

1 ML020930285 UNITED STATES OF AMERICA

2 NUCLEAR REGULATORY COMMISSION

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4 SOURCE TERM APPLICABILITY PANEL

5 + + + + +

6 TUESDAY

7 DECEMBER 11, 2001

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9 ROCKVILLE, MARYLAND

10 The Panel met at the Nuclear Regulatory
11 Commission, Two White Flint North, T2B1, 11545
12 Rockville Pike, at 8:30 a.m., Brent Boyack
13 facilitating.

14 PANEL MEMBERS PRESENT:

15 DANA POWERS, ACRS

16 JAMES GIESEKE, Consultant

17 THOMAS KRESS, ACRS

18 BERNARD CLEMENT, CEA

19 JEAN-MICHEL EVRARD, CEA

20 BRENT BOYACK, Facilitator

21 DAVID LEAVER, EPRI

22 ALSO PRESENT:

23 JASON SCHAPEROW

24 RALPH MEYER

25 CHARLES TINKLER

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ALSO PRESENT: (CONT.)

STEVE La VIE

HAROLD SCOTT

* indicates unintelligible word(s) due to
accent.

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high burnup and response to scenario 148

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burnup PWR fuel with ZIRLO cladding 158

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(8:34 a.m.)

1
2 MR. BOYACK: Okay. I'd like to welcome
3 you all to the second meeting of the Source Term
4 Applicability Panel. I've provided you all, I
5 believe, with copies of the agenda, and wanted to just
6 go ahead and make a few comments as we begin.

7 Our primary objective for this meeting is
8 to prepare the Extended Applicability Source Term
9 Tables for at least one case. You may recall that
10 when we met the first time, we were really very much,
11 I think, in an overview and orientation mode as we
12 tried to orient ourselves to the information that was
13 available, discuss the nature of the assignment that
14 had been given to us. And in the process of doing
15 that, there were a number of different cases and
16 options that were discussed.

17 I communicated with the NRC
18 Representatives between this meeting and the first
19 meeting, and drew a chart that shows a number of those
20 options, and they had increased to maybe 10 or 12 if
21 we took every branch on the chart. And so I
22 suggested, and the NRC certainly concurs that the
23 important thing is to get through the process once.
24 And so what we want to do is set for our self the
25 objective, the minimum objective of getting through

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1 the PWR High Burnup Fuel case, with Zirlo cladding,
2 undergoing the low pressure scenario.

3 Now if you take a look at the meeting
4 agenda, there are a few supporting objectives, and
5 during the course of the day today and tomorrow, and
6 on Thursday as we meet, we'll go ahead and go through
7 each of those objectives, and I think reach them.

8 There is one, however, that on your agenda
9 is the last to last bullet at the middle of the page,
10 and that says, "Evaluate and document the
11 applicability of the NUREG-1465 Source Term for High
12 Burnup UO2 in a BWR. So if at all possible, and if
13 the time permits, then what we would like to do is
14 after we've done the PWR case for High Burnup Fuel,
15 then what we'd like to do is we'd like to go through
16 the BWR case. And hopefully, having laid the base by
17 completing the BWR case, we would be in much better
18 shape to go through that rapidly. We've allocated
19 half a day on Thursday to work on that objective.

20 We have three new participants with us
21 this time. We have David Leaver, who is the EPRI
22 Designee from Polstar Applied Technology,
23 Incorporated. And Dave, I wonder if you could just
24 give us a few comments about your background. We did
25 this on the first name. We went --

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1 MR. LEAVER: Right. Yeah, I saw that in
2 the transcripts.

3 I'm not sure, for sure, why I'm here but
4 I did work on the Advanced Lightwater Reactor, and
5 that was really the place in which the whole idea of
6 a more physically correct, realistic Source Term was
7 introduced. That was in the late 80s, and that caught
8 on for the Advanced Lightwater Reactors, in order to
9 provide a better design basis for those plants. And
10 then the operating plants got interested, and then the
11 NRC issued 1465, and we were involved in a lot of that
12 work.

13 And then since that time, my company has
14 been involved in applying the Alternate Source Term to
15 operating plants. We've probably done eight or ten
16 different kinds of applications, so I do know a little
17 bit about what matters in terms of which parameters in
18 the Alternate Source Term really have an impact on the
19 plant, and sort of what the priority would be of
20 different aspects of the Alternate Source Term.

21 MR. BOYACK: Okay. Thank you very much.

22 We have two colleagues with us from
23 France, Bernard Clement, and Jean-Michel Evrard, and
24 I wonder if you would just take a moment and give us
25 a few words of introduction to yourselves.

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1 MR. EVRARD: Okay. I work in, like I said
2 the Department of Prevention and Study of Accidents.
3 And I'm in charge of a team which work from the * to
4 Holistic Safety Assessment, and also the * of source
5 term.

6 MR. BOYACK: Thank you.

7 MR. CLEMENT: Okay. So I'm Bernard
8 Clement from IPSN, from another department, the
9 Reactor Safety Department. I'm working on severe
10 accidents since a long time because I'm involved in
11 the Fuel Safety Program since the beginning, I would
12 say. So, you know, in our Department we make modeling
13 *, we make also experiments, * experiments such as *
14 experiments, try to cover a larger range in order to
15 give these people * studies.

16 MR. BOYACK: Thank you. Now since we have
17 three new Panel Members, I think the people here --
18 that were here the first meeting ought to also
19 briefly introduce themselves. And I wonder, Dana, if
20 you would begin. Just give us a little introduction
21 to yourself.

22 MR. POWERS: I'm Dana Powers. I am
23 seminal in the source term research that NRC did, that
24 eventually led to NUREG-1465. I guess I founded the
25 Source Term Models for Melt Concrete Interaction, and

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1 the Victoria Model for in-vessel release for fuel and
2 transport, Source Term Models for a few other things
3 here and there. I have a long term interest how
4 fission products behave in fuel under similar accident
5 conditions.

6 MR. BOYACK: Okay. Jim.

7 MR. GIESEKE: Jim Gieseke. I'm now
8 retired, but I've worked at the top for lots of years
9 on Source Term issues, and particularly the
10 development or put together the first Comprehensive
11 Model, I believe, of the Source Term Code Package
12 which was a compilation of codes, which was then
13 involved over a number of years, and I did that for --
14 used the code and analyzed Source Terms for quite a
15 few years.

16 MR. KRESS: Tom Kress, lately from the
17 Oakridge National Laboratory. While I was there, I
18 was in charge of the Fission Product Release Programs
19 that were conducted by Morris Osborne and Dick Lance,
20 and people like that. I was also in charge of our
21 Source Term Programs, and I was heavily involved in
22 developing the Source Terms for NUREG-1465.

23 MR. BOYACK: Thank you.

24 MR. SCHAPEROW: Okay. I'm not on the
25 Panel. I'm Jason Schaperow from the NRC. I am the

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1 Project Manager, and in charge of coordinating and
2 laying out the objectives and helping Brent with his
3 mission to facilitate this Panel.

4 MR. BOYACK: That was very good because
5 you gave my introduction too. I'm Brent Boyack from
6 Los Alamos National Laboratory, and as stated, my
7 objective is to facilitate the Panel.

8 Now during the last meeting, we did have
9 some comments that came from the audience, and so I
10 think it would help our recorder if she heard the
11 names of each of the individuals. You've got them
12 all? Okay. Very good.

13 All right. With that then, what I think
14 I'd like to do then is just go ahead and quickly
15 review the agenda with you. What we're going to do
16 first is have a presentation from Jason Schaperow.
17 And he's going to go ahead and talk about the Desired
18 Panel Products, and NRC End Uses of the Panel
19 Products. I'd like to give you just a little bit of
20 background for that.

21 I read the transcript -- tried to
22 carefully read the transcript from the first meeting,
23 and during that first meeting we were examining and
24 talking about many different options and things that
25 we ought to do. And there were comments and issues

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1 that were raised that would tend to broaden the scope
2 of the Panel. And so, given the need to come to an
3 end point with reaching several of the objectives
4 regarding Extended Applicability of the Source Term,
5 we decided that we needed to have a presentation that
6 would sort of clearly identify what the NRC, the
7 primary customer, wanted and needed out of this, so
8 that's the first presentation.

9 Now after that, and after the break, then
10 what we'll have is we've asked our French colleagues
11 to go ahead and present to us the results of their
12 research in France. And then following that, a
13 description of the PWR Fuel and cladding at High
14 Burnup, and a response to the scenario.

