1 equipment and personnel. As a corrosionist, I
particularly

2 licked my chops over the state of the art corrosion

3 research equipment and staff.

4

With regard to other impressions of the visit,

5 several of the laboratories, the QA bibles were
displayed

6 in such prominent positions it would be easy to
conclude

7 that this was job one.

8

Considering the immense and expensive effort

9 required, one wonders if it might be possible to
capture

10 at least some of the effort on behalf of other

11 laboratories concerned with QA programs.

12

Perhaps QA approved procedures could be
published

13 in some suitable form along with a list of any
appropriate

14 applicable literature references. Possible
publishers

15 might be ASTM or NACE, for example.

16 In support of this idea, it was noted that the
17 availability of an ASTM standard for conducting
18 potentiodynamic polarization tests greatly simplified
the

19 obtaining of QA approval for corrosion test
procedures

20 using the potentiostatic equipment. And that could
be a

21 nice piece of economy to capture some of that cost.

22 Apparently the major activity to date has
involved

23 review of the literature and QA. By comparison,

24 relatively little actual laboratory research has been

25 recorded at least.

144

1 In the meantime, an outstanding array of
equipment

2 has been assembled, much of which now has been
qualified

3 through QA programs and greatly increased research

4 productivity is obviously anticipated.

5 It's hoped that today's speakers will include
in

6 their comments a few extra little goodies here. Some

7 indication of when the program being presented had
its

8 start and what its history's been, as well as the
present

any 9 status of the laboratory research programs including
10 milestones for work that has been planned.

when 11 Secondly, we'd like to have some indication of
12 some sort of bottom line conclusions may be expected
13 concerning materials for the waste package container.

any 14 Then if possible in addition, we'd appreciate
15 comments from the speakers with regards to the
questions

would 16 posed yesterday in the introductory remarks, namely
package 17 shifting additional responsibility to the waste
the 18 from the host rock for containment and isolation of
19 waste be an advantageous alternative.

rising 20 And secondly, would in placing the waste under
effect 21 conditions that avoid the near field temperature
22 above the boiling point of water have a beneficial
23 on containment life.

can 24 That's a big order, but if any of these things
25 be put into the situation I think it would be very
1 helpful. 145

speaker 2 Yesterday we transferred forward the last
charge of 3 from the program. Will, are you going to be in
it 4 this? Suppose I turn it over to you and let you pick

5 up from there. We'll hear from the first speaker.

will be

6 MR. CLARKE: Okay. The first speaker then

radiation

7 the carryover from yesterday. This is Richard Van
8 Konynenburg, and he is going to be discussing
9 chemical effects, the effects on the environment.

technical

10 This is work that has been done under my

not

11 area. Rich actually is in our technical area so it's

today.

12 inappropriate that he start our material selection

basically

13 The work that he is going to report on

Laboratory.

14 was done under subcontract to Argonne National

15 Rich will go over the people involved in that effort.

the

16 It is a very interesting piece of work that is
17 being done and it is very vital for us to understand

and

18 environment as it relates to the corrosion mechanisms

day.

19 processes that we'll be discussing throughout the

20 So with that, Rich, would you like to come up,
21 please.

talk to

22 DR. VAN KONYNENBURG: It is my pleasure to

that we

23 you today about the chemical effects of radiation

24 expect in the near field of the waste packages.

25 Could I have the next slide.

of 1 In response to your question about the history
2 the project, I'd like to just say that there have
been 3 several people involved at three different
laboratories.

4 And some of the radiation chemistry work has
been 5 done in cooperation with other parts of the project,
for 6 example the waste form dissolution. The work done by
John 7 Bates and his group at Argonne, the bottom three
folks 8 here, was involved with that.

9 And we did radiation chemical studies at the
same 10 time he was doing leaching of the glass under gamma
11 radiation.

12 Wayne Yunker at Westinghouse has done some
work on 13 corrosion of copper alloys in gamma radiation
environment.

14 And that was part of our copper feasibility study
that was 15 held a few years ago in response to the request to
16 consider copper as a candidate.

17 And then Bob Glass and George Overturf at our
18 laboratory did some work also some years ago, looking
19 primarily at the effects on corrosion potential. And
Joe 20 Farmer will be showing some of that data later on in
his

21 talk.

22 The material I'll be presenting today has
primarily
23 been done by Don Reed and the next two gentlemen
there at
24 Argonne National Laboratory.

25 Okay. Can we have the next one.

147

1 And just to recap from yesterday, we talked
about
2 the various environments that we're talking about,
both
3 expected and bounding. And for the corrosion work,
4 because of the range of environments that could be
5 possible in Yucca Mountain, we're considering
corrosion in
6 considerable environments.

7 And particularly in this talk I'll be talking
about
8 the radiation chemistry in these environments. And
it
9 includes water vapor, mixtures of air and water
vapor,
10 liquid water solutions as you can see here, and then
11 two-phase where there is both air and water in
contact.

12 Okay.

13 This is sort of a summary of the talk. I'll
start
14 out and talk about the types of radiation that we
expect
15 and dose rates. Then I'll talk about the elemental
16 composition that we are radiating.

17 And then the effects on the environment, and

these

18 are essentially the same environments that I showed
you
19 except it also has now dry air as kind of a limiting
case
20 which is helpful to understand radiation chemistry.

21 And then finally I'll talk about some effects
of
22 these two products on corrosion of candidate
material.

23 I'll be primarily talking about moist air. We have
done
24 some of this work. And as I said, Joe Farmer will
present
25 some of that data later.

radiation do
1 Okay. But first of all, what kind of
2 we have? Well, fission products and actinides, which
are
3 the components of high level waste and spent fuel,
produce
4 the whole gamut of types of radiation.

5 Okay. Could we have the next one.
6 Now, the important thing here is that as long
as we
7 have intact cans, a lot of these types of radiation
will
8 not be able to penetrate the wall and get to the
9 environment outside the waste package.

10 So I have here sort of a nominal container
wall
11 thickness and I put down 10 millimeters -- this is
subject
12 to some change as design proceeds and so on -- but

this is

13 roughly the range we've been talking about.

14 You can see then that the types of radiation
that

15 are higher on the chart here have shorter ranges,
would

16 not be able to penetrate the wall. On the other
hand,

17 these below would be able to.

18 We can reject neutrinos right away. They have
a

19 range so long that they won't do any observable
damage to

20 the environment right around the can. Neutrinos can
go

21 through the sun after all.

22 Neutrons we can also get rid of. The dose
rate due

23 to neutrons is something like five orders of
magnitude

24 lower than that due to gamma rays in spent fuel. So
again

25 we can rule that one out.

149

1 We're left then with gamma radiation.

2 Can we have the next one?

3 Now, this is a calculation done by Don Reed
and a

4 coworker of the dose rates of gamma rays expected.
Now

5 this is a calculation done with a tough environment
around

6 the waste package. In this case it was a copper
waste

7 package with various wall thicknesses.

rate 8 And there are two plots here. One is the dose

9 in rads per hour as a function of distance from the
10 container.

11 The other is dose rate in rads per hour as a
12 function of time located at various distances.

that 13 Now, the important things are, first of all,

Rock is 14 the dose rate dropped very rapidly with distance.

15 a good shield for gamma ray.

orders 16 So in a few tens of centimeters, you can see

importance of 17 of magnitude decrease in the dose rate. The

going 18 this is that the radiation chemical effects that are

Once 19 to be significant will be right near the packages.

small 20 you get out into the rock the dose rates will be too

21 to have serious effect.

time 22 The other thing is that we have a dropoff in

23 which is something like a 30-year half life. That's

24 because CZ137 is a dominant gamma emitter during the

life. 25 containment period. It has about a 30-year half

notice is 1 And then the final thing I'd like you to

have 2 the size of the dose rate. And the maximum values we

3 are in the range of 10 to the fourth rads per hour,

spent 4 something times 10 to the fourth. And that's for
5 fuel.

like 6 Now for glass waste forms we expect something
7 an order of magnitude less in terms of maximum dose
rate.

package, 8 And then it depends on the exact design of the
these 9 the age of the waste in the package and so on. But

10 are roughly the numbers we're talking about. Okay.

radiating 11 Now, the other important thing is what are we
12 radiating with these gamma rays? And we are
--

we've got 13 the expected environment here is moist air. And

other 14 a couple of variables. One is temperature and the

here, 15 is humidity. So I show plots for two temperatures

16 90 and 120, and range of relative humidity.

really 17 Now, the point that I want to make is it

for 18 makes a difference when you vary relative humidity,

19 example, what species you're actually radiating.

dry 20 You could, for example, if you had relatively

21 air be radiating primarily nitrogen if your relative

80 22 humidity were down here, because air is essentially

23 percent nitrogen, 20 percent oxygen.

24 On the other hand, if you were at say a higher
25 temperature and you had a high humidity, you could be
1 essentially radiating pure steam, pure water vapor.

2 Now, the chemistry that you get out of this
depends
in,
and
that
3 on what you're radiating, because the gamma rays come
4 they interact with the electrons primarily by cause
5 effect, and then they cause ionization of the species
6 the electrons were found in.

7 And from there on, those ionized species
undergo
on
8 chemical reaction and what reactions you get depends
9 what species those are. Okay.

10 Okay. So here I'd just like to summarize.
This
11 information is primarily from the literature.
However,
12 we've done some of our own experiments as well and
13 confirmed a lot of these results.

14 The literature data is primarily at room
15 temperature. We of course are interested not only in
16 ambient temperature but also elevated temperatures up
to
17 something like 200 or 250 as we talked about
yesterday.

18 So we've been doing studies to see if the
effects
19 change very much when we go to high temperatures and
also

20 high humidities. A lot of the moist air work, for
21 example, is done at fairly low humidity in the
literature.

22 We're interested even in higher humidities.

23 So first of all, I have put down here some
limiting
24 cases for what happens to these various environments
when
25 they're radiated with gamma rays.

1 First of all, pure water vapor, what one finds
is
2 small steady-state concentrations of hydrogen gas,
oxygen
3 and hydrogen peroxide. Now, there are back reactions
that
4 cause these to reform water and that's the reason
they
5 don't keep building up. You just reach a
steady-state
6 small concentration.

7 Now, if there are catalytic materials present,
and
8 a couple examples are copper, which is the basis for
some
9 of our candidate materials, or manganese dioxide
which has
10 been reported in the tuff environment, if those are
11 present those serve as good catalysts for the
12 decomposition of hydrogen peroxide. And so if that
13 occurs, you come back to water and oxygen.

14 Now, a living case here is dry air. We don't
15 expect dry air in the repository, but suppose we
consider

the 16 that first because it makes it easier to understand

17 moist air case.

oxide, 18 If dry air is radiated, one obtains nitrous

19 otherwise known as laughing gas, ozone and N₂O₅.

This 20 And then a very short time later, the ozone
21 decomposes, converts the nitrogen pentoxide to NO₂.

22 is the brown gas we're all familiar with in smog.

N₂O 23 And then the long-term products then are the

24 and the NO₂.

stable so 25 Now, N₂O is fairly inert, it's chemically

153

and 1 we don't have to worry about that from a corrosion
2 standpoint. On the other hand, NO₂ is a reactive gas

3 particularly with copper. Okay.

and 4 Now, suppose we have some moisture in the air

get 5 we radiate it, things are somewhat similar at room
6 temperature and low humidity, which is what's in the
7 literature primarily. Again we get the N₂O, again we

8 ozone.

state. 9 But now we get nitric acid in the gaseous

10 At high humidity, and this is our own work, this is
11 relatively new work, we found at high humidity we can
12 observe a small amount of ammonia. That was a
surprise.

13 In the literature, whenever oxygen has been
present
14 in any sizable amount, the reactions have gone toward
the
15 nitrogen oxide side. Here we're seeing it going
toward
16 the reduced side, ammonia to a small extent.

17 The reason I bring that up is because some
copper
18 alloys have been known to be sensitive to ammonia in
terms
19 of stress corrosion cracking. So it's an important
thing
20 for us.

21 Now, for liquid water, if one has pure water
in a
22 closed system, again one sees small steady-state
pure
23 concentrations of these species just as we saw in
24 steam.

25 If solutes are present in water, which they
always
1 are in real groundwater or vadose water, or if the
system
2 is open so that these gases could escape, then one
could
3 see net radiolysis to hydrogen and oxygen. And as
time
4 progresses the water breaks down into hydrogen
oxygen,
5 much like an electrolysis process only this is
radiolysis.

6 The reason for that is the back reactions now
no
7 longer occur. The back reactions that would switch

these

8 back to water don't work because the solutes are
9 scavenging up the free radicals.

have

10 Okay. Then in the two-phase system where we
11 moist air in contact with liquid water, for example
12 pores of the rock, we find that nitrogen from the air
13 fixed as nitrite and nitrate ions in the water.

in the

is

and

14 So we start with nitrogen gas, radiate that,
15 that then dissolves in the water and comes out in the
16 form of nitrite and nitrate in the water.

form

amounts.

17 We also produced hydrogen ions in equal
18 So the result of that is we've got nitrous acid and
19 nitric acid in the water.

nitric

our

20 Now the pH, of course, then drops because it's
21 becoming acid, unless a buffer is present. Now, in
22 situation bicarbonate is a main anion and that's a
23 good buffer.

good

this

24 So we found in experiments at Argonne that in
25 kind of a system we dropped the pH to about six and a

half

long

155
1 and that's where it held because we didn't radiate
2 enough to overwhelm the bicarbonate buffer. So

that's an

3 important factor.

also
4 Radiolysis of water to hydrogen and oxygen
5 occurs, particularly if solutes are present. Again
for
6 the same reason we talked about. Okay.

7 Now, I'm going to switch and talk about the
second
8 part, which is, what are the effects of these various
9 regulated species, these products, what are the
effects on
10 corrosion.

11 Now, as you'll be hearing later on today,
we've got
12 several candidates and three of those are copper
based
13 alloys. And so we looked in the literature for
effects of
14 radiated air on copper and copper alloys.

15 And there is some data going back to the later
'50s
16 indicating that at room temperature under some
conditions
17 you get a species known as dicopper trihydroxide
nitrate
18 or basic copper nitrate, which is sort of a
blue-green
19 material forming on copper. And this has been
reported by
20 several groups over the years.

21 So we were concerned about that. We didn't
know if
22 that was a protective species. What would the
corrosion

23 rate be. Would they be parabolic tapering off, would
they

24 be linear.

25 We had to know what the corrosion product was
to

1 understand the mechanism to get down to what is the
2 corrosion rate versus time, which is what we need to
check
3 for the future.

4 So in order to try to get an idea about this,
we
5 considered where could we find an environment that
had
6 been subject to large amounts of radiation for a long
time
7 in moist air with copper alloys present.

8 Well, it turned out that down the street we
have an
9 electron linear accelerator and this facility was
about 15
10 years old. This is a zero degree cave, which is a
room
11 underground straight off the end of the accelerator.

So
12 that's where the beam dump is and that room has been
13 subject to bremsstrahlung and X radiation for a long
time
14 at dose rates that are the highest at our laboratory
and I
15 don't have a good number for what they are.

16 So we can't get really quantitative about
17 production rate here, but we can sort of look at this
as

18 an analog for this kind of situation.

19 Well, you'll notice that there is a lot of
20 blue-green color in this picture. Most of that color
is
21 found on copper cooling water pipes. For example,
these
22 pipes you see here, those are all ordinary copper
cooling
23 water pipes running down along the floor. There's
also
24 copper tubing here.

25 And you'll notice that they jibe pretty well
with
1 the blue-green color here on the color chart.

157

2 Now, just because copper looks blue-green does
not
3 mean you have basic copper nitrate. There are lots
of
4 other corrosion products of copper, for example the
basic
5 chloride, the basic sulfate which you see on the
Statue of
6 Liberty, the basic carbonates and so on. Same sort
of
7 color.

8 So we did X-ray to fraction analysis and we
did
9 identify that this is the nitrate. Now that's
unusual,
10 normally you don't see the nitrate. Nitrogen is a
fairly
11 stable gas, and to break the triple bond of nitrogen
you
12 need to do something drastic.

13 So here's an example of how radiation
corrosion

14 really does show up. Okay.

15 This is the end of the beam dump. This is
16 stainless steel here. This is a copper jacket and it
was

17 covered, of course, with this basic copper nitrate.
You

18 can see I scraped it off and that's where we did the
19 analysis. It was quite thick.

20 Okay. So then we proceeded to do some
corrosion

21 experiments of our own. These were done by Don Reed
and

22 his group at Argonne Laboratory.

23 And you see here that we did put in our three
24 candidate copper based alloys. We also put in Alloy
825

25 more or less as a control.

158
1 These are preliminary experiments, so we have
only

2 one coupon of each material. The statistics is not
great.

3 We are in process now of doing experiments with
larger

4 number of coupons for a longer time.

5 We did do a range of relative humidities and
the

6 total pressure was floating. In other words, the
pressure

7 of air was constant of dry air. But then on top of
that

8 is whatever the vapor pressure of water is for these

9 relative humidities and whatever temperature we ran.

10 Okay. So the total pressure floats depending
on
11 what the water partial pressure is. But the amount
of air
12 in there is constant.

13 We ran for one month and this dose rate, as
you can
14 see, is in the range that we were talking about, ten
to
15 the fourth rads per hour range.

16 We looked at the sample by weight loss and
gain,
17 x-ray to fraction, scanning electron microscope, the
18 analysis of the corrosion product.

19 Now, there's a picture -- you can't always
tell a
20 lot from pictures, but let's look at the pictures and
then
21 I'll talk about the analysis.

22 The first thing to notice here -- again, these
are
23 all done at that same gamma ray dose rate. It's
moist air
24 environment. And these coupons are about one
centimeter
25 by two centimeters, that's the scale.

159

1 And these are the relative humidities. First
we
2 have dry air here on copper at 90 centigrade, and
then we
3 have 100 percent relative humidity.

4 Now, you can see the tremendous effect of
humidity.

corrosion 5 And we found our largest dose rate, our largest

6 rates at the 100 percent relative humidity.

see for 7 Here's the aluminium-bronze. Again you can

bit of 8 dry air it didn't do too much. And we have quite a

9 oxidation at the high end.

three 10 This is a higher temperature on copper and

effect 11 relative humidities. And you can again see the big

but 12 of relative humidity. It might be hard to see here,

13 we have some flaking of the corrosion process here.

see 14 Here's the copper-nickel. And again you can

here at 15 the effect of humidity, sort of mottled appearance

16 the high humidity.

is a 17 And here's aluminum-bronze. And again, this

these 18 little bit harder to see, it didn't show up. But

again 19 were very thin corrosion layers here and this one

20 was .6.

21 Could you rotate that and -- okay.

scale, 22 Now, what we have here is you can see the

was 23 one centimeter, this is a copper-nickel specimen that

times 10 24 irradiated at a little bit higher dose rate, two

fourth. 25 to the fifth. Now, the others were 7 x 10 to the
120 1 This was one 2 x 10 to the fifth, the temperature was
2 centigrade.
3 And you can see here that this corrosion that
you
4 can observe, but also the feature I'd like you to
look at
5 is this large feature here. And we have a blowup in
the
6 next shot of that. That's one millimeter. So you
can see
7 it's not exactly a pit, it's more like a crater.
8 But the important thing is we saw something
like
9 three of those on this specimen that was a centimeter
by
10 two centimeters. We only have the one specimen in
this
11 condition and we are repeating these results.
12 So I think it's important to say that we need
to
13 confirm this and find out is this repeatable.
14 But we did analyze this, gave good data for
X-ray
15 to fraction and it is the basic copper nitrate that
I'm
16 talking about. So we do see this forming.
17 And an important thing is that it really is a
18 function of humidity. Earlier performance done by
Wayne
19 Yunker at Hanford did not show this, and we now
believe

20 that the result that he saw happened because the
humidity

21 was much higher there.

22 In our case when we run up to the high
humidities,

23 we do not see the nitrate. We just see the oxides,

24 cuprous and cupric oxide. But when we run to low or

25 intermediate humidities, we do see it. Okay.

fraction 1 So then this is a result of the X-ray to
161

2 in the SEM work to see what we actually had on the

3 surface. And for the pure copper I've listed here
the

4 three -- they're the same in each one.

5 On the pure copper we always have cuprous
oxide as

6 the major product. And this is -- this is what one
finds

7 when you don't irradiate, that's very common.

8 We also found cupric oxide when our humidity
was

9 high. And the nitrate phase then was present at low
10 relative humidity.

11 For the copper-nickel, again we saw a lot of
high 12 cuprous oxide and we saw some cupric oxide at the

13 humidity and the nitrate phase was the major product
at

14 low relative humidity, the blue-green color.

15 Aluminum-bronze, again cuprous oxide, some
cupric,

16 and at low relative humidity we saw nitrate as a

major

17 one.

looked

18 Alloy 825 we didn't observe anything. It

coming

19 like a mirror going in, it looked like a mirror

of

20 out. There was no weight change within our precision

microscope.