15 Now the thought here was that it would be
16 very good if we had a common perspective on the
17 specific characteristics of High Burnup Fuel that we
18 were considering as we went ahead and went through the
19 Source Term Applicability effort, and then we could
20 have lunch.

21 Now what I needed to ask, I know that
22 there have been some preparations that have been made
23 by Dana Powers and by Tom Kress, based upon our first
24 meeting. Tom says he has a handout, and Dana refuses
25 to really tell me what he had, but did you have

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1 information you either wanted to present by way of
2 handouts, or otherwise?

3 MR. POWERS: Well, I think I could
4 probably chat a little bit about what I know about the
5 restructuring of the fuel.

6 MR. BOYACK Okay.

7 MR. POWERS Changes in the microstructure,
8 how you go about calculating -- how you have to keep
9 this booth model in change to reflect that, and how
10 this could possibly impact the release fractions that
11 end up in your tables with the Source Term.

12 MR. BOYACK All right. Now, Dave, did you
13 -- did I see that you had material there, or are you
14 just -- did you have any material you wanted to
15 present?

16 MR. LEAVER: You know what, I just -- I
17 had copies of the transcripts of the first meeting.

18 MR. BOYACK: Okay.

19 MR. LEAVER: And just some other reference
20 material.

21 MR. BOYACK: Okay.

22 MR. MEYER: Could I say that Dana, from
23 what I heard from Dana, that his comments would
24 probably fit nicely after mine, because I have some of
25 those microstructures to show.

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1 MR. BOYACK: All right. Well, I thought
2 what we would do is handle it the following way.
3 There's a little bit of flexibility. In fact, there's
4 a lot of flexibility in the schedule. You'll notice
5 if you go to the back of the agenda, that once we --
6 once we come to the afternoon of today, we have
7 literally a day and a half with just a statement that
8 we're going to continue our discussion on PWR Source
9 Term Applicability, so what we'll do is as we finish
10 the Pre-Planned Presentations, then we'll have the
11 presentation of any additional information. And I
12 like Ralph's suggestion that Dana could go ahead and
13 continue his shortly after Ralph's. Now that may be
14 after the lunch break, depending on where we are in
15 time. And so, we'll hear from Dana, from Tom, and at
16 that point, I believe we'll enter into our discussions
17 of the Source Term Applicability for the PWR Low
18 Pressure scenario.

19 Let me just briefly describe how we
20 planned to handle that, so that if there is any
21 comments or questions, then you can go ahead and let
22 me know before -- by noon or after.

23 What I've done is tried to consider how we
24 could go ahead and produce information that would
25 facilitate the preparation of the document, so I

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1 brought a projector that I can hook up to the
2 computer. And what I plan to do is basically on line,
3 project on the screen here your comments, summary
4 comments as we go through the various Source Terms
5 phase by phase. And the hope here is that in effect,
6 we will sort of, in writing, with your concurrence,
7 have the key points associated with the Applicability
8 statements that are made. And then we'll go ahead and
9 process those, and at the end of the day we'll all
10 transmit the files to Jason. He'll have them printed,
11 and they'll be available tomorrow. At the end of
12 tomorrow, they'll be available Thursday morning.

13 And the thought here is that in this
14 process, we could essentially write the tables and the
15 justification on line, and then we won't be trying to
16 extract that information solely from the transcript.
17 I have found out that by going back to the transcript,
18 that's a good source, but it's always a slightly
19 imperfect source. Better to see it in writing, and
20 we'll do that. So those are the initial comments that
21 I have. Are there any questions or comments, either
22 Members of the Panel or the Audience have?

23 All right. Well, with that, let me just
24 indicate that I have two pieces of information I'm
25 going to pass around for the Panel Members, and those

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1 in the audience to sign up. The first is just the
2 attendance list, and if you go ahead and put your
3 name, institution, telephone number and email address
4 on that. And then the second is primarily the Source
5 Term Applicability Panel has the contact information.
6 I've updated that to reflect any information that I
7 received from you, and so if you go ahead and take a
8 look, and make sure that that's still all correct.

9 Okay. Well, with that, let's go ahead and
10 proceed with the agenda as printed, which is to have
11 the first presentation by Jason Schaperow.

12 MR. SCHAPEROW: Okay. I'm going to lead
13 off the meeting here with a presentation on Overview
14 of what we're hoping to get out of this as far as this
15 Expert Panel effort, and also to mention a few of our
16 thoughts and perspectives on where we think there may
17 or may not be issues, or at least what we're aware of
18 at this point.

19 I'd like to skip to the third slide. The
20 second one just gives an outline of the talk. The
21 objective of this work, as we are hoping, is to have
22 a Fission Product Source Terms, a recommendation from
23 the Panel on Fission Product Source terms for reactors
24 using High Burnup Fuels for this meeting, and the next
25 meeting we hope to go through MOX Fuels.

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1 The approach, as far as we understand
2 that's going here, is to reconstitute the Panel, the
3 original Panel that developed the basis for the
4 revised Source Term as much as we could. In that
5 regard, we've asked that Dr. Kress, Dr. Gieseke and
6 Dr. Powers to come and be Members of this Panel.

7 This approach involves considering recent
8 data and insights from international experts, and we
9 are very pleased that Dr. Clement and Dr. Evrard have
10 been able to come and tell us about what they're
11 working on, and to give us their insights.

12 We expect the Panel will be very heavy in
13 discussing the physical phenomena affecting the Source
14 Terms. And finally, we are looking for
15 recommendations on how the Revised Source Term should
16 be modified, if needed, for High Burnup and MOX Fuels.

17 Now I'd like to go over the Regulatory
18 Applications for the Revised Source Term, and this is
19 an area that I have been very heavily involved in over
20 the last several years.

21 The main application, as I see it there in
22 my Source Term, is that what we've done is we've taken
23 the gap in early in-vessel release phases, and we've
24 used that for our LOCA Design Basis Analysis. The
25 Regulation used to be called PAR 100 for this. I

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1 think the new regulation is 50.67, but actually, there
2 is -- and under this category, the main application,
3 as I understand it, has been individual dose, the
4 exclusionary boundary, typically at the fence line of
5 the facility, the low population zone distance, and --
6 which is further out, and doses to an individual in
7 the control room.

8 The second item listed here, "Containment,
9 Isolation and Valve Closure Time", that's been keyed
10 on the one point which is the start of the gap
11 release. We've had some detailed thermal-hydraulic
12 calculations for a large grade LOCA, and we've got a
13 gap release start time of about 30 seconds.

14 And similarly, for a BWR, we've got a gap
15 release start time of two minutes, so it takes two
16 minutes from when the pipe shears off until you start
17 having fuel rod failures.

18 Now we've also used the Revised Source
19 Term to look at the integrated dose for equipment
20 qualification in the containment. We've examined the
21 post accident shielding, sampling and access using the
22 Revised Source Term. And finally, we've also used it
23 to look at hydrogen generated by radiolytic
24 decomposition of water, and that particular issue is
25 covered in Regulatory Guide 1.7.

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1 Also, we believe that the -- all four
2 phases of the Source Term could be used for Severe
3 Accident Risk Assessment. And we actually applied
4 this in one case for a recent -- for a study of spent
5 fuel pool accidents, where we needed a Source Term,
6 and we didn't have detailed Severe Accident Code
7 calculations, so we needed a generic source, and what
8 can we use? And we used this. We felt this was the
9 best Source Term to apply. We did modify it somewhat,
10 to account for special conditions of a spent fuel pool
11 accident, but we started with it.

12 We believe there are a lot of benefits of
13 using the Revised Source Term in licensing, and
14 industry does too. We've had a number of plants come
15 in, voluntarily come to the NRC and say we'd like to
16 apply the Revised Source Term. And this costly for
17 them, because they have to go through the licensing
18 process. They have to pay not only for their re-
19 analysis for the Revised Source Term, but they have to
20 pay for us too, to say that you can use the Revised
21 Source Term. And I talked with our licensing group in
22 Nuclear Reaction Regulation, and what I've gotten here
23 is a list of the license amendments that we've issued
24 so far.

25 I've got six plants listed here, and these

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1 have all done these LOCA analyses with the Revised
2 Source Term. Also, there are three applications under
3 review with the Revised Source Term.

4 Now I'd like to talk a little more about
5 the approach for this Expert Panel effort on Source
6 Terms. Again, we are asking the Expert Panel to
7 recommend how the Revised Source Term should be
8 modified, if necessary, for High Burnup and MOX fuels.
9 We're doing this in a series of three meetings. The
10 first meeting which we held in September was the
11 project kickoff, and the current meeting, we would
12 like to ask the Expert Panel to tackle the Source Term
13 for High Burnup Fuel. And in the final meeting, we'd
14 like to tackle the Source Term for MOX fuel.

15 MR. POWERS: Jason, you began your
16 presentation by making it clear that timing is an
17 important part of the Source Term. Do we have
18 information on how the timing of fuel rod behavior
19 changes as it moves up the Higher Burnup, things like
20 rod bursting, ballooning?

21 MR. SCHAPEROW: I am not aware of any, but
22 I probably wouldn't be. Ralph Meyer would be more
23 knowledgeable in that regard.

24 MR. MEYER: We can talk about that a
25 little. We have -- we'll talk about this later.

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1 MR. SCHAPEROW: Go ahead, Ralph.

2 MR. POWERS: It seems like you have a lot
3 of people that work with the Source Terms, and
4 relatively few people, with the exception of Ralph
5 that thought about clad. And when you think about
6 timing aspects of the first two portions of the Source
7 Term, you're really talking about clad event.

8 MR. SCHAPEROW: The first two? The first
9 one, I would say, is the initial failure. What's the
10 second?

11 MR. POWERS: Well, clad has enormous
12 affect on the way fuel degrades, which is what
13 controls the second part of it.

14 MR. SCHAPEROW: All right. Yeah. If it's
15 okay, we could talk when Ralph gets up at around 11.
16 Is that okay? We'll discuss the quality aspects.

17 MR. MEYER: I don't want to give you too
18 much hope because the experimental work that will
19 answer Dana's questions is just underway, and we don't
20 have answers. We can talk about it a little, and I
21 would say that I'm very skeptical that there'll be any
22 changes in the timing of rupture or other events
23 during that phase of the accident that would make a
24 difference. But at this point, that's mere
25 speculation, and there are a couple of areas where

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1 this and the manner of the gap activity. If you're
2 going to generalize the term "Source Term", the word
3 "Source Term", and use it not only to cover the severe
4 accident release, but also to cover gap activity,
5 which I know Steve La Vie uses for things like control
6 room habitability. Then there is work underway on
7 that as well, which is not yet at a point where good
8 answers can be given, so there's a little problem with
9 timing of trying to push. In these two areas, I would
10 say we're off by about a year, but not more than that,
11 so we can talk about this more during my presentation.

12 MR. SCHAPEROW: Yeah. We feel very
13 strongly that we'd like the panel to talk about the
14 need for experiments, the need for research on the
15 experimental area. And I flagged it in here later on
16 as I write confirmatory research, or what have you.
17 But the idea is to -- what kind of experiments do we
18 -- or Code Calculations might be beneficial to support
19 the recommendations of the Panel.

20 Based on what I heard at the first meeting
21 and what we've been kind of pushing here is we're
22 hoping that the Panel will judge the applicability of
23 each aspect of the Revised Source Term, and to look at
24 each phase of the Source Term, as well as the area of
25 chemistry, the physical chemical form of the Source

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1 Term.

2 If Panel Members, or the Panel believes
3 that an aspect of the Revised Source Term is not
4 applicable, we're asking the Panel to state why they
5 think that's the case, and suggest an alternative for
6 what we could use. Again, we're also asking the Panel
7 to identify necessary or desirable confirmatory
8 research.

9 MR. BOYACK: Let me just interrupt for a
10 minute. Ralph, in your presentation are you going to
11 outline the research that's underway? That may not
12 have been something we asked you to do during the
13 first pass at suggesting you come here and talk to us.

14 MR. MEYER: Well, I don't have it on a
15 slide, but we can certainly do it verbally.

16 MR. BOYACK: If you will, yes.

17 MR. SCHAPEROW: Just to summarize what we
18 talked about in September, we went over the overall
19 Program objectives, and discussed potential
20 approaches. We had a presentation by Akihidi Hidaka
21 of JAERI on their Vega experiments, and what they've
22 done in the area in High Burnup and MOX. And we began
23 talking about some of the High Burnup issues. And I
24 thought that I heard at the meeting that the general
25 feeling of the Panel was that the Revised Source Term

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1 was okay in the area of physical and chemical form.
2 Probably didn't see any big changes there.

3 For this meeting, this is a little bit of
4 a rehash of what Brent said this morning. We've asked
5 Ralph Meyer to talk about High Burnup Fuel
6 characteristics. He's been involved in that for quite
7 a while now. We're pleased to have a presentation
8 today by IPSN on their core's work, and then we hope
9 to go through in great length each aspect of the
10 Revised Source Term.

11 And finally, on Thursday afternoon, we've
12 asked for a briefing on the MOX Fuel characteristics
13 to prepare for our final meeting, and we've got a
14 gentleman from Framatome who's gong to be talking
15 about that by the name of Patrick Blanpain. And
16 finally, we've asked you to bring your schedules to
17 select the next -- the final meeting dates.

18 As Brent mentioned, we'd like to try to
19 keep the project as short as possible, the objectives
20 as small as possible so that we can make this doable.
21 And we're requesting the initial evaluation be limited
22 to a maximum Burnup of 75 gigawatt days per ton for
23 the maximum fuel rod or maximum assembly burnup.
24 Stick with one cladding. I just put Zirlo down here,
25 for lack of anything -- if we should do M5 instead,

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1 that's fine. I really wasn't -- don't have any
2 feelings either way. Start with PWR, and from what I
3 heard at the first meeting, I think all we need to
4 really focus on is the lower pressure scenario.

5 The last day of the meeting, we hope to go
6 through the BWR, the process for BRW. And finally, if
7 time permits, we would like to talk about the other t
8 type of cladding that was mentioned, the implied
9 cladding.

10 MR. POWERS: The original Source Term that
11 was published by 1465 specified the fission product
12 release, but acknowledged the fact that these non-
13 radioactive materials might have a substantial impact
14 on the transport through the piping system, and
15 certainly would have an impact on the behavior and
16 containment, and invited the user to invent a Source
17 Term for the non-radioactive materials, and one time
18 suggested some amount of non-radioactive materials,
19 but that was deleted in the final version of 1465.

20 In the course of applying the Source Term
21 to advanced reactors, I think we've some diversity of
22 views on the magnitude of the non-radioactive
23 materials accompanying fission products being
24 released.

25 Is it your aspiration to continue to not

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1 address this non-radioactive Source Term?

2 MR. SCHAPEROW: Okay. I think there still
3 are some ball park magnitudes in NUREG-1465, for the
4 non-radioactive releases and the containment. I think
5 the format of the document was changed, and they got
6 kind of buried in the text. Dave's got it there.

7 MR. LEAVER: I think you're right, but I
8 just can't find it.

9 MR. SCHAPEROW: But you're absolutely
10 right thought, that it certainly has a very strong
11 affect on deposition in the reactor coolant system,
12 and it also has strong affect on deposition in the
13 containment.

14 MR. POWERS: Well, if you stick to the
15 lower pressure scenario, it does not have much affect
16 on the deposition in the primary piping system.

17 MR. KRESS: It does.

18 MR. POWERS: It's always going to affect
19 containment.

20 MR. CLEMENT: It might have an affect on
21 chemical forms * deposition *.

22 MR. KRESS: Yes, it might, but I don't
23 think it's likely to have much of an affect.

24 MR. SCHAPEROW: Yeah. I think --

25 MR. KRESS: Because those things don't --

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1 MR. SCHAPEROW: Yeah, I think that with
2 regard to deposition in the containment, I -- the
3 attention of the Panel was not to talk about that.
4 But in as much as it affects deposition in the RCS, I
5 think we do need to talk about that.

6 MR. KRESS: It might have an affect on
7 this chemical form, so --

8 MR. SCHAPEROW: In the chemical form.

9 MR. KRESS: And if we're dealing with
10 similar part coming in, it could, especially in the
11 late revolatilization --

12 MR. SCHAPEROW: All right. We can
13 certainly talk about all of that. That's fine. I
14 guess I'd like to suggest when we get to that, that
15 part of our talk or our discussion, that today and
16 tomorrow we can talk about that.

17 MR. LEAVER: I have a question on this
18 focusing on the lower pressure sequence. There are a
19 lot of other sequences besides the lower pressure
20 sequences that are interesting. And in fact, if you
21 look at it from a probabilistic standpoint, you would
22 be -- probably be more interested in smaller breaks,
23 rather than extremely large breaks, which you'd need
24 to get a lower pressure sequence.