21 measurement, we couldn't see anything with the

be

22 Okay. To summarize then, gamma radiation will

in the

23 present and dose rates will be as high as somewhere

24 10 to the fourth range rads per hour.

25 Radiation chemical effects will depend very

1 strongly on this humidity, since we have a range of

2 humidities to deal with we need to understand that

3 propensity.

on

4 These are the species that can form, depending

implicated in

5 environmental conditions, and those are all

chemicals.

6 various types of corrosion, they're reactive

have

7 And particularly on copper based materials, we

the

8 seen some pitting and we have seen the formation of

9 nitrate.

on

10 We didn't see any radiation chemical effects

again

11 Alloy 825 in the length of time that we ran, which

12 was only one month for these occurring. And we do
need to

13 do longer term tests and those are underway now.

14 Okay. Are there any questions?

15 DR. PRICE: When did the program begin and has
it

16 been a continuous program, the radiation chemistry?

17 DR. VAN KONYNENBURG: The radiation chemistry
has

18 sort of been, I would say an auxiliary to other
things

19 that have been going on. That's the way it was
initially.

20 As I said, it was done as part of the glass leaching

21 analysis.

22 And then we had a small effort in electric
chemical

23 measurement which Joe will talk about, and I think
that

24 was done in the early '80s.

25 And then we started -- because we were
concerned

1 about the behavior of copper in a radiated
environment

2 when we had the copper feasibility studies, which
were I

3 guess in the mid '80s -- is that right? '85, '86
range --

4 then we had this worked done by Wayne Yunker at
Hanford to

5 see whether copper would have a problem in radiation.

6 At that time we decided that we couldn't say
that

7 it did, because the corrosion rates, while they were
8 somewhat elevated, and we'll see this data later
today,

9 they still weren't huge. But we also did not see the
10 nitrate phase.

11 And now we have continued to do this work at
12 Argonne lab, and that's been going on now for, I
would say

13 two or three years. And we now think we understand
how to
14 interpret the rest of the data that we have.

15 It's a matter now of trying to get
quantitative and

16 to see what these rates really are.

17 DR. PRICE: Would you say you actually started
in

18 the '70s?

19 DR. KONYNENBURG: No. This project didn't
start up

20 till '82.

21 Now, a lot of the literature data that I
described

22 for you was gained on other projects back into the
'50s.

23 DR. VERINK: Was there anything about Carbon
14 in

24 any of these experiments?

25 DR. KONYNENBURG: No, not in these
experiments.

164

1 That's a separate pursuit.

2 DR. VERINK: Is there any background
information on

3 that that we could see or hear?

4 DR. KONYNENBURG: Yes, there is, and I guess I
5 would refer that to Mike Clonniger.

6 MR. CLONNIGER: Dr. Verink, we're looking at
7 Carbon 14 release particularly from the cladding
material
8 itself and the hardware and crud.

9 It can be released as carbon dioxide, as you
know,
10 and through a breached container be released into the
air
11 space, into the rock, and subject to transport as a
gas.

12 And we're looking at how big a problem that might be,
what
13 that might imply in terms of allowable container
failure
14 rates post closure and any engineered solutions that
may
15 be necessary.

16 DR. VERINK: Are there any reports for
anything
17 like this that we could have to look over?

18 MR. CLONNIGER: We have one draft report
submitted
19 and under review now. Rich wrote it. I understand
that
20 we can turn over draft material to the Board.

21 DR. VERINK: Then we'd like very much to have
22 that --

23 MR. CLONNIGER: Sure.

24 MR. VERINK: -- if we may.

25 MR. CLONNIGER: May I ask a clarifying

question,

165

1 Dr. Price?

2 Rich, you said that neutron radiation wasn't a
3 problem.

4 A VOICE: I don't think your mike is on.

How

5 MR. CLONNIGER: Am I coming through at all?

6 about if I talk right here?

7 A VOICE: That's better.

misunderstood

8 MR. CLONNIGER: Okay. Rich, you said that the
9 neutron radiation was not a problem. And I

10 the reasons, because the flux was so long?

from

11 DR. VAN KONYNENBURG: That's right. The flux

neutrons

12 neutrons initially is something like 10 to fourth
13 per square centimeters per second.

that in

14 If you're familiar with reactors, you know

spent

15 an operating reactor core where, for example, the

to

16 fuel came from, you're dealing with something like 10

centimeter

17 twelfth or 10 to thirteenth neutrons per square

18 per second.

would

19 So many orders of magnitude down from what it

actual

20 be in a reactor core, and then if you look at the

dry

21 dose rate in terms of ionization of the moist air or

large

19 enough to cause significant problems as far as
increased

20 corrosion rates?

21 DR. VAN KONYNENBURG: I think the key question
is

22 what will the environment actually be. If the

23 environment is moist air, or essentially a gaseous

24 environment, then the only liquid water we should
have

25 would be something like physisorbed layers on the
surface

1 of the metal. We're talking about less than ten
molecular

2 layers of water.

3 Well, even though the production of radiolytic
4 species is small in terms of total number of mols, if
you

5 dissolve those in a water layer that thin, yeah, then
the

6 concentrations can go up.

7 And additionally if there's no buffer, if that
8 water has no bicarbonate in it, let's say it appeared
9 there by condensation from gaseous water, then
there's no

10 buffer, you can drop pH in a situation like that.

11 And we have seen the effects of peroxide on
the
12 corrosion potential and we'll see that in later
talks.

13 DR. CARTER: So there's a potential there it
could

14 be a significant problem.

15 DR. VAN KONYNENBURG: Yes, I think there is.

16 DR. CARTER: Now, I presume if you gain a
better
17 understanding of the situation as far as the
quantitative
18 side of it, that if need be for corrosion control,
you
19 could basically control or engineer the environment
to
20 minimize those sorts of problems.

21 I'm leading you a considerable amount, I
suppose,
22 but --

23 DR. VAN KONYNENBURG: Do you have in mind
putting
24 some --

25 DR. CARTER: Yes.

1 DR. VAN KONYNENBURG: -- species there to
buffer or
2 to --

3 DR. CARTER: Yes.

4 DR. VAN KONYNENBURG: -- counteract together
the
5 species you're forming --

6 DR. CARTER: Yes.

7 DR. VAN KONYNENBURG: -- or something like
that?
8 Things like that could sure be considered.
9 Okay. Thank you.

10 MR. CLARKE: Okay. What I want to do is set
the
11 stage for the remainder of the day. This as you were

just

12 shown is now called the Container Materials Modeling
and
13 Testing Technical Area, of which I am the technical
area
14 leader.

15 The objectives in our authorized reference
path
16 that I will be discussing, that the speakers the rest
of
17 the day will be discussing and work that they are
doing,
18 is to meet the objectives that are shown on the
board.

19 And that is to select a material and fabrication
porcess
20 for the waste package containers.

21 And then also to identify the most likely
modes of
22 container failure after emplacement, to develop
models for
23 prediction of container lifetime. To perform testing
that
24 is required to develop and confirm those models. And
then
25 to provide the models and the supporting data in a
form

169

1 usable for performance assessment.

2 Now, Les showed you this diagram yesterday. I
want
3 to just repeat because this is the container
configuration
4 that we are currently doing research to select the
5 material for.

somewhere 6 As you know, it is a thin wall container
depending 7 between one and three centimeters in thickness
8 upon the material that is finally selected.

somewhere 9 And alloy like 825 would most likely be
copper 10 about one centimeter in thickness, whereas if pure
11 was selected our current thinking is that it would be
12 somewhere like three centimeters in thickness.

the 13 The size of the container as you have seen,
high 14 spent fuel containers are about 15 and a half feet
15 and the waste glass containers are about 10 and
16 three-quarters feet high.

to be 17 The talks today or the work that we are going
the 18 reporting on is really the strategy for the container
19 material selection, and this gives a breakdown as how
20 talks are organized.

by 21 We will start off with the selection criteria
be 22 Bill Halsey. This criteria is a process that he will
Level 1 23 describing that is now being done under the new QA
into 24 effort. And that, of course, is one of the inputs
combining in 25 the total selection process that Bill will be

2 process.

3 Then after Bill has gone over that part of the
4 talk, Dan McCright will be discussing the degradation
mode
5 survey.

6 I will point out that those are surveys of
existing
7 literature, not data that we have developed here.
8 However, they have indicated areas where testing is
9 needed.

10 Then Joe Farmer will be discussing our
materials
11 testing and modeling effort in support of the
selection
12 process and also beyond the selection process.

13 I just want to in the introduction say a few
words
14 about other parametric studies. We are not prepared
to
15 discuss those today since in many instances work has
not
16 started or is not sufficient at this point to give
you
17 data on. But we will be using information from the
18 process side of other parametric studies that will
feed
19 into the selection process.

20 The output of this then will be the material
for
21 the advanced studies as we lead into licensing.

22 Now, to break each one of those boxes down and
just

23 give a very brief overview, you're going to get
annotated
24 histories from these people and also you will learn
more
25 in detail.

171

1 The selection criteria is a material
independent
2 exercise. The criteria was derived from functional
3 requirements on the container. These come from the
SCP
4 and strategy documents.

5 They will be discussing how a relative
weighting of
6 criteria topics was established.

7 First each candidate must meet the minimum
8 requirements of a pass/fail and then they are
assigned a
9 quantitative score or a figure of merit to allow
10 comparison of the various candidates.

11 The selection criteria that you will be
hearing
12 about this morning has been formally peer reviewed,
and
13 that report is forthcoming.

14 Dan then will be discussing the degradation
mode
15 surveys. This is a very extensive effort as you are
going
16 to hear. Their first -- the staff in total sat down
and
17 determined the various modes that we thought were
18 important after emplacement.

19 There was a survey of the literature by the

entire

20 staff over the last about year and a half, two years.

21 They established the mechanisms that were
22 important, they compiled the data, analyzed that
data.

23 That's what you're going to be hearing about in great
24 detail this morning.

25 And then also that indicated needs for
additional

172
1 data that was required, and that is directly some of
our
2 test efforts.

3 Joe then in the material testing and modeling
area,
4 those people that were on the tour yesterday saw a
great
5 deal of this and talked to Joe and learned a lot
about
6 what he is doing already.

7 However, in selecting models he had to write
the
8 degradation mode surveys, he had to survey the
literature,
9 find those models that are presently existing, those
10 models that maybe we can use but we may have to
modify,
11 and those areas where models are lacking and we will
12 eventually have to develop.

13 So after his evaluation and selecting, he is
now
14 establishing our model needs and then we are entering
into
15 the testing phase.

16 You saw one of the types of accelerated
testing and

17 the critical fitting potentials that Joe was doing
18 yesterday.

19 Also I think Greg Gdowski indicated some of
the

20 long term tests that we have started and we have
others to

21 begin.

22 The model confirmation type of testing is like
what

23 was shown yesterday in the reversing DC area, and
that is

24 crack growth behavior that we can try to make
predictions

25 on for long term behavior and much lower crack growth
173

1 rates.

2 Just an overview of some of the test
environments.

3 You've already heard from Rich on the ANL radiation
tests,

4 and this gives you an indication of the type of
testing

5 that's being done at that facility.

6 These are ongoing tests at Argonne by the way.

7 These tests will at least be carried through to the
end of

8 fiscal year '90.

9 We're also at ANL doing slow strain rate
tests.

10 Most of these tests are over and a report is in

11 preparation by Argonne. These were done in simulated
well

12 J-13 water, both at the 1x and the 20x concentration.
13 Also was done in aqueous and in the gaseous
environments
14 at 90 degrees centigrade.
15 The reversing DC tests that you saw yesterday
have
16 not started although the specimens are in place and
we are
17 in the process now of putting together the
documentation
18 to start these tests.
19 The initial test will be done in simulated
J-13
20 water in the aqueous environment, and the first test
will
21 be done at 150 degrees centigrade.
22 The polarization test that Joe is doing is
also in
23 simulated J-13 water. He is currently varying the pH
and
24 the chloride contents but eventually will be adding
other
25 species to the water. This is aqueous test below
boiling.
174
1 And then the long term corrosion tests that
Greg
2 mentioned yesterday, again in simulated J-13 water in
the
3 gaseous phase initially and at the various
temperatures 50
4 to 200 degrees centigrade.
5 Now, Dan is going to be discussing in great
detail
6 many of these parameters for the various candidate

7 materials, but basically he will be discussing the
8 mechanistic aspects of corrosion, phase analysis and
that
9 sort of thing.

10 There are other parametric parameters that
have to
11 feed into the selection criteria involving the
processes.

12 Weldability. Is the material weldable and
what are
13 the difficulties encountered. Phase stability as
related
14 to weldability. Mechanical properties is one of the
major
15 inputs. Fabricability and closure of the material.

16 One that we consider extremely important that
we
17 have yet to start our effort on is microbiological
18 corrosion. MIC can occur either from microbes that
are
19 present in the unsaturated tuff or also can occur
20 man-made, brought in during drilling operations and
other
21 mechanisms.

22 And then, finally, cost is considered
extremely
23 important.

24 Okay. At this point I'm going to turn it over
to
25 Bill unless there is any questions.

175

1 Okay. Bill Halsey will start then with the
2 selection process.

Halsey 3 DR. HALSEY: Good morning. My name is Bill
4 and I'm going to be discussing some of the material
5 selection issues for the containers.
it 6 You just saw this chart. I'll start out with
7 and you'll see it again. It sort of outlines
everything 8 you're going to be hearing today.
9 I will be discussing some of the selection
material 10 criteria, some of the history of the candidate
11 list and a little bit about the selection process.
review 12 We have also conducted an independent peer
13 of the draft criteria. And we intend to conduct a
peer 14 review of the selection when it is clear. I will
discuss 15 that.
16 Dan McCright and Joe Farmer will discuss
17 information gathering activities which support the
18 selection process.
than 19 The testing and modeling is a different shape
20 the degradation mode survey, because this is an
ongoing 21 activity which supports the selection process but
also 22 iterates with the design and all the way out through
23 container licensing or repository licensing.
24 Parametric studies are also a set of ongoing

in 25 studies that will just describe but are not discussed
176

1 detail.

advanced 2 The goal of all of this is a material for
3 study.

4 A brief outline of the process. We began by
5 developing a list of candidate materials. I will
give a 6 brief history of how that came about.

7 We have recently established selection
criteria.

8 And we are approaching the point of selecting
material for

9 advanced studies based on performance requirements
and

10 what is currently known about material performance
and

11 predicted container service environment.

12 Then there will be a continuing process of
13 developing performance models, performing parametric
14 testing. This will be conducted in parallel with the
15 ongoing site characterizations which will gain
additional

16 information about the service environment.

17 There will be design activities to the detail,
the

18 container designs. There will also be design
analysis and

19 performance assessments and these will be conducted
over a

20 period of years.

21 And then prior to the final design phase which

is

22 referred to here as the license application design,
we
23 hope to confirm the material selection. There may be
a
24 decision to revise it at that point based on site
data and
25 the predicted performance of the container.

177

1 And the long term testing will continue on all
the
2 way out through the license application phase.

3 The question was asked when was there going to
be a
4 bottom line on the material selection for the
materials.

5 And there are competing desires in that.

6 One, we would like to make a decision on
material
7 as soon as possible so you can focus your research
and
8 your efforts on the testing and using that in the
design
9 activities.

10 But on the other hand, the actual service
11 environment will not be completely detailed for many
12 years. That brings out a complex process that turns
into
13 an iteration. We're picking, selecting material
early on
14 based on what we know, and later on confirming or
revising
15 that based on the final information inputs later in
the
16 program.

17 The process started many years ago. This is a
18 viewgraph summary of the document which is referenced
on
19 the last page of this section.

20 A brief history of the container material
candidate
21 selection. Back in the early days of the project,
the
22 repository at Yucca Mountain, repository horizons
both
23 above and below the water table were being
considered.

24 And if you're below the water table, then for
25 accommodating the hydrostatic loads you would look at
178
1 thick container sections. The containers are
partially or
2 completely self shielded, and you need a material
which
3 has a corrosion allowance for a long time period. So
4 there was a lot of emphasis on carbon steel, cast
iron.

5 Once the decision was made to locate the
repository
6 in the unsaturated zone, then the emphasis shifts to
7 thinner section containers. They're lighter. For
the
8 same size container you get more capacity, internal
9 capacity. And you can work with corrosion resistant
10 materials.

11 The list of reference materials or candidate
12 materials has been historically tied to the
preparation of

13 the site characterization plan. So that during an
early
14 draft of that it was proposed to use the bare pour
15 canisters from the defense high level waste as the
16 disposal container.

17 The decision had already been made at that
time to
18 use 304L stainless steel for the pour canister for
the
19 defense high level waste glass at Savannah River. So
at
20 that point with a desire to have a reference material
as a
21 starting point and to compare against, 304L was
selected
22 as a reference material.

23 Although you know that that's not necessarily
the
24 best material, it's a reasonable engineering choice
at
25 that point. So there was a continuing evaluation of
179
1 additional materials.

2 There was a survey of various engineering
metals
3 and alloys. About 31 materials were surveyed
including
4 steels, copper.

5 Base materials, nickel base materials,
titanium, at
6 least one of the zirconium alloys. And it was
narrowed
7 down to 17 materials for a little more detailed
study.

8 And then four equal selection criteria were

9 applied, the mechanical performance, the corrosion
10 performance, the cost and the weldability.

11 To try again to narrow the focus of the
additional
12 reseach as much as possible, four materials were
picked
13 out of one alloy family and that's the austenitic
14 material. 304L was still a reference material, and
then
15 three higher performance alloys, 316L stainless
steel, 321
16 stainless steel and Alloy 825, which is a nickel base
17 alloy but it's still in the iron nickel austenite
series.

18 There is a reference report on that selection.

19 In 1984 the program was asked by Congress to
with
20 reevaluate the copper alloys. And the program worked
then
21 the copper industry looking at five alloys. It was
22 narrowed down to three, CDA 102, 613 and 715.

23 And about this time it was also apparent that
som
24 of the thermal processing in forming the glass into
the
25 304L was bringing up the possibility of
sensitization, a

180

1 nucleation of sensitized microstructures.

2 And it was not a good idea and a viable
concept to
3 use that as a disposable container.

4 At that point we decided that whatever
disposal

5 container was used for spent fuel would be used as an
6 overpack for the defense high level waste.

7 In the '84, '85, '86 time frame copper was
studied
8 in laboratory testing, surveys of existing
information.

9 And some feasibility reports were prepared. They did
not
10 show any real show stoppers.

11 About this time there was a material review
board
12 convened to examine the waste package container
materials.

13 They made a number of comments and those have been
folded
14 into the program and have helped direct it.

15 More recently as the site characterization
plan was
16 finalized the candidate list was narrowed to six,
three
17 austenitic materials. Alloy 321 was dropped because
it

18 was -- its performance overlapped 316L and Alloy 825.
And

19 three copper base materials. These were technically
20 reviewed as part of the site characterization plan,
21 technical review. And that list exists now.

22 This whole history is described more fully in
a
23 document which I believe the Board has been provided,
the
24 annotated history of the waste package container by
25 McCright.

here
1 If there aren't any questions on that part,
2 are the austenitic candidate materials, 304L
stainless,
3 316L stainless, and Alloy 825, and all of the iron,
4 chrome, nickel austenitic material series.

will
5 Some of the properties of these Dan McCright
6 be discussing in his talk. Their mechanical
properties in
7 an annealed or hot roll condition are shown down
here.

ductility
8 They all have a reasonably good strength and
9 shown by the elongation number.

10 The copper based alloys, CDA 102 is unalloyed
11 copper.

bronze
12 CDA 613 is a normally seven percent aluminum
13 with three and half percent, a few percent iron in
it.

14 And CDA 715 is a 70/30 copper-nickel.

tensile
15 The mechanical properties for these, the
16 strength or the yield strength is a little lower,
17 particularly in the case of the unalloyed copper.

And
18 that's one of the reasons why Will Clarke mentioned
if we
19 were going to use that material we'd probably use a
20 thicker wall section.

design
21 For a point of reference, the conceptual

years 22 container analysis that was conducted a number of
23 ago in the conceptual design for retrieval loads, the
24 greatest loads on the container would be during a
having 25 retrieval where there had been rock fall so you're
182
1 to pull this thing out against some restraint.

came 2 And the highest wall stresses in that analysis
3 out around 10,000 psi. So that number is in the
ballpark 4 with the largest stresses calculated for the current
5 conceptual design.

6 I'm now going to discuss some of the selection
7 criteria and the selection process. This is the same
8 viewgraph shown by Will Clarke.

a 9 The criteria are material independent down to
10 certain level of detail. I'll point that out when we
get 11 into the details of the criteria.

quantitative 12 At some point when you're measuring
material 13 parameters on materials, that measurement becomes
14 dependent. One example of this is you use different
metals 15 measures of ductility for ceramic materials and
16 alloys, for example.

are 17 But in the topic areas, the way the criteria
18 developed, they are material independent. They are

19 derived from functional requirements on the
container.