25 I guess my understanding has been that

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1 while there certainly was consideration on low
2 pressure sequences in 1465, and perhaps maybe even
3 stronger words were used like reference. I'm not
4 sure, but I really think the way that this has evolved
5 in terms of applying this to operating plants, is
6 we've tried to look at -- we really tried to applied
7 the Source Term in a way that it would be appropriate
8 for a variety of different kinds of sequences.

9 We wanted to be sure that we didn't do the
10 analysis in such a way that there could be some
11 sequence that would give worse releases, or worse
12 doses. Just talking now, you know, within reason.
13 Clearly, there are extremes here that one could go to,
14 but would probably be not appropriate from a
15 probabilistic standpoint. So while I think you need
16 to think about low pressure sequences, I don't
17 understand why we're -- maybe we're not, but I don't
18 think we should be completely focused on that. I
19 think we should be thinking about a variety of break
20 sizes and elevated pressure in the primary system,
21 simply if for no other reason than from a risk
22 perspective, because that's what risk assessment tells
23 you is really significant. And there are some
24 differences.

25 MR. KRESS: I guess I have a different

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1 view on that, and we need to keep within our mind a
2 differentiation between design basis Source Terms and
3 Real Source Terms.

4 MR. LEAVER: Uh-huh.

5 MR. KRESS: Now to make the design basis
6 more realistic, doesn't mean you can factor in all of
7 the types of sequences behavior. It means you do a
8 little more with timing, and a little more with the
9 quantities, but you still have to retain the -- what
10 I would call a kind of defense and depth concept, and
11 that you need a design basis source to be robust, and
12 to be more on the conservative side with respect to
13 the quantities released because it is a design basis,
14 and you want to be able to design your systems to deal
15 with what would be the most -- a more robust Source
16 Term, so you don't want to deal with these maybe
17 higher probability or higher frequency ones, but have
18 less Source Terms --

19 MR. LEAVER: Right.

20 MR. KRESS: -- and the timing is
21 different.

22 MR. LEAVER: Right.

23 MR. KRESS: So I would say the focus
24 should be on low pressure types of severe accidents
25 that give you generally the worst Source Term and the

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1 fastest timing, which are the two things you want to
2 be robust in your design basis.

3 MR. LEAVER: I don't disagree with what
4 you said, but if you take that too far, what will
5 happen is -- for example, take a large LOCA type
6 event, the timing for release for a large LOCA event
7 is very fast, and what would happen, if you use that
8 type of a sequence to dictate your timing, you could
9 drive the design towards, for example, a spray system
10 that's a rather short duration spray system. And
11 there are plants that have such spray systems, and
12 when you demand -- when you have a timing of say one
13 and a half or two hours, those spray systems don't
14 work very well because they may last for 45 minutes,
15 so timing is an example, or duration of release is an
16 example where you wouldn't want to stick with the
17 characteristics of LOCA --

18 MR. KRESS: I may --

19 MR. LEAVER: Understanding that we kind of
20 keep that perspective.

21 MR. KRESS: I maintain that's probably
22 more important for the GAP release, by the timing, fix
23 things like valve isolation closure time. With
24 respect to the spray --

25 MR. LEAVER: Right.

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1 MR. KRESS: -- the duration of the
2 release, the timing when it starts and the duration is
3 really driven a whole lot by the rates at which the
4 core heats up, and the rates at which it -- the core
5 gets uncovered. And that timing doesn't change
6 tremendously with pressure, the type of accidents you
7 have, I don't think, so I would still say you get an
8 acceptable timing with a low pressure release for
9 those type of things. And that doesn't throw too much
10 of a dislocation in how you would design your spray,
11 I don't think. So I personally -- so I would still
12 stick with my focus on the low pressure type of
13 accidents, design basis Source Term.

14 MR. SCHAPEROW: The NRC made a regulatory
15 decision to use low pressure for deposition. We take
16 the release magnitudes --

17 MR. LEAVER: In the RCS you mean?

18 MR. SCHAPEROW: That's right. That RCS.
19 You said that right in that 1465, in the beginning of
20 the section that talks about the magnitudes. And it
21 says, "We are hereby using a low pressure sequence to
22 tilt towards conservatism." But you're right. I have
23 seen some calculation, if you have a large break LOCA
24 with a double-ended pipe break you could melt the core
25 down fast.

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1 MR. LEAVER: You could release --

2 MR. SCHAPEROW: You could cause things to
3 happen in about a half an hour or so. If you have two
4 inch break, that helps -- the two inch break is still
5 a low pressure sequence, and that will -- that draws
6 things out to a couple of hours, which is --

7 MR. LEAVER: You need these -- I can just
8 tell you this. The calculations show that if you have
9 a -- there are spray systems out there that are
10 designed to basically exhaust themselves in less than
11 an hour and has a significant impact on dose versus
12 the spray system that can operate for two, or three,
13 or four, or six hours, or twenty-four hours, so it's
14 just something that -- to keep in mind, that the
15 smaller breaks can push the release out in time, and
16 demand that mitigation systems be able to function for
17 that period of time.

18 MR. KRESS: Yeah. My feeling is to deal
19 with that and risk based space and justify an
20 exemption from using the Design Basis Source Term by
21 using risk arguments after the fact, which would be my
22 approach there.

23 MR. BOYACK: During our --

24 MR. KRESS: There are ways to deal with
25 that problem in the regulatory system is all I'm

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1 saying.

2 MR. BOYACK: During our first meeting, we
3 covered and addressed some of these same topics.
4 Since my contribution to the Panel is not technical,
5 but rather procedural, as I read through the
6 transcript, and as I reflected on the first meeting,
7 the one thing that was clear to me is if we tended to
8 broaden the scope, then we couldn't meet -- work
9 within the parameters that have been set, which was
10 the meeting we're currently in, and one more meeting
11 to cover also a MOX Fuel covered in the last meeting,
12 that we had to go ahead and proceed down some
13 definitive line.

14 Now, Dave, you raised other questions
15 about somehow do we broaden the context or the
16 consideration, and the comments I heard at the last
17 meeting and pursued with the NRC was that this may not
18 necessarily be the last step. It may be the last step
19 for the Panel, but then there might be some follow-on
20 activities that either the utilities or the NRC might
21 engage in. But here, the thought was we had to focus.
22 We had to get through the process once, and so we
23 selected the scenario that is most consistent with the
24 one that was covered in NUREG-1465.

25 MR. SCHAPEROW: Why don't we all touch

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1 upon this a little bit more when we get to that
2 particular aspect that you think is timing sensitive,
3 that we need to talk about, Dave. I'd like to go on
4 and talk a little bit about --

5 MR. POWERS: Before you go on though --

6 MR. SCHAPEROW: Okay.

7 MR. POWERS: -- I want to pursue this a
8 little more with Dave, because I think he raises an
9 important point here, especially -- for a lot of
10 reasons.

11 Can you tell me, since you're familiar
12 with these things, how depressurization procedures
13 enter into the Design Basis accident considerations,
14 especially for small breaks?

15 MR. LEAVER: You mean in operating plants?

16 MR. POWERS: Yes.

17 MR. LEAVER: Well, there are some plants,
18 I think that have no way to depressurize, at least for
19 certain sequences, and then there are others that do,
20 so -- and I think that probably accident management
21 procedures would tell the operator to depressurize,
22 but -- and, you know, I'm certainly -- I was involved
23 a lot in the development of -- not in the development
24 of 1465, but we had a lot of meetings and talked a lot
25 about it. And I understand that the low pressure

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1 sequence is -- was one that was emphasized.

2 All I'm saying is when we get into
3 defending what we do all in the Source Term, we just
4 need to be careful that we don't do an analysis which
5 maybe works fine for a particular type of sequence,
6 and then in some other kind of sequence it really
7 doesn't hold up, then it's hard to defend. And we get
8 these questions at the NRC when we do these analyses
9 and come in and present them, and I think they're good
10 questions. So I'm just saying, let's just be aware
11 that for a risk standpoint, certainly for BWRs, large
12 breaks are in the graphs.

13 MR. POWERS: Well, what I'm trying to find
14 out is that if we have a depressurization and the
15 emergency operating procedures don't return all
16 sequences into low pressure sequences?

17 MR. LEAVER: If you can successfully
18 depressurize, then they would, but there are lots of
19 sequences where you can't do that. And there are some
20 plants that don't have the capability to do that.

21 MR. POWERS: So there's a significant
22 vulnerability to just looking at low pressure
23 sequences.

24 MR. LEAVER: I think -- I wouldn't call
25 it, necessarily, a significant vulnerability. And I

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1 don't -- I didn't mean to take this much time. I'm
2 just saying that when this -- this Alternate Source
3 Term is a -- I think representative is the best word
4 I've seen, and you need to be careful when you apply
5 it, that you're just aware that there are other
6 important kinds of sequences, other than those are low
7 pressure, or maybe start out as a low break and go to
8 low pressure. A high pressure station blackout is an
9 example.

10 Now Alternate Source Term does make the
11 very important assumption that the containment systems
12 function as designed, and containment remains in tact,
13 so -- but even with that assumption, there are still
14 different ways for core melts to progress. And we
15 just need to be aware of that, and not lock ourselves
16 into decisions that work well for low pressure
17 sequences, and don't work for other kinds of
18 sequences.

19 MR. BOYACK: Is it fair to say that
20 utilities have somehow been aware of this for some
21 time. They've had NUREG-1465. They've been aware of
22 its shortcomings, or areas where it may not be
23 applicable, and have dealt with that -- been aware and
24 deal with it?

25 MR. LEAVER: I think they are aware, quite

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1 aware, and I think part of that is because when they
2 come to defend what they've done, the NRC has asked
3 these questions, so I think there's a role for certain
4 integrated view of these things, a risk assessment
5 approach, if you will. It doesn't have to be the main
6 thing, the QA calculation can be a low pressure
7 sequence, but one just has to be aware that not all
8 sequences are low pressure sequences, and it can make
9 a difference.

10 MR. KRESS: What does being aware mean in
11 your mind, Dave, that we do something about what we
12 say the Source Term is, the timing?

13 MR. LEAVER: Well, I'm not sure -- Tom,
14 I'm not sure I follow what you said on -- in response
15 to my comment earlier, but I think as we go through
16 this today, if we are making a decision in my mind
17 that may apply well for a low pressure sequence, but
18 not so well for a sequence where the retrocoolant
19 system is a 600 PSI, then I would ask questions about
20 it. That's what I would do.

21 MR. KRESS: Sure.

22 MR. GIESEKE: It seems to me it comes out
23 of a matter of philosophy or intent here a little bit.
24 Obviously, there's a wide range of potential accidents
25 and sequences, and those will have a wide range of

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1 outcomes in terms of the Source Terms.

2 The question is, and nobody doubts that.
3 The question is what are we trying to look at here,
4 and what are we trying to use as a -- I don't know,
5 representative sort of representative Source Term , or
6 a Source Term for comparative purposes. I think we
7 have to realize there are bounds on beyond, you know,
8 uncertainty ranges in all this, but I think we're
9 looking at what's representative, and we call it a
10 Design Basis accident as opposed to the full
11 probabilistic course with -- and I don't know how you
12 ever represent that in a -- fully, without doing this
13 for about 25 years. And I don't think they want the
14 Panel to go on that long.

15 MR. LEAVER: No.

16 MR. SCHAPEROW: One of the things I could
17 bring this afternoon, I could bring a page showing the
18 sequences that were used to come up with the timing.
19 It's one of the pages in 1465. If I don't have enough
20 copies of 1465, I'll just copy that page, and we can
21 look and say here's the sequences that we used. So
22 anyway, I'd like to continue, if that's all right.

23 This is -- I'm going to -- I have four
24 slides here, one for each of the phases of the -- one
25 of the phases that we've identified in a severe

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1 accident. And to just really briefly summarize our
2 understanding of -- the NRC's understanding of the
3 release. And maybe if I heard of somewhere an
4 applicability issue, I've tried to identify it here.
5 I'm sure there's a lot of applicability issues out
6 there that I don't know about, so anyway.

7 On the first slide, I've got the Gap
8 release, and the start time of the Gap release is
9 identified in NUREG-1465. It's the earliest fuel rod
10 failure following a large break LOCA. And as I said,
11 we've done some calculations with our big codes, EPRI
12 and MELCOR to look at this type of thing. Actually,
13 EPRI, not MELCOR.

14 The end time of the Gap release is defined
15 in NUREG-1465 as the point in time where the fuel
16 temperature gets high enough so that the pellet
17 release gets going.

18 And finally, the magnitude of the Gap
19 Release in NUREG-1465 is identified as the -- that
20 which is diffused to the gap duration operation.
21 Also, the magnitude could be affected by deposition in
22 the reactor coolant system. That was not considered
23 in NUREG-1465.

24 On the applicability of the Gap release,
25 in NUREG-1465, the Gap release is small compared to

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1 the early end-vessel release. My guess, and again I'm
2 not on the Expert Panel, but my guess is it will still
3 be small when we get done here compared to the in-
4 vessel release.

5 And also, I've talked a little bit to our
6 fields people. I've talked to Harold Scott in
7 particular about some of the work that they're doing
8 right now, and there is data becoming available based
9 on some experiments. I believe it's the Holden
10 experiments. We're actually going to have numbers for
11 high burnup fuels, what's been put into the gap as a
12 result of operation, so what I -- my pitch here is I
13 don't think we need to focus on this too much in the
14 panel meeting, especially if we have trouble coming up
15 with a number. We're going to have some data. I
16 think we're going to be able --

17 MR. LEAVER: At this meeting we'll have
18 some, or next meeting?

19 MR. SCHAPEROW: It will probably be some
20 time next year. I heard the experiments are currently
21 ongoing, so I heard like in spring or summer we'll
22 have some data. Let me leave this to Ralph. I guess
23 he can mention it a little bit later this morning.

24 On the early -- this is supposed to say
25 early end-vessel release. On the early end-vessel

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1 release the start time of this was the end time of the
2 gap release which is when the fuel temperature gets
3 hot enough to start having significant releases from
4 the fuel pellet.

5 MR. KRESS: And the significant would be
6 what?

7 MR. SCHAPEROW: The significant --

8 MR. BOYACK: That's twice for that word
9 today.

10 MR. SCHAPEROW: Well, when you look at
11 those curves and you see it getting above a couple of
12 percent, it's a subjective -- it's judgment. It was
13 a judgment when the work -- when the number was come
14 up with. And the end time is fairly straight forward,
15 a lower head failure. That was the end of time of the
16 early end-vessel release.

17 The magnitude being determined by the
18 release rate during the fuel heat up and degradation.
19 The timing of the lower head failure, and we discussed
20 these at the last meeting. And also, the affect of
21 deposition which we were kind of surprised to see
22 that the deposition was pretty high even for low
23 pressure scenarios. I think we -- I'm trying to
24 remember the number. Was it 50 percent, or was it --
25 it was a fairly high number.

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1 MR. LEAVER: Yeah, it was, I think. Of
2 course, that depends on the location of the break and
3 a lot of things.

4 MR. SCHAPEROW: But the applicability
5 issue that I thought I heard at the last meeting was
6 -- the big one was the release rate. There seemed to
7 be a feeling that the release rate may be higher
8 during this phase, and you may even release all of the
9 volatile fission products such as iodine and cesium
10 during the -- in this phase.

11 MR. MEYER: Could I make one comment?

12 MR. SCHAPEROW: Sure.

13 MR. MEYER: That first line that you had
14 on both slides, fuel temperature reaches point of
15 significant release from fuel -- from pellet. That
16 really doesn't happen in the previous one when you're
17 talking about the gap activity. During the Design
18 Basis portion of the loss of coolant accident, fuel
19 temperatures are always going to be below 1200 degrees
20 Centigrade, so there's -- it's a time when the pellet
21 itself is cooling down before the in-vessel severe
22 damage starts to take place, so I don't think -- I
23 don't think it's a significant part of the previous
24 slide when it starts like this.

25 MR. SCHAPEROW: The ex-vessel release

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1 begins when the lower head fails, and the -- some of
2 the curium is relocated to the area below the vessel.
3 The end time we've said is when the debris has cooled
4 sufficiently so that the significant quantities of
5 fission products are no longer being released.

6 I believe an end time was chosen when
7 about 90 percent of -- I forget the exact number but
8 it was supposed to be a definitive point when most of
9 the -- certain fission products were released.