20 There is relative weighting factors for the
21 different topic areas that have been established.
There
22 are a set of minimum requirements and these are
intended
23 to be points below which the container material would
not
24 be adequate for meeting the performance requirements
of
25 the waste package.

183

1 And there is an attempt to establish a
quantitative
2 score to allow comparison of candidate materials and
this
3 has been subjected to a formal peer review.

4 At this point let me say a few words about the
5 selection process because the structure that you see
here
6 in the criteria is dependent upon the process.

7 There's a number of ways of trying to make a
8 decision like on selected material and a number of
9 different ways have been considered.

10 And the different criteria that you will be
seeing,
11 some of them are much more -- something you would --
12 property of material that you would like to have, and
the
13 more of it that it has the better such as corrosion
14 resistance. And others are things that you really
have to

15 have, that have to be sufficiently strong to meet the
16 handling requirements.

17 So we have decided to try a combined pass/fail
and
18 quantitative figure of merit. So those areas where
19 there's an obvious passing minimum below which the
20 material is not acceptable establish that and assess
all
21 of the materials against that minimum requirement.

22 And in those areas where there is a material
23 property which beyond a minimum requirement gives you
24 additional advantage, such as corrosion resistance,
put a
25 quantitative figure of merit on that to allow
comparison
184
1 with the materials which are adequate.

2 DR. CARTER: Bill, I wonder if during the
process
3 this might not be the appropriate time, you might
want to
4 do it a little bit later, but I'd be quite interested
if
5 you would discuss with us the Material Review Board.

6 I'm particularly interested in its
composition, the
7 interactions with the working folks, procedures,
expected
8 longevity of the board, its responsibilities and
perhaps
9 its authorities.

10 DR. HALSEY: The Material Review Board was
convened
11 and had a finite lifetime and it issued a report

which --

12 I don't have the reference with me. But it was not
an

13 ongoing, long term -- Bill -- Dan would you like to
14 address that? Dan was --

15 DR. McCRIGHT: I'm trying to recall it. The
16 Material Review Board was composed of, I believe, all
17 university professors and I don't remember all of the
--

18 DR. HALSEY: Use the mike, okay?

19 DR. McCRIGHT: The Materials Review Board, as
best

20 I recall, was convened to review not only the NNWSI
21 project but also the SALT project at that time and
the

22 SALT project. And also to look at what we call the
23 materials characterizations center.

24 I believe the composition was all university
25 professors -- later I could give you the names --
their

1 charter was to look at the activities that were
going on

2 in each project to determine if they thought that the
3 success of what they were doing would lead to a real
4 demonstration of the regulation requirements that
were in

5 effect at that time.

6 They gave reports in 1985. We met with them
again

7 in 1986. The report indicated that they thought
there

8 were some serious deficiencies in the program, part

of

9 which was aimed at the materials that were being
looked at
10 and part of the approach that was being taken at that
11 time.

12 I believe our meetings with them in '86 we
with
13 rectified some of the points of disagreement we had
14 them. They did issue reports that are available, and
I

15 don't know if the Technical Review Board received
that or
16 not --

17 MR. CLONNIGER: Excuse me, Dan. Are we
talking
18 about the Ad Hoc Corrosion Panel?

19 DR. McCRIGHT: Yes.

20 MR. CLONNIGER: Not the Materials Review Board
21 necessarily.

22 DR. McCRIGHT: That's part of the Materials
Review
23 Board, isn't it?

24 MR. CLONNIGER: Well, they were established by
the
25 board but they were a short term group and they were
186
1 called the Ad Hoc Corrosion Panel.

2 DR. CARTER: Well, I was particularly
interested
3 in the board as far as its history and, like I say,
these
4 points that I mentioned.

5 I guess the other question, sounds like to me

that

6 that board has gone out of business. Is that
correct?

7 And I presume then the program does not feel a
need

8 for an independent material review board or someone
in

9 that -- or is there something else that's taken over
this

10 function?

11 DR. HALSEY: Within the program at Livermore,
the

12 independent peer review panel serves a similar
function.

13 We ask their opinion at certain milestone points,
where,

14 for example, the criteria are established, we ask
their

15 opinion when the selection is performed.

16 The Yucca Mountain project has the prerogative
of

17 conducting its own independent peer review and its
own

18 technical assessment of those activities at that
point

19 also.

20 DR. CARTER: I'm thinking particularly now of
21 canister materials, if we can restrict it to that.

22 Is the peer review that you have, is that an
23 ongoing group or is it set up on an ad hoc basis as
24 needed?

25 DR. HALSEY: It's set up on an ongoing but we

187

1 really only ask their opinion typically at decision

points

ask 2 to review a block of work that has been completed and

3 their opinion on that.

4 DR. CARTER: Okay. So that's initiated by the
5 project itself, in essence?

6 DR. HALSEY: Yes.

the 7 In establishing criteria, again referring to

was 8 history of this, while the candidate material list

9 being developed, so was a list of criteria, what's
10 important.

where 11 And I would refer the board to Section
12 8.3.5.9.2.1.1. of the site characterization plan

criteria. 13 there's a discussion of preliminary selection

There 14 These bullets are just the section headings.

on 15 is additional discussion under each of these, it runs

that 16 for several pages, and it gives philosophical points

material. 17 have been set down as the criteria for selecting

Board 18 These were reviewed by the Material Review

19 and there was quite a bit of discussion. They were

were 20 actively involved in reviewing the program as these

21 being developed.

22 Briefly, what material will meet the

performance

23 allocated to the container?

24 Can the performance of the material under

25 repository conditions be adequately predicted?

188

with

1 Will the container material interact favorably

field

2 other components of the waste package and the near

the

3 environment such as the waste form, borehole liners,

4 rock?

this

5 Chemical material. Can a container be made of

6 material, the fabricabilities?

7 Are the container materials and process for

8 fabricating it practicable and similar?

selection

9 And how can additional confidence in the

10 be gained?

points of

11 You can see from this list that these are

12 philosophy, not quantitative parameters.

other

13 So what we've tried to do is take these and

and

14 engineering requirements on the container material

15 establish detailed criteria which can be used for

16 determining adequacy of the material and quantitative

17 figure of merit for comparison of materials.

criteria,

18 There is currently a draft of a selection

19 not a final version, which was prepared at Livermore

and 20 iterative process discussing with staff, consultants
to 21 contract technical personnel, and has been subjected
22 the peer review.

23 There are currently 34 separate criteria and
showing 24 they're divided into seven topic areas. I will be
25 you the structure of the criteria in the next few
1 viewgraphs. 189

2 The criteria address the engineering,
performance 3 and regulatory requirements on the waste package and
the 4 waste package material.

5 Each criterion has a relative weighting factor
6 versus all of the others.

7 And in most cases, the criteria have both a
criteria, 8 pass/fail and quantitative score. Some of the
9 it's not really appropriate to have one or the other.

10 There's either no true minimum requirement so the
11 pass/fail judgment is not applicable, or once you
have met 12 the minimum requirements there's no additional
benefit to 13 be gained from a higher score, so you don't need a
14 quantitative scoring.

15 We divided into seven topic areas, four of
them 16 performance related and three of them nonperformance

17 related.

18 The first part is the mechanical performance.

19 The second part is the chemical performance
which
20 is actually the corrosion issues.

21 C is predictability of performance.

22 D is compatibility with other materials.

23 And then the nonperformance issues are
fabrication,
24 cost and previous engineering experience.

25 The current weighting factor division between
these

190

1 seven topic areas:

2 The corrosion performance is the largest one
at 30
3 percent, and then the ability to predict the
performance,
4 fabrication and the chemical performance at 16
percent, 20
5 percent and 14 percent.

6 Compatibility at 10 percent. Cost and
previous
7 experience at five percent.

8 I will show now an example of how each of
these
9 areas is broken down into subtopics.

10 The corrosion resistance is broken down into
topics
11 of general corrosion which is the oxidation and
general
12 aqueous corrosion.

13 We get some pitting, crevice and localized
attack.

14 Resistance to environmentally accelerated cracking
such as
15 stress corrosion cracking of various types and
hydrogen
16 embrittlement effects. And resistance to
17 microbiologically influenced corrosion.

18 Now, some of these are then broken down
further
19 into individual criteria. For example, that 10
percent
20 which was resistance to environmentally accelerated
21 cracking is further broken down into individual
criteria
22 as listed here.

23 Stress intensity, susceptible phases,
threshold
24 potentials if they can be established, possibilities
for
25 smooth specimen stress corrosion cracking,
concentration

191
1 of chemical species in the environment which will
promote
2 cracking.

3 And the same things for hydrogen, sufficient
4 hydrogen concentration and formation of phases which
are
5 susceptible to hydrogen cracking.

6 So this is where you end up with 34 separate
7 criteria. This the 10 percent which was
environmentally
8 accelerated cracking of the chemical performance
portion.

9 I'm not going to try and go through all of the

they
thought
10 draft criteria. One, it gets long winded, and two,
11 are still draft and they are not finalized. But I
12 the board might like to see an example of what the
13 criteria looked like.

are
said
14 A fairly straightforward one is strength. We
15 using the yield strength as the parameter. And as I
16 from the conceptual design analysis, currently the
passing
17 score looks like around 10,000 psi.

for
18 And the goal is to assure adequate strength
19 both static and handling loads.

scenarios,
one, two
20 Other than in the most extreme retrieval
21 typical loads in the conceptual design are in the
22 or three thousand psi range, as seen here.

at
together
23 Another example would be resistance to general
24 corrosion, both oxidation and aqueous corrosion. And
25 the moment we're looking at lumping all of these

192
1 because the effects tend to interrelate.

and
wetted
are
2 And if you had separate criteria for oxidation
3 aqueous corrosion and at various times you have a
4 or nonwetted surface you now have two criteria which

5 strongly interdependent and that makes the selection
6 process difficult. So they are currently lumped
together.

7 And the parameter is our estimate of the time
8 averaged oxidation rate with a passing score of one
micron

9 per year. That relates to on the average. And that
10 relates to a one millimeter wall thinning during a
11 thousand years.

12 And with conceptual designs of about one
centimeter

13 thick this is a 10 percent reduction in the wall due
to

14 the general oxidation.

15 One final example would be for a subcriteria
in the

16 resistance to environmental accelerated cracking, a
17 subcriterion to that is the threshold stress
intensity for

18 corrosion cracking with a parameter such as K_{Isc} over
 K_{Isc} .

19 We've posed a passing score and then a scale
so the

20 further away from the threshold stress intensity for
21 stress corrosion cracking that you get, the more
likely

22 you are to resist that phenomenon.

23 This goes on through at the moment 34 separate
24 criteria.

25 DR. VERINK: Just for curiosity, how did you
1 arrive at the weighting factors?
193

2 DR. HALSEY: Iteration through opinions of a

3 variety of people, myself, other staff.

4 This has been through other people within the
5 program at other organizations. We've had technical
6 engineering consultants and contract support look at
it
7 and give us their opinion. And these numbers have
8 varied.

9 The ones that you see here reflect some of the
10 opinions of the independent peer review. I'll get to
that
11 in a minute. They suggested a modification of the
number
12 of the weighting factors, but not by very large
amounts.

13 So this is an evolved consensus. Not
everybody
14 agrees.

15 DR. PRICE: Did you use a formal technique
like a
16 Delphi process?

17 MR. HALSEY: No.

18 This is as good a place as any to discuss.
Because
19 things like the weighting factors and the scales, how
you
20 scale the quantitative weighting factors are
subjective.

21 They are an opinion derived from discussions
of a
22 lot of people. Because of that and because in
applying
23 these criteria -- if you look at these criteria
carefully,

24 we are not going to have hard and fast data to nail
down
25 every one of these parameters, not at this point in
the
1 program and not with the amount of testing that has
been
2 completed.

3 We will be able to quantify a number of them.
And
4 others we will be able to get pretty good numbers
from
5 existing literature that you will be hearing about,
6 testing that we are doing from predicted models, from
the
7 current estimates of the expected environment and
bonding
8 environment.

9 But since the exploratory shaft and the site
data
10 have not been available yet and will not be for some
time,
11 some of these will be subjective opinions.

12 We think that this will be adequate. We think
that
13 the environment within these bonding ranges that you
saw
14 yesterday, the bounding range is what we're currently
15 using for design purposes, this material will perform
16 within the minimum pressure criteria.

17 DR. CARTER: By the way, as a matter of
curiosity,
18 how do you quality assure subjective matters?

19 DR. HALSEY: I'm getting to that. That's what

I'm

20 leading up to.

21 DR. CARTER: Good.

22 S DR. HALSEY: And there is a process.

23 DR. PRICE: Before you get to that, I understand

24 there's a draft of selection criteria document; is that

25 correct?

195

1 DR. HALSEY: Yes, there is.

2 DR. PRICE: As an action item we'd like to request

3 that.

4 DR. HALSEY: The way you assure the quality of independent

5 something like that is through a process of peer review where you say what your opinion of the

6 weighting factors is and why and you subject it to the

7 examination of a board of independent technical experts

8 and get their opinion also. And that's what we've done

9 and will continue to do as part of the selection process.

10 The next viewgraph shows -- you may ask where is

11 all the information going to go, or come from to go into

12 these criteria. Here's just a breakdown of the seven

13 topic areas and to the primary information source.

14 Some of it is from our own degradation mode surveys

16 which you will hear about. Some of it is from the
general
17 body of engineering data. Things like mechanical
18 properties of these alloys are available.

19 And, for example, engineering experience and
20 industrial experience in fabrication, we have both
21 fabrication studies and existing engineering data.

22 We are conducting cost studies, our own
parametric
23 testing which you will hear about this afternoon, and
our
24 own modeling studies which you also will hear about
this
25 afternoon.

196
1 One of the things that I want to indicate with
this
2 is that there is in most cases not a single piece of
3 information that will go into one of these topic
areas,
4 but that you're going to use whatever information is
5 available. Both information generated by us and
6 information generated by us and information that we
can
7 gather from the existing engineering information.

8 The peer review process that we have gone
through
9 is select a chairman and members of the panel, to
provide
10 advance information, hold a meeting where we give
them a
11 briefing on the status of the program.

12 We train them to those portions of our quality

13 assurance program which are pertinent to the peer
review,
14 show them the selection criteria, for example, and
then
15 allow them to discuss it.

16 And then we provided a support contractor to
the
17 chairman to assist in preparing a report. It took
them a
18 period of time, actually quite short, about six weeks
or
19 so. They prepared a report iterating between the
members,
20 and they did reach concurrent opinion, at least in
the
21 case of the selection criteria.

22 So we're right at this point now, there has
been a
23 draft report given to us by the peer review, and we
are
24 currently revising the draft criteria taking into
25 consideration the panel comments.

197

They
1 So you asked about the draft of the criteria.
2 are currently being changed in response to the panel
3 comments.

4 And the peer review panel asked if they would
be
5 allowed to view the changes that we make and comment
upon
6 them again, and the panel responding to the revisions
of
7 that has not happened at this point.

8 So both the criteria and the peer review
report

9 itself had one more step to go to completion.

10 DR. CARTER: Are these always consensus
reports or

11 do you have provisions from minority opinion?

12 DR. HALSEY: There is provision for minority
13 opinion as provided in our quality assurance program.

14 DR. CARTER: And this is a formal process.

15 DR. HALSEY: It is a formal process. There
are

16 written requirements on peer review. We have a
written

17 procedure. We have tried to conduct our peer review
--

18 well, it is conducted under our QA program and we

19 attempted to make that program coincide with the NRC

20 position on peer reviews for this program. And we
think

21 we've succeeded, although we haven't had their
opinion on

22 that.

23 The peer review panel that was convened for
the

24 selection criteria occurred in 1988. Revision of the

25 criteria is in progress.

198

1 You had asked us to indicate where there were
2 delays attributable to the quality assurance program.

And
3 in the process of revising the criteria in response
to the

4 peer review is when the new quality assurance program
in

5 the economic project was put into place.

Level 1 6 So we suspended that work because it is QA
7 until the new QA program was in place and was
qualified.

8 Then subjected this to readiness review for the
9 completion. And we now have authorization to
complete the
10 process. So there was a delay.

11 The members in the peer review panel, we were
12 looking for expertise in materials, material
corrosion,
13 predictive modeling, fabrication, performance
assessment,
14 failure analysis and general nuclear engineering
15 experience.

16 And we tried to get a viewpoint from more than
one
17 location. Academic, industrial, the utilities,
people
18 with a variety of backgrounds.

19 The composition of the peer review panel is
shown
20 here. Dr. Robin Jones was and is the chairman and he
is
21 at the Electric Power Research Institute and has been
22 involved for many years in nuclear industry materials
23 issues.

24 Dr. Geoff Egan at Aptech Engineer, again is an
25 engineering consulting firm to the nuclear power
industry

1 on engineering and materials issues.

2 Martin Prager is chairman of Materials
Properties

3 Council.

4 Dr. Robert Long is vice president of GPU
Nuclear

5 Utility for financing and safety.

6 Dr. Rich Gangloff is professor of material
science

7 at University of Virginia.

8 And Dr. Roger Staehle is a consultant in
corrosion

9 and material performance. And after the peer review

10 report was concluded, and he had concurred to it, Dr.

11 Staehle resigned.

12 Their report again has not been finalized.
The

13 final step in their report has not been taken. And
it is

14 fairly lengthy so I'm trying to summarize their
opinion.

15 This is my summary of their response to four
questions

16 that were asked of them.

17 They didn't have to answer these questions.
They

18 were convened to give us their opinion. But these
four

19 questions were asked and they responded to them.

20 One: Is this type of commparison of materials
and

21 this type of selection process a reasonable thing to

22 attempt?

will

with is 21 be conducting. And what we are trying to come up

22 part of the material for advanced study.

23 Are there any questions?

24 The very last viewgraph is a breakdown of the
25 selection criteria showing all 34 points, and I don't
201

hard to 1 think I'll try and go through this, it's a little

see 2 read. It's included in the package so that you can

3 how they are currently structured.

4 DR. CARTER: You mentioned earlier a figure of
5 merit. How do you go about composing that or
constructing

6 it?

7 DR. HALSEY: Okay.

8 DR. CARTER: And how do you use them?

9 DR. HALSEY: Well, I said the selection
process

where we 10 really has two parts. One is on those parameters

will 11 can identify a minimum passing level, the materials

fails 12 be given a pass/fail score. And any material that

13 any of the minimum passing scores will be eliminated.

14 That means it's not adequate for use as a container

15 material.

minimum 16 All the materials which pass all of the

17 requirements will then be compared using quantitative

the 18 figure of merit. And that is obtained by multiplying
material 19 quantitative score on each parameter for that
up 20 times the weighting factor for that parameter to come
21 with a numerical figure of merit for that parameter.

22 Adding all those together for the quantified
material. 23 criteria will give the figure of merit for that

24 And then it's just simply a matter of which one has
the 25 highest figure of merit.

202
essentially 1 DR. CARTER: Okay. So that number is

2 the sum of a series of products.

3 DR. HALSEY: Yes.

4 DR. CARTER: Okay.

5 (Recess Taken.)

6 MR. CLARKE: Okay. To carry on this morning's
want 7 session on the container materials, one thing that I
neglected to 8 to mention before we pass over too far that I

9 say in the opening, and that is in relation to the QA
10 control.

11 Argonne is conducting the program to a RQAP,
have 12 they're under the umbrella of RQAP. But they also
does 13 their own plan in place that we have audited and it
14 comply with the '88-'89 Reg 2 requirements. So that

work

15 is being done and is being upgraded to Level 2.

was

16 Also the selection process, as you just heard,

you

17 a Level 1 activity. The modeling and testing that

18 will hear this afternoon is a Level 2. And for our

a

19 purposes we do not distinguish between a Level 1 and

They are

20 Level 2 in the way that we conduct our business.

21 the same.

from Dan

22 The surveys that you are now about to hear

QA

23 McCright were conducted previously under the previous

24 plan and that was a Level 3 activity. Okay.

25 With that I'd like to give you Dan McCright.

203

1 DR. MCCRIGHT: Thanks very much, Will.

of

2 I'm going to be talking about the performance

3 candidate materials and put the emphasis on the

4 degradation mode surveys.

serving

5 I'm a metallurgical engineer and I'm also

6 as a task leader for the metal barrier selection and

7 testing task.

8 Okay. If I can have the first slide please.

talk

9 What I'm going to try to do is to break my

talk

10 into three parts. And in the first part I'm going to

11 about the background of the degradation mode surveys,
why
12 we did them and how we did them. I'd like to take
about
13 20 minutes on that one.

14 In Part C which is jumping ahead a bit, the
15 comparison and analysis, I'd like to take about 15
minutes
16 there.

17 The part in between which is the highlights of
the
18 degradation mode surveys, to go through, walk you
through,
19 volume by volume, I'd like to be very flexible on the
time
20 and really it's the board's wish how much detail
you'd
21 like me to go into.

22 I'm planning to spend about 40 minutes there,
but I
23 certainly don't want to talk into lunch. So if it
gets
24 too long, I would be glad to terminate it or
certainly to
25 compress it.

204
1 So if I could go on to Part A on the
background.