10 MR. KRESS: Now does 1465 include ex-
11 vessel release?

12 MR. SCHAPEROW: Yeah, it does.

13 MR. LEAVER: It does but --

14 MR. KRESS: It has a separate table for
15 the --

16 MR. SCHAPEROW: Yeah. It's part of the
17 same table, but a separate column, I think.

18 MR. KRESS: A separate column.

19 MR. SCHAPEROW: Yeah. The only
20 application that I -- we've looked at that for
21 equipment qualification, what would happen if we had
22 an ex-vessel release. We've also applied it, as
23 you're aware, for the spent fuel pool risk say last
24 year. Those are the two uses that I'm familiar with
25 that we've done, but other than that -- I'm not -- I

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1 don't think we've done anything with those ex-vessel
2 releases.

3 The magnitude, again it's determined by
4 the release rates during the core-concrete
5 interactions, and there are some statements later in
6 NUREG-1465 that if one were to be able to get flooding
7 of the containment, that you could significantly
8 reduce the ex-vessel release.

9 Actually, Dr. Powers did some work on that
10 several years ago. He did some -- actually, he had
11 some pretty big decontamination factors for overlying
12 water pools. And applicability issues, I wrote here
13 that I'm not aware of any, but that's me. I'm sure
14 there are some, and I'm sure they will be discussed
15 during the meeting. I probably should have left that
16 blank. It was a little bit presumptuous of me to
17 write not aware.

18 MR. POWERS: Well, even if you excuse
19 inventory affect, you know, it's hard to come up with
20 anything. I mean, after you melt the fuel it's kind
21 of forgotten what happened to it in the reactor. The
22 inventory affects, you know, okay. But your Source
23 Term is given as percentages
24 so --

25 MR. SCHAPEROW: Yeah. In terms of burnup.

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1 MR. POWERS: Yeah. In burnup you change
2 the inventory, but if you discount that and recognize
3 that Source Term is a percentage, it's pretty hard to
4 come up with anything there now, and you can go on.
5 There's an approximation built into this view that the
6 ex-vessel release is predominantly core-concrete
7 interactions. That's saying that there's no Source
8 Term due to steam explosions. And that's remarkable
9 because there is a very large Source Term associated
10 in WARSH 1400 that is steam explosions. In fact, that
11 was the big one. And it says that these high pressure
12 sequences, that there's no direct -- high pressure low
13 ejection source flow, so are any of those affected by
14 burnup?

15 Well, once again, it's pretty hard to
16 figure out how burnup affects chemical behavior of
17 fuel that is melt. Now what melting is, is the
18 greater equalizer in this world by plotting the
19 affects of burnup, so I don't have any troubles with
20 you discounting the inventory issue.

21 MR. SCHAPEROW: Finally, late in-vessel
22 release, that also starts when the lower head fails.
23 That's how we define it, and we have an end time of 10
24 hours after lower head failure. And it appears to me
25 that this end time is certainly -- is kind of

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1 arbitrary. I think we did some work, Sandia did some
2 work a couple of years ago for PHEBUS to show that you
3 could keep getting late in-vessel releases for a
4 while. It was not like a specific end point. As long
5 as you had some kind of flow through the system, you
6 could keep getting releases by revaporization or
7 revolatilization.

8 Finally, can the magnitude here as
9 determined by revaporization, and I'm not aware of any
10 applicability issues, but we'll get to that, I guess,
11 when we get to that again.

12 MR. POWERS: I would take strong issue
13 with attributing the late release as being determined
14 by revaporization.

15 MR. LEAVER: Right.

16 MR. POWERS: I would think that
17 revaporization is but a component of it, and that
18 strongly plants a specific component to it. That in
19 fact, the magnitude of late release could be affected
20 by the degradation of residual fuel within the reactor
21 core, because we know that cores don't melt down
22 uniformly. And given the right configurations and the
23 right kinds of designs, that's it's affected by air
24 ingress. Now, I commented the air ingress was
25 deliberately not included in the NUREG-1465 Source

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1 Term.

2 MR. CLEMENT: I would add, also the
3 duration can be affected because this is -- 10 hours
4 is a very low process. You may imagine several
5 affects for which your * will be emitted in a much
6 faster way, so air ingression, that's one. Another
7 one is trying to reflooding your * and you have high
8 steam flow and things like that, so it could be much
9 faster than 10 hours in certain cases, not all the
10 cases.

11 MR. SCHAPEROW: And this is also -- we
12 believe this is also a very important part of the
13 Panel's effort is to talk about determinatory research
14 and to identify what will be necessary, and also what
15 will be desirable.

16 There are -- I've listed here a couple of
17 programs that are underway that I think are in the
18 necessary category. They go -- they're, of course --
19 those are necessary for our work, and there may be
20 others that maybe we'd like to do that aren't being
21 done right now, and there may be others that I'm not
22 aware of.

23 MR. POWERS: You write down PHEBUS with no
24 extender on the end of it.

25 MR. SCHAPEROW: Oh, I'm sorry. I think

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1 there's supposed to be some high burnup tests coming
2 along and MOX test.

3 MR. POWERS Well, in PHEBUS-FP I don't
4 think there are any high burnup tests. Now there is
5 -- there have been discussions of fall lines to feed
6 this FP. I'm hardly the one to talk about it. Maybe
7 Bernard could talk to us about those, but -- and
8 there's also something called PHEBUS LOCA which seems
9 applicable.

10 MR. CLEMENT: Yes. In fact, the first
11 part is possible following programs on severe
12 accidents, with the three main scopes of testing MOX
13 fuel, so with the fuel degradation, and also Source
14 Term from the fuel. High burnup fuel. Not making
15 experiments as complicated as present ones. That
16 means that there will be no experimentation on the
17 containment * but fuel degradation. And the third
18 part would be look at what happens when you try to
19 reflood the degraded core. I mean, the - what were
20 the experiments in core that show that you may have
21 high hydrogen flow rates in such configurations. You
22 may also have very fast Zirco-oxidation that, in fact,
23 would enhance the fuel degradation *. And also, this
24 problem of the resuspension, revaporization of what
25 deposited previously in the RCS, because you may

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1 change the flow rate, the temperature, the oxygen
2 potential and so on, so this is one -- these are *
3 like to investigate. And the previous LOCA Program is
4 really to address the LOCA questions * bundle
5 configuration, but staying at the design basis with
6 the 1200 Celsius maximum cladding temperature and so
7 on. We are thinking about it now.

8 MR. SCHAPEROW: I'd just like to mention
9 the -- in the area of facilitation, we're very happy
10 to have Brent Boyack as our facilitator. He's got
11 enormous amount of expertise in this area, as well as
12 in reactor accidents.

13 MR. POWERS: I have to comment that
14 there's an immediate discrepancy. I mean, we've got
15 to clarify this right away. How do you spell this
16 man's name?

17 MR. BOYACK: As on the slide.

18 MR. POWERS: I would never give you a C.

19 MR. BOYACK: The question is which way
20 would you go.

21 MR. POWERS: I remain mum.

22 MR. SCHAPEROW: We've asked Brent to
23 basically lead the Panel effort, to lead the
24 discussion, be up here with summarizing the Panel's
25 judgments and recording everything, and it's -- he's

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1 going to have an extra hand, I think, for this job,
2 and he'll have to use both sides of his brain
3 independently. At the end --

4 MR. BOYACK: Dana is willing to give me
5 the extra hand, but I also want to make sure that we
6 qualify how that's delivered.

7 MR. KRESS: Backhanded.

8 MR. SCHAPEROW: And finally, I have two
9 bullets here at the end of this slide to suggest that
10 something that might help us move forward with it, so
11 we're all basically on the -- literally on the same
12 page. At the end of each day, Brent is going to pass
13 out a typed summary of what we came up with, so around
14 5:00 today, Brent is going to hand out, hey, this is
15 what the Panel's judgments are. And then if -- we're
16 asking your indulgence to maybe take a look at it
17 sometime before tomorrow morning. And if you have any
18 more comments tomorrow morning, we can talk about it
19 at that point.

20 MR. BOYACK: Well, let me just correct
21 that. Actually, I don't have a mechanism for getting
22 it out of the computer here at the NRC thing for
23 printing. What happens is that at the end of each
24 day, I go ahead and wrap that up, and I'll email it to
25 you as PDF file, so it will be available to you first

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1 thing next morning.

2 MR. SCHAPEROW: Well, if you send it to me
3 like at 4:45, I'll run upstairs and print it out and
4 bring it down for the Panel. I mean, that's just
5 taking a few minutes.

6 MR. BOYACK: If I can get it done, I'll be
7 glad to do that. I certainly will be able to give you
8 what I have.

9 MR. SCHAPEROW: Okay.

10 MR. BOYACK: The question is I have to
11 email it.

12 MR. SCHAPEROW: All right. Okay.

13 MR. BOYACK: I just --

14 MR. SCHAPEROW: Well, how about a
15 diskette, how about a three and a half inch diskette?

16 MR. BOYACK: The computers don't have
17 those. A zip drive is all that I've got.

18 MR. SCHAPEROW: I'm sorry.

19 MR. BOYACK: What we'll do is fine,
20 towards the end of the day I can go ahead, and I just
21 need access to a telephone line.

22 MR. SCHAPEROW: Yeah. That's not a
23 problem. There are lines here.

24 MR. BOYACK: All right.

25 MR. SCHAPEROW: But yeah, I really would

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1 like to pass it out before -- not out to try to burden
2 the Panel at all, but it's only probably a page or
3 two. I don't -- it's not going to be a long thing.
4 You can take a quick look at it tonight or tomorrow
5 morning, and we can talk about it at the start of the
6 meeting, just to make sure that we're all together.
7 If somebody's views were not properly represented,
8 we'd like to know that as soon as possible.

9 And finally, Brent alluded to what he's
10 calling a product. We'd like to have a Panel report
11 on recommending a six chapter report. This could be
12 changed a little bit. This is just kind of an idea
13 who the players are, what people are going to do.
14 We've asked Mosen Khatib-Rahbar to pull together an
15 introduction chapter. We've asked Hossein Nourbakhish
16 to summarize what's -- in a couple of pages what's in
17 1465, to kind of lead us into hey, here's what the
18 Panel thinks. And then finally, we've asked Mosen to
19 also take a look at what we've done in the first three
20 chapters, and summarize conclusions. And similarly,
21 chapters five and six will be just like three and
22 four. We'll again have the Panel recommendations and
23 thoughts, and finally a conclusions chapter on MOX
24 fuel.

25 With regard to schedule, after everything

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1 is pulled together after this meeting, we're going to
2 try to get something to the Panel sometime in January
3 so that you folks can take a look at it, again prior
4 to the last meeting, so if you have any concerns, or
5 again, things weren't captured properly, or there are
6 some additional disagreements, we could talk about
7 those at the last meeting.

8 Finally, I'd like to present a very simple
9 calculation I did yesterday, and this does not address
10 a lot of the issues that Dave Leaver has raised. It's
11 got a lot of applications that Revised Source Term,
12 but this is what I like to call my -- I'll pass this
13 out. It's too hard to read. This is what I call my
14 generic dose calculation with a Revised Source Term.

15 I guess it's a little bit hard to read on
16 the overhead, but I've given you a handout. This is
17 -- I've taken a reactor, a typical 3000 megawatt
18 thermal reactor. This is supposed to be a LOCA does
19 at the exclusionary of boundary. I've taken a 3000
20 megawatt reactor, used the Source Term for 1465, which
21 is the -- I'm calling it the in-vessel release. It's
22 the combination of the Gap and early in-vessel.
23 Containment leak rate, again another typical number of
24 .1 percent per day. The next thing is the dispersion
25 factor that we used, just -- I pulled a number that

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1 may be typical. It may be a little low actually, 10
2 to the minus four seconds per meters cubed. A
3 breathing rate for somebody digging a ditch. And
4 finally, we use an exposure period of two hours, the
5 person is standing there for two hours.

6 I did the dose calculation with our Design
7 Basis Code and came up with about 6 rem for a person
8 standing there for two hours, because the accident is
9 going along. The containment is in tact, but it's
10 leaking at this very, very small rate, at a Design
11 Basis rate.

12 I did this just to see, as Dave Leaver,
13 had said, well, what's important? As we're going
14 through our discussions today, what might be
15 important? What things might deserve maybe a little
16 more attention than others.

17 What hits me in the eye is iodine. I had
18 most of the doses from iodine, and then followed by
19 cesium and strontium.

20 MR. KRESS: You need to be a little
21 careful with those, for thinking in terms of failed
22 containments. This would look different, and it might
23 look differently if you were thinking in terms of land
24 contamination. The cesium would probably occupy most
25 of that term.

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1 MR. SCHAPEROW: I agree with you
2 completely.

3 MR. KRESS: And strontium. So you think
4 -- you need to keep in mind there's more than one
5 regulatory objective of the Source Term.

6 MR. SCHAPEROW: That's true. This is
7 intended to be like, again, our Design Basis LOCA Dose
8 Calculation.

9 MR. KRESS: Right.

10 MR. SCHAPEROW: This is a person standing
11 there breathing heavily at the site boundary. But Dr.
12 Kress is right, long term stuff, you know, this has
13 got short half life for one thing. Iodine is gone
14 after like a month or so, so you're left with cesium,
15 a 30 year half life, and maybe -- possibly rhodium if
16 you have air ingress, and that's important.

17 MR. POWERS: I'm interested, Tom. What
18 are those Regulatory Objectives in the Source Term?
19 You said there's more than one.

20 MR. LEAVER: Well, one of them is to be
21 sure you have a robust containment, that doesn't fail
22 under Design Basis conditions, but may fail under
23 other conditions. And it's those other conditions
24 that worry me.

25 Actually, from the standpoint of uses on

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1 the Source Term, I don't think I attach much to this
2 kind of curve, because you're really dealing with how
3 to design your systems, and so it's not -- you know,
4 I worry about those other things in Risk Base, so I
5 may have misspoke a little bit.

6 MR. LEAVER: Well, one Regulatory use of
7 the Source Term is to give you a basis from which to
8 design mitigation systems.

9 MR. KRESS: Yeah, and that --

10 MR. LEAVER: And the most important thing
11 is to keep the containment in tact. If you do that,
12 then you've solved most of the problems that we all,
13 you know, think about. But there are other things
14 too, that you can do. And in some cases, I think in
15 our operating plants we've done the things that we
16 didn't need to do, but maybe we're getting a little
17 smarter now. But certainly, the fact that a huge
18 amount of the dose as iodine, I think if you're
19 talking about a 30 day dose, like controlling dose,
20 that might even be more, because not much aerosol gets
21 out. I mean, now you're talking about organic and
22 maybe a little I2 that tends to control the dose, so
23 it is a basis for designing mitigation systems.

24 MR. KRESS: Yeah, I agree. You're right.

25 MR. SCHAPEROW: Okay. That's all I had for

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1 the Panel. I guess I was going to ask -- I think the
2 next item is we would like to ask the French to talk
3 about their work on their experiments.

4 MR. BOYACK: First thing we do is take a
5 break.

6 MR. SCHAPEROW: Oh, I'm sorry.

7 MR. BOYACK: Always take breaks. Fifteen
8 minutes, if you could come back at 10. Restrooms are
9 on the second floor here if you need those. And under
10 the current conditions, we have to be escorted if we
11 go off the floor, so if you need to go down to get
12 coffee or something like that, we'll have to have an
13 NRC person walk down with you.

14 (Whereupon, the proceedings went off the
15 record at 9:48 a.m. and went back on the record at
16 10:06 a.m.)

17 MR. BOYACK: Charlie Tinkler.

18 MR. TINKLER: Yeah. The point I want to
19 make, when Jason was showing the pie chart with the
20 importance of different radionuclide groups, you know,
21 the message I got -- I get out of that is that for the
22 Regulatory analysis, the important radionuclide groups
23 are the volatiles, iodine and cesium. And I thought
24 about your question, Tom, about well, what if you
25 weren't worried about the worst two hour dose to an

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1 individual at the ARB or the LPZ. What if you had
2 other concerns that you wanted to be addressed? And
3 I think most of our most spent fuel pool work
4 indicated that issues like land contamination were
5 still often driven largely by the cesium dose - okay -
6 which is in the group of volatiles, so not likely to
7 change. And I only say that when the Panel gets to
8 deliberating some of the low volatile radionuclide
9 groups, where the uncertainty is larger, and NUREG-
10 1465 struggled with mean and 75th percentile, because
11 the numbers were -- they have -- there's a potential
12 for a much wider spread on the numbers there, that the
13 panel when it considers it's deliberations, reflects
14 on things like that where for most of our
15 applications, and remember we're concerned about the
16 early in-vessel and gap release, it's pretty much
17 driven by the volatile groups. And to us, at least,
18 in our simple way of thinking about it, that makes the
19 problem attractable for us in terms of applicability.