2 Okay. Just from the regulations in 10CFR60
there
3 is a section that says that the design shall include
but
4 not be limited to consideration of the following
factors,
5 and then the factors are listed.

6 And again, the emphasis of the talk today and
the
7 emphasis on the long term performance of the
candidate
8 materials is going to be obviously the corrosion
behavior
9 of them. But virtually every other item that's
listed on
10 there influences the corrosion behavior of the
material.

11 Oxidation/reduction reaction, solubility of species,
12 hydriding, hydrogen that's produced by
electrochemical
13 production, by radiolytic production, gas generation
--
14 Rich talked some about that earlier -- thermal
effects,
15 mechanical properties, radiolysis and so forth.

16 And you've heard some before and you'll hear
some
17 later today. But all these factors are important and
they
18 all interact with one another.

19 Next slide, please.

20 Generally, we wrote the Yucca Mountain project
and
21 site characterization plan Information Needs 1.4.2
which
22 is talking about the materials properties, and it's
right
23 from there we talked about the degradation mode
surveys
24 and why we would do that.

25 The historical development of them was that
the

And 1 first volume was started in 1987, early part of 1987.
effects 2 we did the draft of the phase stability, hydrogen
part of 3 and oxidation and general corrosion in the earlier
year. 4 1987. And they were completed at the end of that
stress 5 Then the volumes on localized corrosion,
begun 6 corrosion, the lengthier volumes I might add, were
7 in late 1987.
concomitant 8 And then it became apparent with the
9 surveys being performed by Babcock and Wilcox on
much 10 fabrication and welding processes that there was so
ultimate 11 interaction between the welding processes and
12 performance concerns of the welding regions that we
13 thought that that area alone deserved some special
welding 14 treatment. So we added volumes to deal with the
15 effects in the spring of 1988.
June of 16 Drafts of all the volumes were completed in
the 17 1988, and because of the length and the breadth of
that. 18 subject an overview was written to go along with
19
in 20 Drafts were made available for the selection
20 criteria peer review panel that Bill Halsey described

met 21 his -- in his talk, so that they could see when they

22 with us in September of 1988 where we stood on the
23 degradation mode surveys and analyses.

reports 24 And during the rest of 1988 and 1989 these

25 underwent a very thorough review. All of our reports
206

these, 1 undergo a review of this caliber, but because of the
2 length and the subject matter and the importance of

bit 3 the review was very extensive and it did take quite a
4 of time.

and 5 They underwent technical review, policy review

in 6 QA review both at Livermore and at the project office
7 Las Vegas.

in 8 And finally, the eight-volume set was approved
9 November of 1989, and advance copies were sent to the
10 technical review board panel members.

11 Okay. If I could have the next slide, please.

around, 12 What I would like to do is to walk people

in 13 just assume we've got a vertically in place container

14 Yucca Mountain, and just to look at some of the
15 degradation features, degradation modes that could
happen

16 over the long term containment period and beyond.

17 And for the purposes of this illustration I

made

18 some assumptions on how the container might be
fabricated,

19 but there are many other processes that were being
20 considered.

21 I've also made some assumptions on the
22 configuration as far as how it would be in place with
23 respect to shield plugs and borehole liners and other
24 items that would be in and around the waste package.

And

25 it's a schematic, it's not drawn to scale.

207

a 1 I'd like to point out I'm doing this more from
to 2 pedagogical point of view so I have a lot of material
of 3 talk from. But certainly from an engineering point
waste 4 view, by proper design of the waste package and the
would 5 package peripherals and the choice of materials, we
6 try to minimize many of these problems, either try to
7 eliminate them or certainly to mitigate those
problems.

like 8 So if we could have the first slide, what I'd

9 to do is consider primarily the metallurgical and
10 mechanical considerations.

11 And first of all, let's assume that this waste
12 package container was made by a very conventional
process

13 from rolled and welded plate. And that would be the
body

6 gap separated from the the other metallic, which is
the
7 borehole liner, that perhaps during the course of
events
8 in the repository, that there's some shifting and
there's
9 another contact between those metals and if they are
10 dissimilar metals there can be a galvanic corrosion
11 problem there.

12 Let's move on to the next slide which is
dealing
13 with the chemical and environmental considerations.

14 For instance, we have a shield plug here for
15 radiation protection and a borehole liner. These
will be
16 cooler objects than the container, so that moisture
from
17 the moist air environment around them may condense on
18 these surfaces and then as it condenses and forms
droplets
19 then these can drop onto the body of the container.

20 Well, in so doing they may contain a very
dilute
21 concentration of electrolyte but, repeated droppings
of
22 this kind can cause a buildup of electrolyte on the
23 container surface causing a concentration of the
24 electrolytes.

25 Also, because this water may have been in
contact
210
1 with other elements around the waste package, there
could
2 be some chemical modification of that because of the

3 differences of materials, which were talked about
4 yesterday, there's quite a range of possible chemical
5 environments that could take place.

6 We could also have perhaps something happens
to

7 borehole walls it was nice and smooth at the
beginning but

8 rock slides occur at a very local level and we have
rock

9 fall against a container creating again, now, another
10 crevice site and again a loss of the air gap and with
a

11 possible collection of moisture in that area.

12 As we talked yesterday in some of the
geological

13 presentations about fracture-matrix flow we had a
14 condition of fracture flow, water coming to the near
15 vicinity of the waste package. And then if the
drainage

16 is inadequate there can get an accumulation of water
there

17 with temperatures such that they are below the
boiling

18 point of water.

19 Over a long period of time, for instance,
there may

20 be microbiological activity, as was mentioned
earlier,

21 which could be the inherent microbiological action
that's

22 present at Yucca Mountain, or maybe more probably
that

23 which would be introduced during the drilling and

24 operational activities, again and intervention into
the
25 repository environment.

211

1 We also have with us container rest against
some
2 sort of support plate, there would be another
location of
3 a crevice site.

4 We also, as Rich talked earlier, we have gamma
5 radiation from the decaying waste which causes
changes in
6 the chemical environment.

7 One other item is that for the most part we
8 consider the environment and corrosion effects on the
9 outside. It's also possible that there may be some
10 effects from the side.

11 There is some spent fuel because of its
reactor
12 history which is waterlogged, and if this waterlogged
13 spent fuel is put inside the container it creates a
humid
14 internal environmental, there of course would be
gamma
15 radiation plus chemical changes in that, and because
this
16 may be an inert gaseous environment there would be a
17 different kind of oxidation behavior inside than
there
18 would be outside.

19 So, in other words, this container material is
20 going to be exposed or it has the potential of being

21 exposed to a very wide variety of physical, chemical,
22 mechanical and metallurgical conditions. And that's
the

23 point I would like to make with these two slides.

24 And that's the basis that we tried to conduct
our
25 degradation mode survey, that we would try to survey
as

1 much as possible that wide range of possible
conditions. ²¹²

2 Can we go on to the next side, please.

3 Again the methodology that we used, we used
4 computer searches where they were available on data
bases,

5 particularly the Metadex and the Chem Abstracts data
6 bases.

7 We found review articles on many subjects.
For
8 instance, NACE has produced a number of volumes on
9 specific corrosion topics like localized corrosion,
stress
10 corrosion and so on. And those are very, very good
11 sources to begin a literature survey.

12 And if one obtains a review article, that in
turn
13 references earlier work and so we obtain those
references.

14 Then there are ongoing corrosion conferences.
15 There's the annual NACE conference among others.

16 ASTM from time to time puts on corrosion
17 conferences usually related to very specific
subjects.

data in

17 light of the conditions that we thought would be
expected
18 and the bounding case that has a wide variety of
possible
19 conditions in Yucca Mountain.

20 This resulted in an eight-volume publication
and an
21 overview. And then finally when it was typeset it was
400
22 typeset pages. During the earlier draft it was a lot
23 longer than that because this is a very condensed way
of
24 doing it. But there were more than 1,200 references
that
25 were cited in this.

214
1 I might also add from the QA point of view in
their
2 archives they want all 1200 references, hard copies
of
3 this, so that was no small task to get them all
together.

4 The surveys will be used, of course, as Bill
talked
5 out, in material selection. As Joe will be talking
about
6 later, when we do the degradation mode surveys along
with
7 that came a lot of information relating to the
mechanisms
8 and model development and so on. And it was largely
on
9 that basis that he began a lot of his modeling
activity.

10 And so in surveying the literature, of course,

we

11 found out what things we don't know, the pieces of
12 information we'd like to know about the candidate
13 material, and particularly to apply them to Yucca
14 Mountain.

15 So this became the basis for a lot of our
planning
16 activities on what kind of experiments we should run
to
17 generate what we call the parametric studies. In
other
18 words, what range of chlorides, what range of pH,
what
19 range of different chemical, physical parameters did
we
20 need to do. And particularly how do we compare
alloys
21 from different families. That isn't often so evident
from
22 the literature.

23 Next slide, please, Liz.

24 And again, here the listing of the eight
volumes.
25 The way we went about organizing this was again
dependent

215
1 a little bit on the way the information was found in
the
2 literature.

3 Some combinations were just natural. For
instance,
4 many of the mechanisms for localized corrosion were
also
5 applicable to stress corrosion. According to some

6 researchers, the localized attack precedes stress
7 corrosion cracking. So in those cases it was logical
to
8 group those kinds of modes.
9 In some volumes we just talked about one
family of
10 alloys. In others, for instance in Volume 1 and 2 we
--
11 volumes, they deal with both alloy systems, usually
in
12 Part A, say the copper based materials, and Part B
would
13 be the austenitic materials.
14 And now I'm ready to go into Part B of my
talk, and
15 the way I'd like to do this is I'd like to dwell a
bit on
16 the phase stability, because the phase stability is
very
17 important in all the welding effects and also it
affects
18 some of the corrosion behavior, and spend some time
on
19 localized and stress corrosion, because those are the
20 kinds of corrosion that are generally more
performance
21 limiting than the other forms.
22 Also, it's often a difficult job to try to
present
23 a large body of information like this in sort of
24 capsulized form. What I'm going to try to do is
whenever
25 possible, is to choose examples where there's a
comparison

1 between the different alloys.

2 And again I will try my best to explain as I
go

3 along -- we tend to go from one analysis into
another,

4 from one chemical medium to another. But again, if
5 there's something unclear please stop me and I will
try my

6 best to explain the details of it.

7 We want to go, Volume 1, phase stability and
I'll

8 begin with the copper.

9 First of all, why we would be interested in
the

10 phase stability and its analysis and to identify the
phase

11 transformations and then to, after we've identified
them,

12 what would be the effects of those phase
transformations

13 on the mechanical properties and on the corrosion
14 properties of the alloys.

15 For the copper-based materials. For the
16 oxygen-free high conductivity copper, it's a very
simple

17 material, single phase, pure element, essentially,
fcc

18 metal.

19 There is in a way a disadvantage because it is
20 oxygen free or there's been such an effort done in
the

21 processing of this metal to take all the oxygen out,
you

22 might say that the material is very hungry for
oxygen.

23 And so during high temperature processing, and
24 particularly in welding, if there's any oxygen
present,

25 even very small amounts, this material will absorb
oxygen,

217

1 and internal oxidation could be a long term physical
2 metallurgy property problem with this material.

3 And because of this, this is why we
recommended

4 that we also look at some of the different deoxidized
5 grades of copper, particularly phosphorus-deoxidized
6 alloy, that's perhaps the most widely used and we
have the
7 most information on it.

8 The other copper-based candidate material, the
9 aluminum bronze is a single phase material but with
iron
10 precipitates in it. In other words, the bulk phase
is
11 single, it's bulk material with single phase.

12 The iron precipitates help to harden the alloy
13 system. There's a very small tin addition on the
order of
14 like .2 to .5 percent, and this improves a lot of the
15 intergranular behavior of this material, a very
important
16 addition.

17 So because you have such a wide galvanic
difference
18 between copper and aluminum, dealloying is always a

19 concern with this material.

20 With the copper-nickel alloy, for an alloy
this is
21 probably one of the simplest alloy systems possible,
it's
22 a solid solution of nickel and copper.

23 At the nickel rich end there is the
possibility of
24 having miscibility gaps, but to the best of my
knowledge
25 this is not really a limiting case either from a
corrosion

218
1 point of view or from a mechanical point of view.

2 On the next slide I do have a diagram of the
3 copper-nickel phase diagram. And as you can it is a
4 single phase in the solid region. The alloy that is
of
5 interest to us is the approximately 70 copper/30
nickel
6 alloy because here it is all single phase. And it is
a
7 little bit hard to say if that is going to be the
case
8 right down to room temperature.

9 What often happens is, of course, it's very
10 difficult to have equilibrium at very low
temperatures
11 because of the diffusion rates are so slow, so small,
so
12 one tends to retain the higher temperature structure
to
13 lower temperatures.

14 When we get into the alternate discussion a
little

15 bit later, where there is an alloy Monel 400 that may
be

16 of interest, it's over in this part of the diagram.

17 Next slide shows the copper aluminum phase
diagram.

18 This is a bit more complex than the one you saw
earlier.

19 And the alloy range of interest here is approximately
20 seven to nine percent aluminum.

21 So in some cases there is a very high
temperature

22 beta phase present, and depending on the particular

23 process and often during the welding operation there
would

24 be some retention of the beta phase at lower
temperatures.

25 And the significance of this is that the beta
phase

219
1 will be much richer in aluminum than the alpha phase.

So

2 there is a built-in, what you might say a built-in

3 galvanic cell in that case, because you're getting
the

4 widely electrochemical difference between copper and

5 aluminum.

6 Now, I'd like to go on to the austenite
materials.

7 These are iron-nickel-chromium alloys.

8 And just as background material, iron
undergoes a

9 phase transformation. At room temperature it's a
body

10 center cubic material which we call the alpha phase,

it 11 ferrite, and at approximately 900 degrees centigrade
with a 12 transforms to austenite, which is signified usually
13 gamma in the phase diagram.

at 14 And this is a face center cubic material. And
15 even high temperatures of 1,400 degrees or so it
16 transforms back to ferrite, it's often signified by a
17 delta ferrite at the high temperature part.

steel, 18 But, anyway, in the metallurgy of stainless
19 one is always trying to balance the ferrite forming
20 elements with the austenite forming elements.

the 21 Chromium is added. And of course, chromium is
22 element that gives stainless steel the stainless
it 23 character. Chromium is also a body center cubic, so
24 tends to stay with the ferrite, the body center cubic
25 phase.

austenitic, in 1 Nickel is added to make the material
2 other words to bring the gamma field down to room
3 temperature stability. And again, nickel in
conjunction 4 with the chromium even improves the overall corrosion
5 resistance all the more.

act 6 So in other words, there's quite a balancing
7 which goes on in making stainless steel without
having the

8 proportionate body center cubic and face center cubic
9 alloy additions.

10 As it turns out, the 304L and 316L, these are
11 metastable alloys. They would have a tendency to
12 transform some of the austenite back to ferrite and
to a
13 another metastable phase called martensite at lower
14 temperatures.

15 Because of the alloy composition of 825 it has
an
16 exceedingly large amount of nickel in it and the
austenite
17 is stable at all temperatures.

18 These materials, stainless steel and stainless
19 alloys have carbon in them, the carbon again results
from
20 the initial formation of iron from pig iron, from the
ore,
21 and so much of steel making is the control and to
take out
22 a lot of the carbon.

23 But the carbon is there, and it is a useful
element
24 and it does give some strength, but it can also cause
a
25 number of corrosion problems.

221
1 And that is because the carbon would like to
2 combine with particularly the chromium and
precipitate out
3 usually at grain boundary. In other words to take
the
4 chromium out of the alloy it takes -- the local

chromium

5 is temporarily depleted and we have a sensitized
structure

6 in that area.

7 And then because we have the bulk of the alloy
so

8 rich in chromium with grain boundaries poor in
chromium we

9 could have most of the corrosion occurring at the
grain

10 boundaries and this can result in intergranular
attack and

11 with stresses there, and also the intergranular
stress

12 corrosion cracking.

13 So the composition is very important in
whether a

14 material sensitizes or not. The thermal history is
very

15 important. Generally the lower the carbon the more

16 resistant the material is to sensitization.

17 And there is also a problem of perhaps it may
not

18 sensitize during the initial cooldown from say the

19 processing operation and from the welding operation
nuclei

20 form over a long period of time it may sensitize due
to

21 the low temperature sensitization.

22 There are also, and we'll talk about it a
little

23 bit later, there are some intermetallic phases that
can

24 form in austenitic materials and these can degrade

the

25 mechanical and corrosion properties.

222

a 1 In other words, the austenitic materials from

2 physical metallurgic point of view are a more
complicated

3 material.

4 This is a ternary phase diagram. And again,
one

5 has to take some liberties and some simplification
when

6 trying to show an alloy on a relatively simple plot
like

7 this, because commercial alloys have many, many
components

8 and you just would run out of dimensions to try to
show

9 them all.

10 But anyway, this is an attempt to give you
somewhat

11 of a map of where the different alloys of interest
lie.

12 825 is in the gamma field, the austenite
region,

13 and it's significant in that it's well removed from
all

14 the boundaries.

15 304L and 316L and all the other candidates are
near

16 the boundaries.

17 This was an isothermal section at 650 degrees
18 centigrade. If we went to the lower temperatures we
would

19 find that these are indeed located over in the

13 point of view. But we don't have any alloys of
commercial
14 significance above about 35 percent chromium because
of
15 sigma phase formation.

16 Also it can cause intergranular corrosion
because
17 it's got the difference in the electrochemical
behavior of
18 the sigma phase versus the parent phase.

19 And some other element also influential in
20 promoting sigma phase.

21 Molybdenum is very important in preventing
sigma
22 phase. And sigma phase has been identified in some
pieces
23 of 316L stainless steel. Its presence has been
speculated
24 in some pieces of 825, but from the results of our
survey
25 it's not conclusive whether sigma phase could form in
825.

225
1 There's also a chi phase that is in many
respects
2 similar to the sigma phase. It's again favored by
high
3 chromium, high molybdenum contents in the alloy can
also
4 cause intergranular embrittlement.

5 There's a laves phase which is again favored
by
6 molybdenum addition, and that can cause an
intergranular
7 embrittlement.

ingredient 8 As I said earlier, carbon is a necessary
9 in austenitic materials. It can form as carbides on
grain 10 boundaries.

11 And because the carbide is rich in M which in
most 12 cases is chromium rich, a lot of chromium is taken
out of 13 the solid solution, the chromium then imparts to the
areas 14 *stainless character to the material. So in those
15 we have an area that's more prone to corrosion cracks
is 16 particularly along grain boundaries where the carbide
17 most likely to form.

18 This is very dependent on the alloy
composition and 19 the history, it primarily occurs in the 500 to 800
degree 20 centigrade range. So it's real important often in
weld 21 cooldown of the time that is spent in that
temperature 22 range.

23 Generally the low carbon grades are
susceptible. 24 It's also possible to add other elements, what we
call 25 stabilizing elements. This is usually also a very
strong

carbide forming element, forming other kind of
carbide and 226
2 you need some of the chromium from combining with

carbide

3 so it stays in solution.

4 And again, if one were to discuss the relative
5 resistances to intergranular attack and intergranular
6 stress corrosion cracking, 825 is the least
susceptible,

7 it's the most resistant and is in the order in which
they
8 would fall.

9 As we said earlier, there's a possibility of
low
10 temperature sensitization, but again in very low
carbon

11 materials, this appears that by some annalysis that
has

12 been done, both in the nuclear power industry and
13 elsewhere, that it just doesn't seem to occur, at
least at
14 the temperature ranges that we would be interested in
and

15 even at very long periods of time.

16 It's also possible because of the initial
chromium

17 depletion given the long soak times that we have at
18 modestly elevated temperatures so we can have
chromium

19 redifusion back into those deplete regions, in other
words

20 you have a natural healing effect.

21 Next slide.

22 This shows the microstructures of Alloy 825,
again

23 what one might call the optimum microstructure an

alloy

900

exactly

titanium

the

appears

and

I'll

data

kinds

different

24 given the stabilization treatment at possibility of

25 degrees centigrade for many hours. I don't recall

227

1 how many.

2 But this in other words, was to favor the

3 carbide precipitation. Alloy 825 has an addition of

4 approximately one percent titanium. And that forms

5 carbide.

6 It does form some chromium carbide if one does

7 appropriate ASTM steps to try to reveal if there's a

8 susceptibility of intergranular attack, but it

9 that this alloy is very, very highly resistant.

10 Now, I'd like to go into the general corrosion

11 oxidation of the two candidate alloy systems. And

12 begin again with the copper based material.

13 This is some long term atmospheric corrosion

14 taken from different sites in the world, different

15 of atmosphere.

16 As we talked earlier, particularly in Rich's

17 presentation about the protective natures of

18 copper corrosion products, for instance with a marine

19 humid atmosphere, we have a protective copper, basic

20 copper chloride.

would 21 In an industrial atmosphere, Pennsylvania, we
22 likely have a basic copper sulfate material that was
23 formed.

copper, 24 These tend to form protective films on the
high, 25 again the corrosion rates of copper are relatively
other 1 the general corrosion rate, compared to some of the
2 candidate material.

a 3 But if one were to use this, this certainly is
prevail 4 benchmark point here. If these conditions were to
material 5 over the whole full thousand years this would be a
6 penetration that would result in a millimeter of
we 7 lost, so it would be a tenth of the wall thickness if
8 were assuming a one centimeter thick container.

a 9 What we said earlier was that particularly in
whether 10 radiation environment, one of the key analogs is
the 11 the basic copper nitrate that forms under certain
12 radiolyte conditions, whether that would have some of
basic 13 same protective qualities that these other kind of
14 copper corrosion products have.

we 15 This is some material, some information that

work 16 obtained under NNWSI auspices some years ago with the
17 that was done both at Livermore and at Westinghouse
18 Hanford.

19 And this gives some comparison, comparative as
20 possible between irradiated and nonirradiated
conditions.

21 So if we group the two together, for instance here's
the
22 J-13 immersion and J-13 water, again one can see that
in
23 this case the irradiation is not too much different
from
24 the normal nonirradiated condition.

25 But in the theory where we have condensed
steam

229
1 that forms on the surface, where again we have the
2 greatest possibility of having some of the NOx's plus
3 hydrogen peroxide and other materials, other species
that
4 are very, very oxidizing toward copper, we see that
the
5 irradiated substance does produce quite striking
increases
6 in the corrosion rate. And particularly for the
7 copper-nickel alloy which in many cases is some of
the
8 more resistant in the nonirradiated condition.

9 The comparable results from the austenitic
10 materials, again first of all, the index is much,
much
11 lower here. This would be a hundredth of the wall

over 12 thickness loss if these conditions were to prevail

13 the full thousand year period.

types 14 But, as I think most people know, stainless

15 of materials are very, very resistant to oxidation,

16 general corrosion, and even to radiation induced

showed 17 corrosion -- if you remember the 825 coupon which

Argonne 18 that in an intense gamma radiation environment at

19 National Laboratory.

20 Again the rates are very, very small. And

corrosion 21 radiation has hardly any effect on the general

22 rates or oxidation rates.

corrosion 23 I'd like to switch now into the localized

alloys. 24 and stress corrosion cracking of the austenitic

regard 25 In some respects this slide says it all with

in an 1 to the localized corrosion attack of these materials

2 aggressive environment.

3 This environment is ferric chloride. Ferric

4 chloride is the medium that's often used in some

these 5 standardized ASTM tests to show the differences in

6 families of materials.

It 7 It's very aggressive, high chloride content.

8 gives acidic hydrolysis, ferric iron is, of course,

very

9 oxidizing so it's quite aggressive.

of 10 But this shows that the molybdenum conditions

11 the alloy is very important when determining what the
12 resistance to localized corrosion attacks will be.

13 The Alloy 825 has some resistance to localized
14 corrosion but not complete. This is again a very
15 aggressive environment. Alloys with much higher
16 molybdenum content are much more resistant.

these 17 However, there are some disadvantages with

18 alloys that I'll try to point out later.

yesterday you 19 When you were visiting the laboratory

one 20 saw our work on generating polarization curves. And

has 21 of the uses of polarization curves is to predict the
22 so-called breakdown potential where the passive film

give 23 been protective of the material you have in here to

and 24 us a low corrosion rate. Then something breaks down

25 bare metal is exposed to the solution and then the
1 corrosion rate goes up considerably. 231

finds 2 And, again, if one were to arrange these, one

down at 3 that the Type 304 stainless steel starts to break

4 much lower potential than the more highly alloyed
5 material.

3 repository environment by some of the operations that
4 would be going on during the drilling operation over
parts
5 of the repository, also some of the microbiological
6 entities could produce SO subscript 2 because many of
the
7 metabolism products of microbiological activity deals
with
8 the various oxidation states of sulfur in reducing
and
9 oxidizing sulfur. So often SO subscript 2 is the
10 metabolism product that would be formed. But again,
under
11 acidic chloride conditions, again one sees with the
825
12 it's more resistant than the stainless steels and, of
13 course, the 625 is often used as the weld material
for
14 joining 825.

15 This is a curve that many corrosion people
have
16 called one of the so-called classic curves. This was
17 developed by Copson at Internation Nickel, and I
believe
18 starting in the 1940s.

19 But one of the great technological limitations
of
20 austenitic stainless steels is their susceptibility
to
21 chloride induced stress corrosion cracking, usually
22 results in a transgranular propagation of the crack.

23 And it's often because of this susceptibility,
the

24 susceptibility is greater, the curve is the lowest,
it
25 just at the range that most of the 300 stainless
steels of
233
1 composition nickel lie.
2 One could solve that problem in two ways. One
can
3 either have an alloy with no nickel in it or one can
have
4 an alloy with a lot of nickel in it.
5 On the basis of this curve, this has many of
the
6 alloys like 825 or above, particularly with 42
percent
7 nickel or so. But this is the region where it's -- I
hate
8 to use the word immune, but it's certainly very
highly
9 resistant to cracking and as well as magnesium
chloride.
10 Magnesium chloride, just like the FECL
subscript 3
11 that I talked about earlier, is again one of these
ASTM
12 tests that have been developed over a long period of
time
13 as a basis for comparing different kinds of stainless
14 steels, different stainless alloys.
15 And so for instance, when a new stainless
steel is
16 developed, one of the first things one does is to
test it
17 in boiling magnesium chloride to see how it fares
compared
18 to some of the older grades of material.

19 I'd like to go on to the next slide, please.

20 This shows the same kind of data that's now
21 collected for various alloys.

22 A point I'd like to make on this slide, it
came
23 from the lab discussion yesterday, and again, it
leads a
24 lot in the modeling and even into some philosophical
25 discussion.

234
1 It's very common for one in the corrosion
2 engineering point of view to consider different
3 thresholds. And I'm only using this because one must
4 argue that, well, if we keep the stress down low
enough
5 the material will never crack.

6 Well, this is the kind of question that has to
be
7 examined in a project like this, particularly where
we're
8 trying to make these long term projections, because
what
9 if thresholds do indeed really exist.

10 And Joe is going to say a few words about that
11 later, about the modeling that have been developed
where
12 essentially they just predict a longer and longer and
13 longer incubation times.

14 Because one can only see a little bit from the
15 flavor of this curve whether that becomes really,
really
16 straight or whether there's still some slope to that

curve

17 that even after a very, very, very long time that we
18 would -- at very low stress values we would intercept
that
19 curve. And even under those conditions we would have
20 failure.

21 By comparison, 825 isn't shown here because
again
22 sometimes 825 cracks and sometimes it doesn't. It
23 depends very, very markedly on small variations in
the
24 compositional differences and how it's processed.

But it
25 would presumably be way up there somewhat off the
curve.

235
1 And just to show that magnesium chloride as we
said
2 earlier is somewhat the chosen test review because it
is
3 so aggressive. This shows the relative corrosivity of
4 other chlorides. Magnesium is more corrosive than
calcium
5 chloride.

6 And again, one can interpret this from the
point of
7 view that magnesium chloride generally gives an acid
8 hydrolysis more than calcium chloride.

9 Another bad actor is ferric chloride as we
10 mentioned earlier in promoting local corrosion and
also
11 promotes stress corrosion cracking, and again because
it
12 is an aggressive medium.

one 13 The significance in the repository is that if
and 14 were to build the borehole liner and the shield plug
that 15 so on out of carbon steel, and corrosion products
present, if 16 form on the carbon steel and the chlorides are
17 one can perhaps generate scenarios of getting ferric
18 chloride to the surface of the container.

quite 19 This is a comparative study, again really
20 short term data with the candidates of interest. And
sees 21 again, it's an acid chloride medium. And again, one
22 no cracking of the stainless steel -- of any of the
the 23 materials in 10 days, but then under the 30 days all
24 stainless steels cracked and the 825 did not crack.

many, 25 A relationship that's been developed over
236
1 many years, and which seems to occur over repeatedly
relationship 2 sometimes at different levels here, is the
3 between chloride and oxygen.

extreme 4 And this one shows that almost in another
5 case it goes back to work done in the 1950s on boiler
shows 6 water with an alkaline phosphate treatment, which
7 that somewhat at very low concentrations of chloride
or 8 oxygen that there's a synergistic relationship

between

9 those materials that fail under stress corrosion
cracking

10 and when there is no failure.

11 So what you see is the threshold in these
cases is

12 quite low. And in our case where we do have a
chloride

13 content with J-13 water in this region, and then as
we

14 talked earlier in some of the clear water it can be

15 somewhat higher.

16 But we do have oxidizing conditions
prevailing,

17 either oxygen present in the atmosphere or there's
nitrate

18 present in the water which is an oxidizing species of
its

19 own, some of the radiation effects can create even

20 additional oxidizing species.

21 So in other words, one would predict, and we
have

22 done some work here and at Pacific Northwest
Laboratory,

23 when one takes a 304L, a 304 or 304L stainless steel
for

24 that matter, and puts it into J-13 water in a highly

25 irradiated environment, it does undergo stress
corrosion

1 cracking and has transgranular end morphology and
that

2 suggests that it's a chloride induced kind of
failure.

3 This is work that was done by the Japanese

again

4 with 304L stainless steel. And where there's no
5 irradiation present, in other words the oxygen
content or
6 the oxidizing power would be lower, then again when
7 irradiation is introduced the oxidizing power goes
way up,
8 the material becomes much more sensitive, much more
9 susceptible to stress corrosion cracking.

10 This again is work that was done in support of
the
11 nuclear power industry for 304 piping, work done at
12 General Electric in Schenectady, New York. But
again,
13 this is sort of a map of different degradation modes.

14 But when the material is more highly
sensitized,
15 the failure tends to be intergranular. If the
material is
16 not heavily sensitized, then the material tends to be
17 transgranular. And in between we have a granulated,
a
18 mixed mode, there's some transgranular and some
19 intergranular effect.

20 Also you'll notice the significance of the
strain
21 rate as you saw on the lab tour earlier, we are doing
or
22 planning to do some slow strain rate tests of the
23 material.

24 And these are just some of the relatively low
25 strain rates -- if one wants the high strain rates,

they

238

to

the

very

this

1 have a ductile failure which is not usually related
2 anything of other corrosion significance -- this is
3 low strain rates, which again we would expect with a
4 statically loaded item that we had, and that would be
5 area of significance.

6 Now, I believe I'm going to go on to stress
7 corrosion cracking in copper base alloys.

chloride

number

8 And as we alluded to yesterday, it's the
9 in the austenitic materials which is probably the
10 one causitive, number one stress corroding positive
11 species. It's ammonia that is the major culprit that
12 would affect copper base materials, and in some cases
13 other nitrogen bearing species can also be induced to
14 stress corrosion cracking.

diagram.

a

15 This shows a section of a potential pH
16 This indicates that ammoniated copper complex becomes
17 stable at 1 pH range and approximately seven, also at
18 higher pH range.

probably

this

protective

19 But the one that is of interest to us is
20 this one over here. When the complex becomes stable,
21 is at the expense of what would have been the

an 22 cuprous oxide film. And in that case when you have
23 unstable pass of film on the metal surface that's a
24 condition that often leads to stress corrosion
cracking.

say 25 And indeed, many copper alloys, and I'd almost

239
1 that virtually all of them are susceptible to stress
2 corrosion cracking in ammoniated environments, some
more,
3 some do have some degree of resistance, but it is a
very
4 devastating species to the copper based material.

5 Some work that was done to support the Swedish
6 nuclear program, work that was done at the University
of
7 Newcastle-upon-Tyne in England. It shows that the
other
8 nitrogen bearing species may be significant.

9 And these are some slow rate, slow strain rate
test
10 specimens of high purity copper to nitrite solutions
of
11 varying concentrations shown here. Again nitrate and
12 nitrite ion concentration increases the
susceptibility
13 also increases.

J-13 14 Again the significance of nitrite would be the
15 water contains nitrate, and almost invariably if one
16 introduces a metal into a nitrate environment there
will
17 be redox reactions occurring on the metal surface to

14 environments.

15 And pitting corrosion, if one were to examine
16 pitting corrosion, we find that generally the high
purity
17 copper and the 70/30 copper are the better performing
18 ones, aluminum bronze is the worst.

19 When dealing with dealloying effects,
naturally the
20 pure metal is the best, and particularly the
21 aluminum-bronze is the worst.

22 Crevice corrosion, in this case the two alloys
are
23 very good but the high purity copper is not so good.

24 In biofouling, the significance of biofouling
is
25 not so much that we would expect that in Yucca
Mountain

241
1 except this might be indicative in a very general way
of
2 what microbiological organisms would do.

3 One of the reasons why copper is used so much
in
4 marine applications is because the copper corrosion
5 products are toxic to marine life and so it's very
6 resistant to biofouling. As one alloy of copper one
7 reasons that effect because the concentration of
copper
8 corrosion products becomes less.

9 Now I'll talk a bit about hydrogen effects on
these
10 two alloy systems.

earlier, 11 In the copper base materials, as we said
12 one of the deficiencies or one of the weak points of
the 13 high purity copper was that it would tend to take up
14 oxygen during rolling operations or other high
temperature 15 operations where oxygen is present in the atmosphere.

16 When this material is then subsequently
exposed to 17 a hydrogen generating environment, which could occur
18 during radiolytic processes or even doing long term
19 electrochemical processes, then the copper oxide
which is 20 present in the material is transformed into little
water 21 blisters that are inside the material, inside the
copper,
22 and this has been called a hydrogen sickness
phenomenon.

23 If you want to be real authentic, it was
discovered 24 in Germany as the Wasserstoffkrankheit as it's
called in 25 the literature.

242
of 1 Because of this there's a severe degradation
2 mechanical properties when hydrogen sickness is
there.

3 There appears that there may be some mechanical
property 4 degradation in the bronzes because of the absorbed
5 hydrogen.

6 We found very little information on any

detrimental

7 effects of hydrogen in cupronickel. And again on
these

8 philosophical points, when one doesn't find any
9 information, one is asked to conclude it's not a
problem.

10 Again, particularly if one of these materials
have

11 been used in environments that should generate the
cause

12 of the agents and the cause of the kinds of
conditions

13 where comparable materials are affected, that that is
14 usually an indication of good resistance.

15 And also the fact that there hasn't been an
16 incentive to do work in that area or there's not that
much

17 published information maybe should indicate that at
least

18 up to date there's that that's been an observed
technical

19 limitation on those materials.

20 But I think one must always take that kind of
21 statement to heart when one finds no or little
information

22 on what the repercussions of the interpretation of
that

23 would be.

24 Again the next slide just shows an example of
where

25 we have this line of little water vapor bubbles that
form

243
1 and what that would look like on the fractured
surface of

2 a simple hydrogen sick copper.

3 Copper austenitic materials. Again absorbed
4 hydrogen in degraded mechanical properties. And
these
5 materials are really quite resistant to hydrogen
effects.

6 And what we have discerned in the literature,
to
7 give some comparison, the 304L stainless would be the
more
8 vulnerable to hydrogen embrittlement than the 316L.

9 Again we found very little information on the
10 hydrogen effects in Alloy 825, which again really
tends to
11 lead one to the conclusion that it's not a problem.

12 I might point out that 825 is used a lot in
13 sulfuric acid production and for containment of
sulfuric
14 acid. In other words, because of any corrosion in a
very
15 strongly acidic environment like that would produce
16 hydrogen.

17 So one does feel some comfort in the fact that
it
18 survives in a sulfuric acid environment with no
indication
19 of detrimental mechanical effects, that it is indeed
20 highly resistant to hydrogen embrittlement.

21 Now I'll talk a bit about the welding effects
on
22 the two alloy systems.

23 For the copper based materials, as we just

said

24 previous, is the possibility of the hydrogen sickness

25 phenomena, and is an alternative is the use of the

244

1 oxidized graded copper because in that case we formed
a

2 more stable oxide such as with phosphorous than we
would

3 with water vapors.

4 With Alloy 613, the aluminum-bronze, we have
as far

5 as the fusion weld process what we would think would
be

6 the greatest difficulty, and particularly in the

7 performance of the material that would result from
the

8 welded material.

9 Again one can introduce the particles. As I
said

10 earlier when we were talking about the phase diagrams

11 where we had more tendency toward dealloying and
localized

12 corrosion if we have high aluminum fillers.

13 And the way this material's processed, that we
have

14 that aluminum rich base prevails at room temperature

15 Also there's some loss of ductility in the mid

16 temperature range, and again it would be a question

17 whether that loss of ductility maintained down to the

18 temperatures of interest to us.

19 With the 715, it appears that this would have
the

20 fewest performance related problems due to welding.

16 can be formed.

17 And, again, primarily because of the
metallurgical

18 instability of the 304L, 316L, we have the greatest
19 potential for detrimental welding effects.

20 Again, for a number of reasons but
particularly to

21 prevent any weld cracking during the actual welding
22 operations, there's a tendency to have a balanced
23 composition such that one does have some retained
delta

24 ferrite at high temperature phase of iron to maintain
that

25 down to room temperature.

246
1 And when that's done, that introduces quite a
bit

2 of complexity in what the microstructure and the
various

3 interactions between those quite compositionally
different

4 microstructures would be over a very long time
period.

5 The 825 appears to be particularly simple in
that

6 it's a single phase. However, the complication
that's

7 introduced there, and again a philosophy subject to

8 tracking during the actual welding operation, is to
use

9 this much richer nickel, much richer molybdenum
containing

10 625 material.

11 From a galvanic corrosion point of view it's

an

Alloy

it

that

so

part

summarize

degradation

is

is

are

lot

effects,

12 ideal arrangement, but it's much more noble than the
13 825. So in any kind of preferential corrosion attack
14 would be the base material that would be corroded and
15 corrosion would be distributed over a much wider area
16 that the filler material would not be preferentially
17 attacked.

18 I believe now we're ready to go on to the last
19 of the talk.

20 And what we have done in this slide is to
21 and put into one table the results from the
22 mode surveys compared by the different kinds of
23 degradation for the three austenitic alloys.

24 And as one can see, the 825 in every category
25 the most resistant material, and in general the 304L
247
1 the least resistant material.

2 I should say that these last two items that
3 information here is not very thorough and there's a
4 more work that need to be done there. So we have
5 information on radiation effects and microbial
6 but this is just a little bit of information we have

7 gathered.

but in 8 These are discussed not as separate volumes
9 microbial for instance because it often affects the
10 localized stress corrosion behavior in those volumes.

And 11 radiation behavior is discussed in the general
corrosion 12 oxidation volume.

the 13 The next slide shows a similar analysis with
14 copper based material. But in this case there is no
one 15 candidate that comes out as being the best in all
interplay 16 categories. There's really quite a mixture and
17 of which one seems to be the better performing.

715, 18 Our conclusion or our analysis is that the
19 perhaps all things considered, is the more resistant
20 material, but the 613 also has some merit.

some of 21 The high purity copper, as I indicated from
a 22 the processing and welding points of view, has quite
23 number of disadvantages we feel.

this, 24 Now, we say somewhat the bottom line of all
resistant 25 we feel that the Alloy 825 is the most corrosion

1 among the austenitic materials. 248

that's 2 The 715 is probably the copper base material

are 3 the most resistant, all things considered. But there
4 some cases where the 613 merits more consideration.

that 5 But I really want to make this point emphatic,
6 this is just the analysis based on the degradation
mode 7 surveys and there are other factors that have to be
8 included in making a selection as Bill Halsey talks
about.

9 Those would be some parametric study results,
10 particularly when we try to compare these two
families of 11 materials and compare them under more representative
Yucca 12 Mountain repository conditions.

13 We have yet to evaluate the fabrication and
closure 14 process evaluations and results from them on the
relative 15 behaviors and relative rankings of the candidate
16 materials.

17 And then on -- and Joe will get into this much
behavior, 18 later on -- on model mechanisms of degradation
19 and particularly as we would judge our success in
we 20 predicting different kinds of corrosion based on what
out in 21 already know or based on what we think we can find
important 22 the next few years. And those are all the very
23 factors that can go into the selection criteria.

24 And then the next slide, what I'm trying to do
--

25 and again, it should lead very much into Joe's
249
1 discussion -- is trying to compare Alloy 825 with the
2 copper base materials.

3 And, again, there are very few direct
comparisons
4 of these materials. And much of our planned
parametric
5 work is aimed at making those comparisons.

6 And to give some of the pluses and minuses of
each
7 one, the 825 is more sensitive to halide ions and
copper
8 base materials, as a rule, is less sensitive to
halide
9 ions. The copper base materials are more sensitive
to
10 nitrogen bearing species.

11 Well, in our environment we've got both, so
that's
12 the kinds of decisions that we have to make and the
13 significance of them are that they very much affect
the
14 localized and stress corrosion effects.

15 As we talked earlier in Rich's talk we knew
from
16 the outset that the copper base materials would be
more
17 sensitive to radiation induced corrosion oxidation.

18 What we have to determine in the near future
is
19 whether that is indeed going to be performance
limiting.

products 20 And particularly to establish that the corroding
21 are protective.

take 22 Often copper materials, when they corrode they
years 23 a long time to reach steady stage. It takes really
24 of exposure to get to that condition.

levels 25 So sometimes we have short term data where the
1 rates are very high at the beginning and then just
if 2 out with time. And what we have to do is make sure
3 indeed such a threshold exists when we get to that
point.

austenitic 4 And then on the other hand the 825 and
metallurgy 5 materials in general are more complex physical
and 6 consideration. The 715 is a much simpler material,
7 there is a lot to be said for simplicity.

have 8 And often the result of that is that we would
long 9 fewer welding effects, fewer physical metallurgical,
simple 10 range physical metallurgical considerations for the
11 material.

12 And that concludes my presentation.

this 13 DR. VERINK: Dan, I'm sorry for not bringing
14 up earlier, but recognizing that there may be

any 15 configurational things that influence the design, has
16 attention been given to pressure welding as an
alternative
17 to friction welding and others?

18 As you may know, if you can reduce the
thickness by
19 50 percent you can get 100 percent efficient welds
20 nominally at room temperature, not counting the
heating
21 that you get from deformation on combinations of
22 materials.

23 DR. McCRIGHT: The best source on that, Ellis,
24 would be the fabrication and closure reports of
Babcock
25 and Wilcox Developing.

251
1 They looked through a wide variety of
processes and
2 then they recommended ones for additional
consideration,

3 and inertial welding was one of those that they did.

4 And I don't recall -- apparently the pressure
5 welding wasn't one that they recommended, because we
6 didn't pursue that one.

7 DR. VERINK: Well, one of the things that is
8 complicated about it what do you do about a tube,
because
9 you have to first either bend it out so it has
flanged, do
10 the pressure welding, and bend it back. But it's
been a
11 very successful kind of process in many kinds of

12 industrial uses.

13 DR. McCRIGHT: Yes.

14 DR. CLARKE: Okay. It's 11:30. Did you want
to
15 start into Joe's or wait until just after lunch? The
16 gentleman needs a break on his hands here for a
moment.

17 After lunch? Start an early lunch and return a
little bit
18 earlier?

19 DR. VERINK: I think that sounds like a
workable
20 scheme.

21 DR. CLARKE: Then we can report back at --
what
22 time do you have on your agenda?

23 DR. CLARKE: 1:00 o'clock?

24 DR. VERINK: Come back at 1:00?

25 DR. CLARKE: Yes.

1 DR. VERINK: Okay. Let's shoot for 1:00. 252

2 (Lunch break taken.)

3 DR. CLARKE: Okay. We would like to continue
with
4 the container materials program this morning. As you
see

5 by the flow chart, the square boxes are basically
6 activities that are completed.

7 The selection criteria as you heard from Mr.
Halsey
8 still is going through its final approval stage but
the
9 actual criterion work has been developed.

done, 10 The degradation mode surveys obviously are

11 and as Dan indicated, have been published.

relative 12 You are now going to hear from Joe Farmer
13 to our material testing and modeling.

will be 14 Those of you that were on the tour yesterday
15 probably got some of the advanced information that
the 16 presented today. That is an ongoing activity, as is
17 other parametric studies.

selection 18 All of this information is input to the
material 19 process, as Bill indicated, and will lead to our
20 selection.

21 With that, Joe.

with 22 DR. FARMER: As Bill said, I'll be discussing
doing to 23 you the corrosion modeling and testing that we're
24 support the waste container.

this 25 In this presentation I'd like to try to follow

253

1 outline to the best I can.

outside 2 I'll begin by telling you about conditions
this 3 of one specific spent fuel container. I wanted to do
for 4 so that you'll be reminded and have an appreciation

5 the types of environment that we're talking about as

we

6 discuss the corrosion processes.

that we

7 Then I'll tell you about the documentation
8 have of existing models to support our modeling
9 activities.

with

10 The next two portions of the presentation deal
11 modeling and testing.

that we

12 First I'll tell you about the measurements
13 made of uniform rates of oxidation. This particular
14 experimental activity has been to support modeling
15 for vapor phase corrosion.

work

testing

16 I'll then move on and discuss modeling and
17 to support the aqueous phase environment condition.
18 Trying to tie this back to Dale's talk yesterday, the
19 vapor phase condition is an expected condition, the
20 aqueous environment is the bounding case, the
21 bounding
22 condition.

bounding

modeling and

22 When we get into the discussion of the
23 testing for the aqueous stage environment I'm going
24 to
25 illustrate this activity by discussing in detail
models
26 for pit initiation and propagation and models for
stress

to

models

stress

tell

1 corrosion crack initiation and propagation, and also

we're 2 you about the type of experimental activities that
3 undertaking to support these two modeling efforts.

flavor 4 I'll end the presentation by giving you some
5 about the status of the corrosion research that's
being 6 done here at Lawrence Livermore National Laboratory.

about 7 As I wrap up the presentation and tell you
8 the status of our experimental work, I will first
tell you 9 about measurements that we have made and are making
on the 10 corrosion and pitting potential.

that 11 Then I'll go on and tell you about some work
12 we have done in the past to develop in situ
diagnostic 13 techniques for identification of corrosion products.

We 14 believe that this could be applied in the future to
cases 15 that Rich discussed with you this morning, perhaps
the in 16 situ detection of the basic copper nitrate species.

little 17 And, finally, I'll end up by telling you a
18 bit about a new technique that we worked on that
allows us 19 to detect the initiation of stress corrosion cracks
very, 20 very early.

21 And I'll finish with a few summary statements.

22 First, the conditions outside of one specific
spent
23 fuel container. And I emphasize one specific spent
fuel
24 container because every container will see a slightly
25 different environment. And this is one typical
container

255

1 that I want to discuss with you.

2 In the time immediately following emplacement
we
3 know that the temperature of this container will
remain
4 above the boiling point for a considerable length of
time.

5 We also know from some of the work that Rich
6 discussed with you that we're going to have the
radiolytic
7 formation of nitrogen oxides in the case of dry air,
and
8 we'll have the radiolytic formation of nitric acid
and
9 ammonia in moist air.

10 Of course, we have to have moisture so that we
can
11 have the hydrogen contributive to the formation of
these
12 species.

13 We also have the possible formation, in this
14 initial emplacement period, the possible formation of
a
15 salt crust on the container surface.

16 As you recall, the container is very, very
hot. It

possibly 17 can be up to 250 degrees C. As we have water
18 falling on the container surface it can reflux and
salt 19 evaporate. This will result in the formation of a
20 crust.

21 After very long periods of time the
temperature is
22 expected to drop below the boiling point. This is
due to
23 the decay of the radionuclides inside the waste
container.

boiling 24 After the temperature does drop below the
25 point we have the possible formation of a concentrate
form 1 electrolyte. Water that contacts the salt crust can
2 a concentrated electrolyte.

for 3 And of course, this is a very bad condition
4 corrosion. This is not an expecting condition but a
5 bounding condition, something that is possible.

Rich's 6 You also know from previous discussions in
7 talk that we have the possibility for the radiolytic
with you 8 formation of hydrogen peroxide. And I'll discuss
9 in a few minutes as I did with some of you yesterday
in
peroxide 10 the laboratory, some of the effects of hydrogen
11 on corrosion potential and pitting potential.

12 And finally, even at very long periods of time

the 13 after we're below the boiling point on the surface of
14 container, we have the radiolytic formation of nitric
15 acid.

just 16 Many of you have seen this curve before, but I
17 wanted to put it up to give you a firmer feel for the
type 18 of condition that this one typical spent fuel
container 19 will see.

out 20 You can see that the wall temperature starts
in 21 about 250 degrees C. And after some period of time,
years, it 22 this particular case on the order of a thousand
boiling 23 drops down to a level that begins to approach the
24 point.

one 25 Now, again this is the calculation for just
1 specific waste container. So other containers can be
2 slightly warmer or cooler.

gone to 3 As we've already discussed with you, we've
to 4 great lengths to document the models that we're using
5 support our modeling effort. We're also using these
of 6 theoretical models and mechanistic models to dry some
7 our experimental work.

document 8 We've done the best job that we can to

9 these models in four different places. The most
recent
10 documentation was at the SMiRT-10 conference held
recently
11 in Los Angeles. And I won't read each of these for
you
12 because I know you have them in your handouts.

13 I now want to discuss with you an expected
14 condition. Containers exposed to vapor-phase
15 environments. This is the type of environment that
the
16 containers will see for the first on the order of 300
to a
17 thousand years.

18 This diagram represents the type of modeling
effort
19 we have to have in order to predict the type of
failure
20 that these containers might undergo in a repository
and
21 again, in a vapor-phase environment.

22 We had three information inputs into the
model.
23 These are along the top of the viewgraph.

24 We had environmental information that's been
put
25 into the model, materials properties input, and
mechanical

1 force inputs. 258

2 When we considered the environment we had
several
3 things to be concerned about. The temperature, the
4 partial pressure of both water vapor and radiolysis

5 products, as well as the possibility of microbial
growth.

6 And we're doing our best to take these things into
7 account.

8 When we consider materials properties, we have
to
9 know mechanical properties of the materials as Bill
Halsey

10 has already discussed with you. We have to know
of
11 metallurgical properties, things related to the face
12 these alloys, and we also have to know about their
13 chemical properties. How resistant are they to the
14 chemical types of attack that you see in corrosive
15 environments?

16 We have to have some knowledge about the
mechanical
17 forces acting on these containers. We expect that we
18 could have four different types of mechanical loads
19 imposed on the containers.

20 Force due to residual stress near the weld.
This
21 would be expected to be somewhere near the yield
stress of
22 the material.

23 We could have the possibility of unexpected
24 lithostatic stresses operating on the containers.
Again
25 this is not expected, it's an unexpected condition,
but

1 it's something we need to at least give some thought
to.

2 We could have the possibility of building up
3 internal gas pressure in the container. This would
be due
4 to a scenario where the container would be subjected
to
5 perhaps a transportation fire and the heating of the
gas
6 inside the container would result in significant
pressure
7 so the container has to be capable of withstanding
this
8 internal pressure.

9 And then it has to be able to withstand
structural
10 loads due to movement and emplacement.

11 These three types of input were fed into
models in
12 the case of vapor-phase corrosion for uniform
oxidation,
13 stress corrosion cracking and mechanical failure.

14 In the case of uniform oxidation we have two
basic
15 types of corrosion models that we concern ourselves
with,
16 a simple linear growth of oxide or corrosion product
on
17 the surface and a slightly more complicated but not
very
18 complicated situation where we have parabolic growth
of
19 the oxide or corrosion product on the surface. The
20 parabolic growth, of course, is due to the diffusion
21 limitations of this growth process.

whether 22 In the case of stress corrosion cracking
23 it's in an aqueous phase or a vapor-phase, we have to
24 concern ourselves with microstructural changes which
occur
25 in some of the alloys such as the austenites that Dan
has
260
1 already discussed with you.
2 Some of the microstructural changes which are
of
3 special interest to us include sensitization. After
we
4 have sensitization, of course, we can have
intergranular
5 stress corrosion cracking occur.
6 When we think about modeling the stress
corrosion
7 cracking process, we divide the modeling effort into
two
8 types, models dealing with the initiation step for
stress
9 corrosion cracking and models dealing with the
propagation
10 of stress corrosion crack through the container wall.
11 And finally we have classical mechanical
failure.
12 I'm not going to discuss this today.
13 When we take our overall modeling effort, the
end
14 goal is to predict the time required for complete
15 penetration of the container wall and a failure of
this
16 container.
17 In this viewgraph I want to summarize for you

what

18 we've done to date and what we think in terms of
modeling

19 the oxidation process in a vapor-phase environment.

20 Again we have two basic types of models for
21 vapor-phase oxidation, parabolic models and linear
models.

22 The parabolic growth law is usually cases
where we

23 have adherent protective oxide films. This growth

24 process, some people refer to this as Bogger's law,
but

25 it's a diffusion limited process and that's why you
have

261

1 the parabolic growth.

2 We have a second scenario where we can have
linear

3 growth of this corrosion produce on the surface. In
this

4 particular case we don't have the same diffusion

5 limitation. The reason is because the oxide film
falls

6 off the surface and the corrosion product does not
form a

7 protective coating over the metal underneath.

8 We're doing various types of tests to support
this

9 model. For instance, we're doing coupon exposures to

10 steam and water. In the next few slides I'll show
you

11 some of the data that we have collected from this
type of

12 activity.

13 When we do these coupon tests we make periodic
14 measurements of the gain in weight of the coupons due
to
15 the formation of this corrosion product on the
surface.

16 We've been performing experiments at
temperatures
17 ranging from 50 to 150 degrees C. And as Rich Van
18 Konynenburg discussed with you earlier, we've also
done
19 what we can to determine the effects of gamma
irradiation
20 on the oxidation process.

21 We've looked at the effect of gamma
irradiation
22 both on rates as well as the type of corrosion
product
23 that we form. And we've gone to great lengths to try
to
24 positively identify all corrosion products using
X-ray
25 diffraction.

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1 These are data taken in our own laboratory and
2 illustrate the corrosion rates that you would expect
to
3 observe in a repository light environment.

4 Here we have data for some of the austenitic
alloys
5 exposed to both water and saturated steam. The
primary
6 conclusion that you draw from looking at this type of
data
7 is that the container life will not be limited by
uniform

8 oxidation provided we build the container out of an
9 austenitic type of material.

10 You'll notice here we have a marker, .1
millimeters
11 and 1,000 years. You'll recall that we're talking
about a
12 container wall thickness that will be somewhere
between
13 one centimeter and three centimeters thick.

14 Well, clearly in a thousand years, if this
15 particular corrosion rate would give us only .1
millimeter
16 of erosion, we're talking about losing less than one
17 percent of the container wall thickness in a thousand
18 years.

19 So, again, we know from our work that
container
20 life will not be limited by uniform rates of
oxidation and
21 corrosion. And this -- pointing out, this is data
that
22 was collected in our own laboratory.

23 Next slide, please.

24 From similar type experiments with the copper
based
25 alloys we have learned that container life may very
well

263
1 be limited in the case of the copper base alloys.

2 Here we have data at three different
temperature
3 levels representing both saturated steam and
saturated
4 liquid.

5 Here you'll notice another marker. In the
previous
6 slide -- I had intended to change this but haven't
had the
7 opportunity yet -- but in the previous slide you saw
a
8 marker for .1 millimeter per year, one percent of the
wall
9 thickness. This marker represents 10 percent of the
wall
10 thickness.

11 So this particular observed corrosion rate
would
12 indicate to us that 10 percent of the container wall
13 thickness would be oxidized away after a thousand
years.

14 Well, clearly, some of these rates that are
being
15 observed are much higher. So in the case of the CDA
715
16 we have high enough rates of oxidation so that we
would
17 expect up to 60 percent of the wall to be oxidized
away.

18 DR. VERNIK: Did I understand from earlier
comments
19 that copper base would be more likely three
centimeters
20 rather than one?

21 DR. FARMER: Probably so. I --

22 DR. VERNIK: So three percent.

23 DR. FARMER: Yes. I think considerations like
this
24 we went with the copper base alloy would drive us to

a

25 thicker wall as well as their ductility and some
other

264

1 considerations.

2 But nonetheless even if you consider 60
percent one

3 centimeter or reduce that by a third, that's still
very

4 significant compared to the types of effects you'd
see

5 with the austenite.

6 Okay. I'll just show you this again. I
mentioned

7 in the outline that we've done considerable work to
try to

8 identify corrosion products as we find them.

9 This slide was shown to you before by Rich,
and we

10 have gone to great lengths to try to identify
corrosion

11 products that we see in various places such as some
of our

12 particle accelerators.

13 These are the X-ray diffraction data that
we've

14 taken to identify these corrosion products. And if
you

15 compare our observed X-ray diffraction pattern with
that

16 of a known basic copper nitrate diffraction pattern
you

17 can see that there's quite good agreement. If you
look at

18 the major piece here you see that you have quite good

19 agreement.

some of 20 Now I'd like to go on and discuss with you
that 21 the modeling that we're doing and testing to support
22 modeling for aqueous phase environments.

going 23 These aqueous phase environments again are a
24 bounding condition, not an expected condition. I'm
though 25 to spend considerable time discussing this with you

testing 1 because from a theoretical point of view, from a
2 point of view, it's a much more complicated case than
3 simple oxidation. So it requires more explanation.

model. 4 Again we have three types of inputs into the

properties 5 We have environmental inputs, we have materials
similar 6 inputs, and we have mechanical force input, very
7 to what you saw in the case of vapor-phase oxidation.

up an 8 In this particular modeling effort we picked
9 additional mode of failure, localized attack. You'll
10 recall in the previous slide we were concerned with
I 11 uniform oxidation, in the case of aqueous corrosion,
12 call it uniform oxidation.

pick 13 We had the uniform attack mode, we had stress
14 corrosion cracking and mechanical failure. But now we
15 up an additional mode of localized attack.

worry 16 In the case of aqueous corrosion we have to
17 both about passivation and dissolution processes. In
account 18 modeling our localized attack we have to take into
19 crevice corrosion as well as pitting. Pitting is
very 20 much like stress corrosion cracking.

step and 21 We have models that explain the initiation
22 models that explain the propagation step. Stress
23 corrosion cracking, again we have to worry about
24 sensitization and formation of M₂₃C₆ carbides. We
have to 25 worry about the initiation of these stress corrosion
266
the 1 cracks and we have to worry about the propagation of
2 stress corrosion cracks through the container wall.

mechanical 3 And finally, we have to also worry about
4 failure. The end goal, of course, is to predict the
time 5 of failure.

to 6 In the remainder of the discussion I'm going
7 concentrate on the pitting corrosion and stress
corrosion 8 cracking models. More specifically, I'm going to
9 illustrate for you one model in each of these two
10 categories, pitting initiation model and a pitting
11 propagation model, stress corrosion cracking
initiation

12 model and a stress corrosion cracking propagation
model.

13 With the end objective being to predict time of
failure.

14 From the documentation we have gathered on all
of

15 these models, we have come to the conclusion that
these

16 are the basic initiation and propagation models for
17 pitting.

18 We have six primary types of models for the
19 initiation of pits on the surface of austenitic
alloys,

20 and I emphasize austenitic alloys. The halide nuclei
21 theory developed by Professor Okada of Japan; point
defect

22 model developed by Digby McDonald and his coworkers
at

23 SOI; critical suppression of pH model developed by
Galvele

24 in '76; an electrostriction model developed by Sato;
an

25 inclusion model, which is more a conceptual model
than

1 mathematical model, developed by Manning; and the
2 applications of stochastic probability theory by
Shibata

3 and Takeyama in '77.

4 When we think about the propagation of pits in
5 austenitic alloys we have two primary types of models
to

6 concern ourselves with when we go through the review
of

7 accepted literature.

8 The first model is a quasi-steady-state mass
9 transport model. And this basically means that you
let
10 the time derivative be zero and assume that you've
always
11 come to some steady state in solving the differential
12 equations for the transport processes.

13 This model was first developed by Pickering
and
14 Frankenthal in '72. And it was later modified by
Galvele
15 to take into account the hydrolysis reaction at the
base
16 of the pit.

17 Galvele's contribution to this modeling is
18 important because it gave us some appreciation for
the
19 importance of pH suppression in pits and gave us an
20 understanding of why the pH suppression drives the
pit
21 propagation process.

22 The second generic type of model we find for
pit
23 propagation is a transient mass transport model. One
of
24 the first developed very thoroughly in the literature
was
25 presented by Beck and Alkire in 1978. This was in
the

1 Journal of the Electrochemical Society.

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2 Now, you'll notice here I've emphasized that
these
3 models are applicable to austenitic alloys. The

is 4 theoretical work that is documented in the literature
5 for austenitic alloys.

work 6 We've concluded from going through all of that
alloys 7 that predicted models for pitting of copper based
of 8 do not exist. We cannot quantitatively predict rates
base 9 initiation on pit propagation in the case of copper
10 alloy.

that 11 This is a need that we've identified and one
resources 12 will have to be addressed. And again, time and
13 will be required for the development of this type of
14 model.

the 15 Now, first, as I discussed with some of you in
you 16 laboratory yesterday, I would like to illustrate for
pit 17 some of the modeling and testing effort to support a
18 initiation model, specifically the model of Professor
19 Okada, the halide nuclei theory.

upon 20 So the primary thing that I wanted to impress
is 21 you as I discuss this particular pit initiation model
22 first of all two important parameters are derived by
incubation 23 Okada, the critical pitting potential and the

initiate 24 time for pitting, how long it takes for a pit to
25 on the surface of the container.

allow 1 You'll notice that both of these expressions
2 one to calculate the effect of chloride on the
pitting 3 potential and the effect of chloride on the
incubation 4 time. There are actually more recent derivations
which 5 also allow us to take into account pH.

look 6 But the important thing to appreciate as you
7 at these expressions is that they are logarithmically
8 linear in chloride concentration. And this gives us
an 9 important experimental handle as we try to treat our
data.

10 The other important thing that I would like to
11 impress upon you about the type of work that we find
in 12 the literature, especially that of researchers such
as 13 Professor Okada, is that he's used two independent
14 theoretical approaches to derive these expressions.

one 15 He has used nonsteady state thermodynamics as
16 approach and he's come up with this functionality.
And 17 he's also applied perturbation theory and he's come
up 18 with these two expressions.

19 So two independent theoretical starting

places, but

20 it brought him to the same functionality.

the 21 Now that gives us quite a bit of confidence in

22 generality of those expressions as we go and try to
treat

23 our data in using those expressions.

look at 24 We also developed confidence, because as we

as 25 the derivations and work from other researchers such

they use 270
1 Cal and McDonald at SRI, we find that even though

also 2 a point defect model as their starting place, they

3 derive the same functional expressions.

Galvele 4 Similar equations have been developed by

this 5 and have been verified empirically by Matamala. And

course, 6 in fact is his correlation. And you can see, of

7 that we had this logarithmic dependence on chloride

8 concentration and linear dependence on pH and
temperature.

9 You'll also notice the appearance of these two

10 factor interactions in this empirical expression.

to the 11 Okay. So we have models that are applicable

12 pit initiation process. We now have to go and do

are 13 experiments to support those types of models. These

those 14 the types of experiments that we're doing to support

15 pit initiation models.

16 We're making measurements of the critical
pitting

17 potential using potentiodynamic linear sweep
polarization

18 as you saw yesterday in the laboratory.

19 We're also making measurements of the
incubation

20 time by doing potentiostatic polarization of single
and

21 multiple samples. When we do polarization of
multiple

22 samples we can again apply the stochastic probability
the

23 theory to the analysis of the results, and that is
the

24 statement that you see here.

25 The thing that I want to show you in the next
few

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1 viewgraphs has to do with the use of factorial
designs to

2 minimize the number of experiments that are required
to

3 determine the dependence of pitting potential and
4 incubation time on facts such as chloride, pH and
5 temperature.

6 Actually before I get to the discussion of the
7 factorial design, I show you this viewgraph again as
a

8 reminder of the type of experiment that we're doing
to

9 measure the pitting potential.

10 As Dan discussed with you before, the pitting

breakdown 11 potential is measured as the point where we have
amounts 12 of the passive film and begin to pass substantial
again, 13 of current while doing the polarization curve. And
14 some alloys are better than others.

have 15 To minimize the number of experiments that we
potential and 16 to do to determine the dependence of pitting
use 17 incubation time on temperature, chloride and pH, we
18 this particular type of strategy.

pick up 19 The factorial design allows us not only to
20 the important two factor interactions such as the
here, but 21 interaction between pH and chloride that you see
22 it also allows us to pick up potentially important
three 23 factor interactions.

relatively 24 And, again, even though this equation is
we 25 complicated and takes into account numerous effects,

And 1 can fit this equation using only eight experiments.
also 2 if we employ factorial designed experiments we can
3 determine the confidence intervals on these
parameters.

parameters, it 4 So it not only allows us to fit the
5 also gives us statistics with only eight experiments.

for a 6 This is the factorial design that we're using
7 typical pitting potential series.

8 Here we have eight experiments. The plus
9 represents a high level of the variable that we're
the 10 interested in. The minus represents a low level of
11 variable.

both 12 And here you see the plus and minus levels for
13 the independent variables as well as the two factor
14 interactions and the three factor interactions.

it 15 Now, I'm not going -- because of the time that
the 16 requires, I'm not going to discuss in detail with you
we 17 pit propagation models, but I wanted to tell you how
18 have gone about quantifying pit depth and quantifying
and 19 things having to do with pit propagation in the past
20 how we plan to do these things in the future.

propagation 21 The first thing that we do in the pit
22 measurements is we want to determine pit depth as a
procedure 23 function of time. And we normally follow this
an 24 in order to do this. We first expose our coupons to
some 25 environment of interest, be it J-13 well water or
1 modified J-13 well water.

the
of the
the
some
2 We then use optical microscopy to determine
3 distance from the surface of the coupon to the base
4 pit by measuring the focal distance at the base of
5 pit. This is a fairly standard practice and I'm sure
6 of you probably have done it yourselves.

large
7 We can also use optical microscopy of
8 metallographic cross-sections where the pits are
9 enough.

yet
digital
is a
to
10 We have plans but we haven't implemented them
11 to use optical microscopy with a video camera and
12 image processing to actually quantify the fractional
13 coverage of these surfaces by pits. And I think this
14 relatively new technology that we're anxious to apply
15 this problem.

weight
16 And, finally, we always make measurements of
17 gain or weight loss.

any
of
slide
18 As I said in the previous slide, there aren't
19 models to quantitatively predict the rate of pit
20 initiation or the rate of pit propagation in the case
21 copper based alloys. And I wanted to show you this
22 so that you would have an appreciation for why those

23 models do not exist.

24 The pitting process on a stainless steel is
25 relatively simple. You have the formation of a
halide
single
1 crystallite on the surface of the oxide film, a
274
2 crystallite.

3 And you can see that is in dramatic contrast
to the
4 type of processes that you have occurring in the
pitting
5 of copper. Here you can see that you have multiple
6 diffusion barriers and very complicated chemistry.

7 So to solve the differential equations for
this
8 it's challenging to say the least. And this is the
reason
9 why these quantitative models do not exist in the
case of
10 copper based alloys.

11 I'd now like to go on and discuss with you
what we
12 know about the modeling of stress corrosion cracking
and
13 then elaborate further to tell you about the types of
14 experiments that we're doing to support this stress
15 corrosion cracking modeling effort.

16 Again, we have two phases in the stress
corrosion
17 cracking process that we have to be concerned with,
the
18 initiation step and the propagation step.

periodic

16 fracture of a passive film at the crack tip. Every
time

17 you rupture the passive film at the tip of the crack
you

18 have an elongation of the crack.

19 And finally we have a film-induced cleavage
model

20 that was proposed and developed by Paskin and some of
his

21 coworkers. However, this is a very controversial
model

22 and we haven't put much emphasis on it.

23 Most of our emphasis in terms of propagation
models

24 is on the periodic fracture model and most of our
effort

25 in the initiation area is using the crack-tip-opening
276

1 displacement model initially proposed by Buck and
Ranjan.

2 These are some of the underlying assumptions
of our

3 stress corrosion initiation model.

4 First of all, it's assumed that stress
corrosion

5 cracking initiates at pits. You can't have stress

6 corrosion cracks initiate on the surface unless you
have

7 some sort of preexisting flaw such as a pit.

8 Secondly, there were assumptions that were
made

9 about the electrochemistry that occurs inside or
around

10 the pit.

11 First it's assumed that the base of the pit is
12 active, and secondly it's assumed that the pit depth
13 varies linearly with time. This is inherent in the
14 assumption of Butler-Volmer kinetics.

15 We have to assume that we have sufficient
16 displacement at the mouth of the pit due to an
applied
17 stress so that we don't have blunting of the crack
tip.

18 And finally, we assume that the propagation
rate of
19 microcracks at the base of the pits are proportional
to
20 this opening displacement at the mouth of the pit.

21 The crack tip opening displacement model by
Buck
22 and Ranjan allows us to predict both the conditions
and
23 time required for the initiation of stress corrosion
24 cracking.

25 In order to get at the conditions required for
1 stress corrosion cracking they give us two criteria.
277
2 First of all, the displacement at the mouth of the
pit has
3 to be greater than some critical value, Δ_{sub}
naught
4 plus $\Delta_{sub c}$.

5 And secondly, the applied stress σ has to
be
6 greater -- this is an end quality so you should take
this
7 stress intensity factor over to the right-hand side

of the

8 end quality margin. But at any rate, this quantity
has to

9 be larger than this quantity.

10 So that we have two criteria that have to be
11 satisfied before we can have initiation of stress
12 corrosion crack at site of pitting.

13 Starting with these criteria, these two
14 investigators have developed an expression that
allows us

15 to predict the time required for initiation of a
stress
16 corrosion crack.

17 The expression that they had developed for
this
18 initiation time has two factors in it. The first
factor

19 allows us to take into account mechanical effects.
The

20 second parameter allows us to take into account
21 environmental effects through electrochemical
corrosion.

22 The reason I showed you that slide is I
thought
23 that it was important for you to have an appreciation
for

24 why we're having to run some of the experiments that
we
25 are. These are experiments that we're doing to
support

1 initiation models.

2 We're making measurements of the threshold
stress

3 intensity factor for stress corrosion cracking K₁SCC,
4 using modified wedge-opening-loading fracture
specimen,
5 WOL specimen.

6 We're also trying to make measurements of the
7 incubation time required for the initiation of stress
8 corrosion. And this describes in brief the procedure
9 we're going through to make these measurements of
10 incubation time.

11 We are loading specimens in a screw-driven
tensile
12 machine. This is the same procedure that Buck and
Ranjan
13 have employed in the past.

14 We're then subjecting the loaded specimen to
15 various environments and we're varying the
environmental
16 chemistry, the electrochemical polarization and the
17 temperature.

18 We're then measuring the time required for
19 reduction in stress at constant displacement. For
20 instance, when you initiate a stress corrosion crack
you
21 see the signal from your load cell begin to diminish.

So
22 that is our technique for measuring the initiation
time
23 required for stress corrosion crack, one of the
24 techniques.

25 I now want to go on and discuss with you the
type

1 of models that we're employing and the types of
2 experiments that we're doing to address the problem
of the
3 propagation of stress corrosion cracks through a
container
4 wall.

5 The primary model that we're relying on is one
6 developed by Andresen and Ford and it involves the
7 periodic fracture of passive film at the tip of the
crack.

8 This is the expression that they have that
allows
9 us to predict the rate of crack propagation as a
function
10 of the crack tip strain rate, the film fracture
strain and

11 the thickness of the passive film at the crack tip.
The
12 thickness of the passive film at the crack tip is
13 represented by this electrochemical grounder.

14 We have molecular weight and $Q_{sub F}$. The $Q_{sub F}$
sub F
15 is the amount of anodic charge involved in
repassivation
16 of the crack tip after it fractures.

17 Z is the number of electrons involved in the
18 repassivation process, rho is density of the oxide
film,
19 and F, of course, is ferrous constant.

20 At any rate, this expression gives you an
21 appreciation for the types of phenomena that are
involved
22 in the propagation of stress corrosion cracks.

as 20 intensity factor is one where it is expected to vary
varies to 21 the square of K. In reality we observed that it
22 the fourth power of K.

you 23 And I wanted to show you this to emphasize to
where we 24 that theoretical models are good and we use them
models 25 can, but there are situations where the theoretical

281
1 don't agree with the data and we have to rely upon
empiricism 2 semi-empirical correlations and mirrors between
is 3 and mechanistic models to make things work. And this
4 one of those situations.

of 5 You saw in the laboratory yesterday the type
on 6 instrumentation that we're using to make measurements
7 the crack propagation rate. This is our reverse DC
8 instrument. It was built by General Electric.

9 The reason we decided to use the reverse DC
rates 10 instrumentation for measurement of crack propagation
the 11 is because it is being used in several BWRs around
been 12 world and has -- and a great deal of credibility has
13 built around this particular instrumentation.

14 In the machine you saw yesterday there are two
15 autoclaves. Each autoclave has three testing

stations.

16 We have three testing stations in this autoclave for
17 copper based alloys, three testing stations in this
18 particular autoclave for the austenitic materials.

19 The electronics in the center rack is
responsible

20 for applying the reversing DC pulse of current which
is

21 about five amps in amplitude and about one hertz
22 frequency.

23 And we basically measure the potential drop in
this

24 instrument across the crack and correlate that
potential

25 drop with the length of the crack. But it's
fundamentally

1 a very simple measurement even though the
instrumentation

2 is large.

3 And we're using this technique to measure the
4 parameter of D80T. And then we're fitting D80T as a
5 function of K to determine, whether it's K to the
fourth

6 or fifth or whatever.

7 Okay. Now I want to move on and tell you
about

8 some of the experiments that we've done in the past.
A

9 lot of the work that I've discussed up to now has to
do

10 with modeling, the documentation of those models,
what we

11 plan to do with modeling, and the experiments that we

plan

12 to use to quantify the parameters of those models.

that

13 I now want to tell you about the experiments

first

14 we've actually conducted in the past. One of the

with

15 experiments that I wanted to tell you about has to do

in a

16 some electrochemical measurements that we have made

17 gamma pit on site at the laboratory.

involved

18 This is the electrochemical cell that was

much

19 in those gamma irradiolysis experiments. It's very

20 like the electrochemical cell that we used to do the

been

21 standard polarization test in except the geometry has

the

22 compressed a bit so that we could fit it down into

23 gamma pit.

24 And you'll notice that it has the standard

25 electrochemical cell configuration. We have working

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1 electrode, reference electrode, Luggin probe, counter

access

2 electrode, so on and so forth, and the ability to

3 the electrolyte in the cell.

4 This whole cell is lowered down into the gamma

5 field when we do an experiment.

years ago

6 These are data that were gathered several

we

7 before one of our stop work orders so that we can --

8 did these experiments so that we could develop an
9 understanding of the effects of gamma irradiation on
10 corrosion potential.

11 These markers off and on represent conditions
where

12 we modulated the gamma field around the
electrochemical

13 cell. We modulated the gamma field by lowering the
14 electrochemical cell down into and moving it from the
15 gamma bed.

16 And you can see that when we turn the gamma
field

17 off the corrosion potential drops, it moves in
cathodic

18 direction. When we turn the gamma field on we have a
19 positive deviation or excursion in the corrosion
20 potential.

21 We did other experiments and finally came to
the

22 conclusion that these modulations of corrosion
potential

23 were due to the formation of hydrogen peroxide.

24 Hydrogen peroxide, when it is reacted on the
25 surface of the electrode, it moves the mix potential
in

1 the anodic direction anywhere from 100²⁸⁴ to 200
millivolts.

2 The previous data was from one of our
austenitic

3 candidates. This data was taken for OFHC copper.
Here

4 you can see the same general effect.

5 When we first expose the sample to the gamma
field
6 we see a positive deviation in the corrosion
potential by
7 about 100 millivolts, then the potential decays
8 exponentially until we turn the gamma source off.
And at
9 that point it drops to background levels.

10 We did not observe this rapid exponential
decay in
11 the case of the austenitic materials. This
particular
12 decay is due to the electrochemical reduction of the
13 hydrogen peroxide on the copper surface. Copper
turns out
14 to be a very good reduction catalyst.

15 Again, I apologize. I know I've shown most of
you
16 these slides twice. But just bear with me and I'll
get on
17 to something new in a bit.

18 We've also investigated the effects of gamma
19 irradiation on the pitting potential of 316L in
sodium
20 chloride solutionn. Again we did this in the same
21 electrochemical cell that you saw in the slide
previously.

22 We modulated the gamma field by lowering the
cell
23 into a region close to a cobalt source, and then
removing
24 it from that area.

25 You can see that the corrosion potential has

1 shifted very substantially by the presence of gamma
2 irradiation. The starred values represent values
measured
3 in the presence of the gamma field.

4 The shift here is on the order of 200
millivolts
5 which is comparable to the types of deviation that
you saw
6 in the previous viewgraphs.

7 In contrast, if you look at the pitting
potential
8 you can see that there's very little effect of the
9 radiolysis on the pitting potential. And if
anything, it
10 may be a bit better -- or I'm sorry, not a bit better
--

11 it's only a bit worse in the presence of the gamma
12 irradiation.

13 And again we quantify the resistance of a
14 particular alloy to localized attack by taking the
15 difference between the corrosion potential and the
pitting
16 potential.

17 Since implementation of our new QA plan we've
been
18 trying to determine quantitatively the effects of
chloride
19 concentration on the pitting potential and the
incubation
20 time. This is one example of some of the data that
we're
21 gathering for our 316L.

a 17 chloride concentration scale and trying to determine
18 critical chloride level.

localized 19 This is the level that we begin to induce
20 attack of this particular candidate material, 316L.

critical 21 And we so far have determined that the
thousand 22 chloride concentration lies somewhere between a
we're 23 and 5,000 parts per millimeter. And as we speak,
24 gaining additional beta points to fill on this curve.

has 25 Rich discussed with you experiments that he

order to 1 done and some investigations that he has done in
2 identify corrosion products in a gamma field.

corrosion 3 One problem that we have in looking at
4 products and trying to identify them is the in situ
is 5 identification of these corrosion products. And this
6 especially true in cases where you have gamma fields.

7 In the past we've developed in situ diagnostic
8 techniques that allow us to determine and identify
9 corrosion products on services.

Raman 10 Next slide. One of these techniques is laser
11 the technique that I just showed you.

pH 12 These are spectra that we have collected in an
13 experiment with copper in a solution of approximately

done 14 12 to 13. In this particular experiment what we've
15 is perform a linear polarization experiment while we
16 simultaneously observe the surface using the laser
Raman.

17 And you can see that by doing this we can
18 experimentally map Pourbaix diagrams. And we have
19 developed good techniques to do this.

cuprous 20 Here we see initially the formation of of
21 oxide as you would expect to see from the Pourbaix
diagram 22 with the ultimate formation of cupric oxide in an
23 intermediate region and cupric hydroxide ultimately.

cupric 24 The reason we don't see strong bands for the
25 oxide in this particular case is because it's very
weak

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1 Raman scatter.

2 We've gone on and extended diagnostic
techniques

3 such as these to the investigation of model alloys.
This

4 is a copper silver alloy. We looked at this alloy
because

5 all of the species which we expected to form from a
6 Pourbaix diagram had very strong Raman scattering
7 cross-sections.

8 To our surprise, however, all these species
9 occurred at potentials that were very much different
than

10 we expected from Pourbaix type calculations. So

there is

11 some need for in situ determination of stability of
these 12 compounds.

13 And we've even identified some products which
are 14 not identifiable. For instance, you will notice that
15 these bands have no weight on them, that's because
they 16 can't be identified based upon any known standard.

17 We've also been working hard to develop new
18 techniques, not only for the identification of
corrosion 19 products in situ, but also for the early detection of
20 stress corrosion cracking.

21 And as I show you this data, I purposely tried
to 22 show you data pretty much as we collected it because
I 23 wanted you to appreciate the fact that it is indeed
data 24 and it's not terribly polished.

25 But this is an instrument that we put together
in

289
1 our laboratory that's equipped with acoustic emission
2 detection. And in this particular apparatus we put
3 acoustic emission sensors on both sides of a tensile
4 specimen. As that tensile specimen begins to crack
it 5 generates acoustic emissions.

6 Next slide.

7 This shows acoustic emissions that we

collected

8 from that electrochemical cell. Here we see acoustic
9 emissions as a function of gauge length along the
tensile
10 specimen and acoustic emissions as a function of
time.

11 Time is along the Z axis, the number of
acoustic
12 emissions is along the Y axis, and here the number of
--
13 I'm sorry -- distance lies along the X axis. This is
the
14 center of the gauge length and the two extreme ends
of the
15 gauge length.

16 And this turned out to be a very tricky
17 measurement. We had to use four sensors
simultaneously to
18 image these stress corrosion crack initiation events,
if
19 you will.

20 We've had to use sensors on both ends of the
gauge
21 length, the actual detection sensors as well as two
guard
22 sensors to discriminate against spurious acoustic
signals.

23 As we discussed with you yesterday, we've gone
to
24 great lengths to implement a workable QA plan. We've
now
25 identified required activities by subactivity
numbers. In

290

1 this particular column we see a description of the

2 subactivities.

3 We have corrosion modeling which is now
referred to

4 as Subactivity E-20-16a, linear polarization
measurements

5 E-20-18a, so on and so forth. You can see that all
of our

6 planning documents, as we showed you yesterday in the
7 laboratory, have been approved.

8 Thus far, the only two activities that are
really

9 underway under the new QA plan are the radiation
effects

10 experiments that are being done in collaboration
between

11 our lab and Argonne National Laboratory, and the
linear

12 polarization measurements that are being done
principally

13 in our laboratory.

14 In summary, what I had planned to do for you
is to

15 begin by reminding you about the types of conditions
we

16 expect to see outside of one typical spent fuel
container.

17 I showed you a predicted temperature profile
to

18 give you hopefully a better feel for the type of

19 temperature history that some of these containers
will

20 see.

21 I also discussed with you the formation of
various

22 corrosion products on the surface by gamma
radiolysis, and

23 I had discussed with you the role of various ions on
the

24 localized attack of these container materials.

25 I then went on and reviewed for you models and
291

1 testing strategies that address uniform oxidation,
2 initiation of pits and the propagation of the pits
through

3 the container wall, as well as models and testing for
the

4 initiation and propagation of stress corrosion
cracks.

5 Overall I believe that we have found and
documented

6 models to predict the failure of container materials
in

7 the environments of interest.

8 The model that I discussed with you today
include

9 the halide nuclei theory, a point defect model, a
crack

10 tip opening displacement model and a film fracture
model.

11 We have been implementing a QA approved
12 experimental strategy to determine the various
parameters

13 of importance.

14 As I stated before, we're determining
corrosion

15 potential, pitting potential, incubation time, the

16 threshold stress intensity factor for stress
corrosion

17 cracking, the incubation time and the crack

propagation

18 rate. We're determining parameters such as these
19 experimentally.

20 And, finally, the work is being done in
accordance

21 with the quality assurance requirements of 10CFR60.
This

22 has required that we have spent significant time in
23 writing detailed activity plans, effectively
implementing
24 procedures and individual software plans.

25 And I believe that I've also illustrated for
you

292
1 how some of our past research, research done before
2 implementation of our QA plan, has led to some
insight
3 into the types of corrosion chemistry that's
important in
4 the life of these containers.

5 If there are any questions I'll be happy to
try and
6 address them.

7 DR. PRICE: I have a couple. What is your
comment

8 on the similarities that you expect to see between
the

9 J-13 well water and the actual near field water
having

10 gone through evaporation and condensation and so
forth,

11 whatever it goes through?

12 DR. FARMER: Well, I guess first I would have
to

electrolytes.

of 11 So as you concentrate these at some level some
12 the ions will be there at their saturation levels and
13 others will continue to increase.

different, 14 DR. PRICE: So it could be considerably
15 would you say?

16 DR. FARMER: Than J-13?

17 DR. PRICE: Yes.

correct. 18 DR. FARMER: I believe that, yes, that's

19 And we're trying to take that into account in our
20 experiments, if that's the question you're asking.

and the 21 DR. PRICE: Second question is a little more
22 philosophical. What do you see as the relationship
23 between your relatively short term corrosion tests
24 long term of hundreds of years, maybe thousands of
years?

this 25 DR. FARMER: Well, the goal of doing all of

294
1 work is to try to determine parameters in predicted
2 models.

part 3 For instance, I think it would be naive on my
4 to say, for instance, to take this polarization data
and
5 to assume without verification that that will last
for a
6 thousand years.

7 But I believe once we, you know, collect the

short

will 8 term data in the laboratory and fit these models we
and try 9 make every effort to go on for some period of time
10 to verify those models and make sure that those
11 impressions are correct.

12 Is that what you're asking?

difficult 13 DR. PRICE: Yes. But isn't it a very
14 problem?

there's no 15 DR. FARMER: Well, it is very difficult,
16 doubt about it.

in 17 In showing you these models I haven't tried to
18 convey to you that, you know, we have absolute faith
19 these models and that we've done unshakeable
predictions.

gone 20 What I've tried to do is show you that we have
that's 21 through all the corrosion modeling literature --
22 very controversial literature, by the way -- and we
tried 23 to extract the best that we can, models that we feel
will 24 help us have some predictive capability in terms of
25 predicting performance life.

295

models. 1 We now have to take the experimental data that
2 we're gathering and fit the parameters in those

3 And it's yet to be determined how well those models

will

4 predict reality. That's something that yet has to be
5 determined.

6 DR. PRICE: Well, for such a long term
validation

7 of the models it's going to be a challenge?

8 DR. FARMER: That's right.

9 Thank you very much.

10 MR. CLARKE: Okay. Before starting, let me
11 mention, I'm sure you've already noticed there were
a few

12 of the slides missing from Joe's presentation in your
13 handouts. That was strictly by accident and we will
14 assemble those. And I've already discussed with
Helen, we

15 will mail those out to you.

16 Okay. I am going to, in the next few moments,
17 discuss the alternates program that was at the
laboratory

18 a year ago, until about June of 1989, and discuss
just a

19 little bit the reasons that we felt at the time that
the

20 alternate materials program was needed.

21 The first bullet indicates that it does need a
22 regulatory requirement. I won't go through that, but
all

23 of that is 10CFR60.21 plus all the subparts.

24 And because this is an important regulation, I
took

25 the liberty to bring it along to read it so that I
could

regulatory 1 get the wording right. And that particular
shall 2 requirement indicates that a safety analysis report
to 3 also include a comparative evaluation of alternatives
alternatives 4 the major design features that are important to waste
5 isolation, with particular attention to the
and 6 that would provide longer radium nuclei containment
7 isolation.

that a 8 Now, it's reasonable to conclude from that
meet 9 fully developed alternative design is not required to
10 that evaluation.

year 11 However, we did strike off in a path about a
went 12 ago in that we have a reference design case that I
13 over this morning and also an alternate path design.

And 14 that's what I'm going to talk about is just the
alternate 15 path here for the next few moments.

16 Some of the reasons that we felt were very
17 important, it protects against a different set of
18 environmental circumstances. We do not have fully
19 characterized site data at this time.

out 20 Once we do obtain that information it may turn
21 that we have more water. We may have more aggressive

22 water chemistry and we also, for whatever reason, may
have

23 higher loads than is expected.

24 Also a concern is that somewhere down the
road, for

25 whatever reason, that the reference design or the
297

1 reference material will not meet the performance
2 assurance. And that could be that the containment
release

3 requirements may not simply be met by the metal
barrier.

4 Also we know from the nuclear power industry
5 business that having a redundant design often
provides
6 licensing conservatives and it makes licensing
easier.

7 Now, the container material selection process
is,

8 as you notice, very much the same as what we had
intended
9 for the metal barrier.

10 We started out with screening the concepts, we
will
11 develop criteria, we would do degradation mode
surveys

12 based on that criteria and the modes that were
identified,

13 there would be parametric testing done, and finally
14 selection, performance testing and development of the
15 models for performance assessment.

16 What I will be describing today is the
screening of

17 concepts portion of the program.

14 There was a trip to Sweden to review the
container

15 progress, their container progress.

16 There was a candidate manufacture survey
completed.

17 There was a closure study started at the
laboratory

18 and there was a model report written which has not
been

19 completed.

20 There also was a graphite workshop conducted.
And

21 then there were preparations to reassign this task to
the

22 management operations organization. And so we
prepared a

23 turnover package and that was transmitted to you back
in

24 June of '89.

25 Now, just to give a few words about the
concepts

299

1 that we were considering at the time, some we talked
about

2 a little more than others, some we actually did some
work

3 in. Ceramics was on top of the list. Graphites was
one

4 of our concepts. Bimetals, other single metals than
the

5 six that you've been hearing about this morning.

6 We also discussed briefly things like coatings
and

7 fillers. And then thicker wall metals, which I am
not

8 prepared to talk about today because there was no

work in

9 that area, but this would be very much like what is
being
10 done presently in Canada and Sweden, where I believe
that
11 their reference design is currently four-inch thick
12 copper.

13 In terms of the ceramics, the primary
candidates
14 that were discussed, as you heard yesterday, was
aluminum
15 and titanium. Both have superior corrosion
resistance to
16 the metals and they are geologically very stable at
Yucca
17 Mountain.

18 The data that you see there is real data
developed
19 by the Swedes and given to us during the trip. Less
than
20 one millimeter over the 10,000 year period for
aluminum.
21 This was done in 30 degree centigrade in oxygen
bearing
22 siliceous water.

23 And another value, less than 10 to the minus
12
24 millimeter for 10,000 years where titanium is a real
25 value. They did this using titanium 44 radioactive
300
1 traces.

2 One of the biggest concerns -- and again, you
had a
3 very good presentation of this yesterday during the
tour,

4 the delay fracture due to defects we feel can be
5 eliminated by minimization of the residual stress.
This
6 becomes fabrication concerns and closure concerns.
7 Our ceramics people at the laboratory feel
that the
8 fabrication technology, mass production of high
quality
9 alumina is well understood. Obviously work would
have to
10 be done in large shapes and lengths such as the
11 containers.
12 Closure was always considered to be one of the
13 major concerns but it is believed that containers
from
14 either alumina or titania can be closed
satisfactorily.
15 The ceramic study was conducted at Livermore
and it
16 was on November 2nd of 1988. The two topics were
alumina
17 and titania.
18 Based upon that workshop there was a request
for
19 proposal issued by the laboratory to fabricate half
scale
20 demonstration containers, and all of the
specifications
21 and all of the drawings to procure those half scale
22 containers was put into place.
23 The closure study was initiated and there were
24 requisitions placed for parts and supplies. There
also

25 was a preliminary nondestructive examination study
301
1 initiated, and there the concern was how we could
measure
2 and identify residual stress, voids and defects, and
those
3 types of things that we considered would give us a
problem
4 during closure.

5 There also, as you heard yesterday, was
preliminary
6 HIP hot isostatic pressing study for closure
initiated
7 concerns over localized heating which would lead to
8 nonuniform thermal stresses, but it was determined
that
9 with the use of compressive pressures up to about 30
psi
10 that the ceramic staff feels that closures could be
made
11 satisfactory in these container ceramics alumina.

12 The closure study looked at high quality
closure
13 temperatures of less than 650 degrees C, and those
are
14 considered to be feasible.

15 One of the problems, as you heard yesterday,
that
16 the Swedes got into was trying to make closure at too
high
17 temperatures which had an impact on the fuel or would
have
18 an impact on the fuel and also on the residual stress
that
19 was produced on the half shells of the ceramic

containers.

20 These lower temperatures are necessary and we feel
that

21 there are ways that these can be done.

22 Also already mentioned, the 35 psi pressure.
There

23 also was work done on metal to ceramic closure using
24 single phase bonding which was considered to be
important.

25 This was for the metal overpacks over -- up to I
think

302

1 about three-inch thick ceramic shells.

2 And, of course, the matching of thermal
expansion

3 was necessary. The work that was done at the
laboratory

4 last year did develop two closure techniques.

5 In the candidate ceramic manufacture survey
there

6 were six U.S. aluminum fabricators contacted. The
listing

7 is shown here. Favorable responses were received
from

8 those six. They agreed to fabricate half-size
alumina or

9 graphite containers.

10 And one of the requirements of that survey,
which

11 was initiated with a telephone call and followed up
by

12 letter, is that we would obtain commitment from these
13 fabricators for long term participation, and we did
obtain

14 that from them.

15 The graphites workshop was also conducted at
16 Livermore November the 17th, 1988. In this case
there
17 were 25 participants, 16 from outside of Livermore.
And
18 there were a whole number of issues considered. All
of
19 those that were discussed yesterday.

20 Some of the more important ones that is not
21 characteristic of metals especially for the surface
22 handling would be things like fire safety,
resistance.

23 Things that we didn't know about would be
24 irradiation effects, that work would have to be done.

25 Also the workshop discussed at length remote
1 handling and closure processes and things like
2 permeability to gases and liquid water.

3 However, the important part of that workshop
were
4 the conclusions that graphite should be considered
and a
5 study should be initiated.

6 In terms of the bimetals there were two types
that
7 were considered. One was to have a metal insert
inside of
8 another metal overpack. And another was double wall
9 containers that would be fabricated by fusion bonding
10 using standard techniques.

11 The concept here is that the outer shell of
the

9 called more high performance alloys.

the
heard
some
quite
10 There were materials that were not included in
11 basic list of six, because earlier criteria, as you
12 Bill Halsey mention this morning, had a criteria of
13 25 percent for cost, and some of these materials are
14 costly.

change
aspect
15 However, the other material, there's
16 interpretations of containment requirements may
17 over time. We wanted to have flexibility in some
18 of the program to be able to look at other newer
19 materials.

corrosion,
may
20 There were other things like knowledge of
21 degradation mode scenarios that were changing or new
22 information that came along. Microbiological
23 the MIC shown there, is becoming a very important
24 corrosion phenomenon in the country today and that
25 change some of the present selection.

with
1 And, also, there may eventually be problems
2 closure in some of the materials, and I've already
3 mentioned that we wanted to keep the door open for
4 technological advancements of materials.

at
5 There's a number of them that have been looked

6 in some degree when the program was first started
that
7 included monel and titanium. Other materials,
hastelloys
8 such as C22, I know is one of the materials that the
NRC
9 is interested in and is a material that we could
consider
10 studying.

11 Coatings. Very little beyond just the talking
12 stage was done on this process, and these would be
fairly
13 thick protective corrosion resistant layers either
applied
14 on the inside and outside or on the outside wall of
the
15 container.

16 Some that was discussed was oxides or nitrides
in
17 the ceramic family, and metallics such as aluminum
and
18 nickel chrome aluminum in the metal area. Of course,
19 they'd have to demonstrate close porosity, substrate
20 adherence and possess crack and corrosion resistance.

And
21 that was about the extent of the thinking at that
time.

22 Also with fillers, not much was done with
those.
23 Continuous or discontinuous solids that would fill
the
24 void spaces within a container, and also there was
25 long-term protection against corrosion that had to be

was 1 studied, radionuclide release in the continuous form

2 an issue.

the 3 Some of the candidates included the magnitude,

4 glass, aluminum, copper, lead and zinc were all
5 considered. And obviously those must demonstrate
6 compatibility, wetability and void detectability.

the 7 Well, that was the extent of the program at

8 time. Just to summarize, the container materials
9 alternate concepts was established. We did provide a
10 package for reassignment to the program to M&O.

documents 11 And I might mention that those planning

are 12 are in place. They are upgraded to Level 1 and they

13 available to conduct the program under the current QA
14 plan.

you 15 DR. PRICE: I have a quick question. Who --

attended 16 might have said and I might have missed -- who

17 the ceramics workshop?

the 18 MR. CLARKE: There were five individuals, I
19 believe. There were four from the university or from

20 laboratory and a professor from the University of
21 California.

22 Clarence, I don't remember his name. Do you?

23 MR. HONIG: Professor Joe Pass.

24 MR. CLARKE: Thank you.

25 Do you have any further questions?

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1 MR. HALE: I would just like to take this
2 opportunity to thank the Board for having the
opportunity
3 for the past couple of days to present these
materials to
4 you.

5 We certainly appreciate your comments and the
6 questions that you've asked. And we will start work
7 immediately toward preparing responses to your
questions.

8 We had allocated time for questions for the
board,

9 and obviously we overestimated the amount of
questions and

10 some of the talks this afternoon. We're not
complaining.

11 But if you have any additional questions, I'm
sure

12 you'll provide them to us.

13 Yes, sir.

14 DR. CARTER: Jack, I'd like to bring up one
area

15 for some discussion. I think this is probably
generic

16 rather than addressed to one individual.

17 But I mentioned yesterday during the
discussion or

18 the talk by Bill Glassley the business of spent fuel
as

19 well as halo waste and possible combinations of this.
Of

20 course, concern about the age of the material and
21 obviously the heat load.

22 But I wanted to ask the question in a generic
23 sense, are there other types of fuel or halo wastes
that
24 you're going to be concerned with and are there plans
that
25 are being made, or are you actually dealing with
this?

308
1 I'm thinking, for example, about special
cases,
2 maybe the halo waste at West Valley, maybe the fuel
from
3 special reactors, the SNAP reactors or this sort of
thing.

4 I wonder if someone would address that
inquiry,
5 because we've heard really primarily about spent
fuel.

6 MR. HALE: Let me take that initially here and
then
7 I'd like to turn it over to Mike Clonniger to give
you
8 some details.

9 I know it does appear that we seem to be
addressing
10 a lot of our attention for the last couple of days on
11 spent fuel.

12 I would like to stress, however, that we do
very
13 definitely have work underway in which we would be
14 addressing the high level waste both from Savannah
River
15 at this time and also from West Valley. And

eventually

16 we'll be considering the fuels from Hanford.

17 We have a substantial effort and in
characterizing

18 the properties of all these high level wastes and
there's

19 active programs right now. Lawrence Livermore is

20 participating in that, and we also have substantial

21 activity going on at PNL, Pacific Northwest Labs, and
then

22 also the Savannah River Laboratories is doing some
work

23 and maybe some others.

24 So we do have this characterization activity

25 underway and certainly we will be designing a waste

1 package to accommodate not just the spent fuel but
these

2 high level wastes also.

3 DR. CARTER: Well, what about the special
sorts of

4 things? Now from what I know, which may be limited,
I

5 would just guess that there's some maybe 10 percent
or so

6 of the waste that may not fit into the standard
categories

7 of either spent fuel, taken as a general category, or
high

8 level waste processed material. Some that either
they

9 have a special cladding on. What about greater than
Class

10 C, for example?

11 There are a number of things I would envision
that
12 are quite different than these two general
categories.

13 MR. HALE: Let me turn it over to Mike to give
you
14 some more of the details on that. We are developing
15 generic waste acceptance criteria. And also with
regard
16 to Class C, I know that is under active consideration
at
17 this time, but a determination has not been made at
this
18 time that we will be putting the Class C into the
19 repository.

20 If we do, of course, that is going to increase
the
21 job that we've been discussing for the past couple of
days
22 by a very substantial amount.

23 But let Mike say something more about the --

24 DR. CARTER: Well, this was the reason for the
25 question, because, you know, if you just limit the
1 discussion to what happens in the near field, some of
2 these things I would think would behave quite
differently.

3 MR. CLONNIGER: Oh, yeah. The -- can you hear
me?

4 The greater Class C wastes are very cold
wastes
5 from a thermal standpoint. About all we know about
them
6 right now is that they will not go into a shallow
land

7 area.

8 That department has other options other than
9 repository to dispose of them where they aren't
restricted
10 to disposing of them in a deep geological repository,
and
11 certainly not necessarily in this first one.

12 As far as --

13 A VOICE FROM AUDIENCE: We can't hear back
here.

14 MR. CLONNIGER: As far as other fuels go, they
make
15 up a very minor portion of the inventory, I would
guess
16 way less than one percent.

17 There's some very exotic fuels out there, some
of
18 them ignite on exposure to air. Their chemistry is
19 entirely different. Some are metal. Some are
ceramic.
20 Some are impregnated graphites.

21 I would guess that many will have to be
22 reprocessed, particularly those that will ignite on
23 exposure to air, will have to be reprocessed in some
form.

24 They'll be treated as special cases, different set of
25 waste acceptance criteria developed for them. We are
not

1 addressing that at this time.

2 MR. HALE: Any more comments?

3 If you would like, we could go over the
actions

and
you
that
list.
have
impacts
plans

4 that have been identified as we have interpreted them
5 see if there's any misunderstanding there. Maybe if
6 have a little bit extra time you'd like to do that.

7 DR. VERINK: If you have the time, I think
8 would be very good, to give us a running list.

9 MR. HALE: Yes. Mike is going to use his

10 MR. CONNIGER: Okay. My understanding, we
11 three action items; is that it?

12 From Dr. North. Regarding the effects or
13 of man-made materials, you would like to know our
14 for carrying out the man-made materials studies and
15 recommend that the plan should address bounding type
16 calculations.

17 We'd like the first cut at bounding answers in
18 about six months after the start of the test, before
19 rather than after turning out the research.

draft
20 From Dr. Verink. You requested a copy of the
21 of Dr. Van Konynenburg's paper on Carbon 14. Okay.

selection
22 And Dr. Price would like a draft of the
23 criteria. And that's all I have.

24 Did someone else record other actions?

got
25 DR. CARTER: Yeah. Well, someone, whether it

1 recorded or not, it may have been in a little bit
2 different category, but I was interested in the
report or
3 the reports by the Material Review Board.

4 MR. CLONNIGER: The ad hoc corrosion panel?

5 DR. CARTER: Yeah.

6 MR. CLONNIGER: Okay. I think those were --

7 DR. CARTER: Well, I don't know if that's the
same
8 or not. What you say may be a part of the --

9 MR. CLONNIGER: Yes.

10 DR. CARTER: -- Board activity.

11 MR. CONNIGER: I was the secretary during
those
12 second series of meetings and the proper name was the
Ad
13 Hoc Corrosion Panel --

14 DR. CARTER: Well, Ralph mentioned getting
that
15 material for us, so I would like to make that part of
the
16 record.

17 MR. CONNIGER: Easily done.

18 MR. HALE: Mike, if you don't have any further
19 comments, I just wonder if Les Jardine would like to
add
20 any final conclusions for us.

21 DR. JARDINE: I'd just like to thank the panel
on
22 behalf of the laboratory and the technical staff who
23 helped provide the information to you.

24 And we certainly will take both the comments
that
25 we recorded and questions -- more like questions, I
guess,
1 and also those that we learned during the tour
yesterday.

313

2 And we had interesting and direct exchanges among the
3 technical staff and yourselves.

4 And you certainly have given me, and I'm sure
the
5 technical staff, some things that we need to be
thinking
6 about, how we can be aiming towards closure on some
of
7 these somewhat and sometimes open issues. And so
we'll
8 take that as a goal in order to learn from this
9 experience. And we welcome future interactions with
you
10 and other members of the Board.

11 DR. VERINK: I would certainly like to express
on
12 behalf of the panel the appreciation of all of us for
the
13 considerable effort that you've gone to to make this
a
14 meaningful meeting and to respond to our concerns.

15 Thank you very much.

16 DR. PRICE: Thank you.

17 (Whereupon, the meeting concluded at
18 2:30 p.m.)

19 ---o0o---

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21
22
23
24
25

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) ss.
2 COUNTY OF CONTRA COSTA)

3
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