20 MR. BOYACK: All right. Thank you.

21 We're now going to continue on with our
22 French colleagues, who will be discussing with us the
23 French data. I've been told that it's sort of a three
24 part presentation. Also, I wanted to acknowledge that
25 we had indicated to them we didn't really know how

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1 long they would need. We're not in any rush, so take
2 a little bit longer to go ahead and go through the
3 data which is, I think, certainly the right thing to
4 do. And the one thing I did want to check, do you
5 have handouts to give to the --

6 MR. CLEMENT: Not for --

7 MR. BOYACK: So after the thing, then we
8 can go ahead and do that. So we'll go ahead and turn
9 it over to our French colleagues, and who will speak
10 first?

11 MR. CLEMENT: I will speak first.

12 MR. BOYACK: Dr. Clement.

13 MR. CLEMENT: So I will start, in fact,
14 with a kind of introduction that will be the first
15 part of our presentations, that will be another view
16 of the --

17 MR. SCHAPEROW: Dr. Clement, the mike --
18 if you could --

19 MR. CLEMENT: Okay. I have to speak here.

20 MR. SCHAPEROW: If you want to be on the
21 other side, I can move this over. All right?

22 MR. CLEMENT: I have to speak here.

23 That's --

24 MR. SCHAPEROW: Oh, okay. I can move it
25 over there if you like, whatever is -- whatever works

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1 for you.

2 MR. CLEMENT: Okay. So this will be * a
3 kind of introduction for other presentations, so speak
4 shortly about experimental programs, maybe about home-
5 made experimental programs because we use all that are
6 available, about * summary and studies on reactors.
7 So this is just a selection of some experimental
8 programs that we are -- that we have used or are using
9 for assessing the Source Term, so for fission product
10 release, we have the old program HEVA, then VERCORS.
11 I will speak about in more detail about VERCORS
12 afterwards, concerning fission product vapor or
13 deposition and condensation. A program was performed
14 a few years ago * developed. Here, I've forgotten to
15 mention the program devoted to the release of *
16 material. One was enacted that was performed in
17 Grenoble for the release of silveranium cadmium, and
18 now we are performing experiments on boron carbide
19 release.

20 Given concerning aerosol behavior of a
21 number of different programs that all terminated * was
22 for the RCS. It was for the containment * was for the
23 * used for containment venting, so this part * now
24 terminated.

25 We've also terminated a program recently

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1 for the affects of spraying. That is named CARAIDAS,
2 with two parts. First of all, how aerosol is trapped
3 by the droplets and go the bottom floor, and how
4 iodine is either trapped by say water when going down
5 with the droplets, or how it could be released if the
6 water is already dirty, and is an important *. This
7 is just terminated.

8 Concerning iodine, in the past we have
9 made a number of bench scale experiments in order to
10 measure release of iodine by * interaction with *,
11 prediction of organic iodides. There are a new series
12 of experiments that will be launched that will be
13 EPICUR, that will address the same questions, but
14 trying to put more emphasis on the kinetics of
15 prediction, and having really a good measurements of
16 kinetics of all these reactions.

17 CAIMAN is a * experiment. That was
18 dealing with iodine chemistry in containment, and CHIP
19 is a new program that we are now launching, trying to
20 get the chemistry of iodine in the RCS in the primary
21 circuit. In fact, in our previous experiment, we
22 think that we have had some volatile iodine in the
23 primary circuit, and we do not understand why, and we
24 don't have the explanation, so we're trying to make
25 measurements. You will see the presentation of PAR3

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1 by Monsieur Michel Evrard, that it is an important
2 point for the Source Term.

3 We * interactions between recombiner and
4 fission product. We've already looked at the possible
5 poisoning of recombined air by fission products.
6 That's H2PAR, and we were launching a new program to
7 see what could be the prediction of organic iodide by
8 acting recombiners, I mean, by thermal decompensation
9 of aerosol particles passing through the recombiner.
10 This is a new experimental program. And also, the *

11 So for codes, we have a system code that's
12 named ASTEC, so it's assigned kind of objectives and
13 it's MELCOR. And we're also * for * in the
14 containment that could be run either in stand alone,
15 but that are generally integrated in *. Okay. Or
16 that * and that could be coupled in that case *.
17 That's more like in *. And * so you've got
18 everything. You've got here all the names of the
19 models, Diva for degradation *, you have transport *
20 SOPHAEROS * calculations, and so on, so * concrete
21 interaction and so on.

22 Okay. Concerning fission product release
23 * we have integrated what some people call semi-
24 mechanistic * semi-empirical *. It depends how you
25 want to see it. The idea for such code is to separate

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1 the fission products in several families, and to model
2 only the dominant mechanism for fission product
3 release. For instance, for volatilized, what is model
4 *. Okay? For semi-volatile you can * pressure, and
5 so on. And for non-volatile, at the time being you
6 release them as uranium. Also, in this * the uranium
7 volatilization is *. That's for the * state.

8 When you reach the * fuel for volatile,
9 you consider that they are all * at that time, and we
10 make thermal chemical calculations for the release
11 within the * pool, so this is still to be implemented
12 in the course. That's * in that case. Also,
13 calculation of release of silver uranium, cadmium and *
14 carbides.

15 We have * that is MFPR that *, so maybe we
16 will not go into all the details about the *. You
17 have a solid solution of fission products in UO_2+X .
18 You have CSI. You have * containing barium, cesium,
19 *, and things like that. Molybdenum *.

20 MR. KRESS: Is burnup dealt with in that
21 --

22 MR. CLEMENT: Yes, it takes account the
23 burnup.

24 MR. KRESS: It does.

25 MR. CLEMENT: The code calculates all the

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1 radiation history of the fuel, and then it looks where
2 are the fission products, if they are still *, if they
3 are midway *, so all of this is calculated by the code
4 during the operation and during the severe accident.
5 * all the details just to save time.

6 Okay. Concerning fission product
7 transport, and we have seen it's quite important. We
8 use SOPHAEROS Code, so that treats vapor * phenomena
9 with homogeneous *, condensation and revaporization on
10 aerosol particles and * in both sites, chemisorptions
11 of vapors on structures. Calculate * chemistry,
12 including 35 elements, giving 84 species, and this is
13 * extended to 65 elements. In fact, we have to cover
14 all the elements that may react, and also interpret
15 some experimental * elements of artifacts in reactor
16 situations.

17 This also includes aerosol phenomena, so
18 do all of the mechanisms for deposition, settling *.
19 I mean, it's quite classical * suspension and
20 agglomeration.

21 Okay. Finally, the * code, but maybe here
22 I will not * to save time for the experimental
23 results, but in fact, we have a number of things that
24 are modeled in gas phase chemistry, that must transfer
25 from gas to the liquid, and also in the liquid phase

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1 phenomena.

2 MR. POWERS: Do you still believe that
3 there's ozone in the atmosphere to react with the
4 iodine?

5 MR. CLEMENT: We are -- there is a
6 possibility. We don't know exactly. It may act with
7 iodine, it may also distract some organic form of
8 iodides, so this could go in a good sense. But, in
9 fact, there are clearly competitions between the
10 reactions of ozone with iodine, and reactions of ozone
11 with other -- with metallic surfaces and so on, so if
12 ozone is trapped by metallic surfaces before having
13 reacted with iodine, the effect will be *, but we
14 don't know yet.

15 MR. POWERS: I have always considered that
16 not -- I mean, people get enthusiastic about this,
17 ozone or nitric oxides, reactions to the iodide
18 strikes me as the worse news one could possibly have,
19 because it will act like a pump, to pump iodine out of
20 solution, put it in the atmosphere. It is
21 extraordinarily tiny little particles that will have
22 really long residence time in the atmosphere.

23 MR. CLEMENT: Yeah. In fact, we don't
24 have all the experimental evidence to say yes or no at
25 this point.

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1 MR. POWERS: We may need to assemble a
2 Panel and take a vote.

3 (Laughter)

4 MR. POWERS: Brent would -- he can chair
5 this thing.

6 MR. CLEMENT: Okay. The last viewgraph of
7 this first presentation, this will be what will be
8 explained by Jean-Michael Evrard later on, so we are
9 * our own reassessment on Source Term. Source studies
10 have been performed between 1997 and 2000, so we have
11 taken into account all of the data and knowledge
12 coming from all of the experimentation and modeling
13 effort, and we have used the deterministic approach
14 based on a limited number of envelope sequences. In
15 fact, again * but this will be explained by Jean-
16 Michel better than I. We have used only low pressure
17 scenarios. This is our basis, but he will explain
18 that, I think.

19 MR. BOYACK: What was the burnup basis for
20 this study?

21 MR. CLEMENT: Some part of burnup is taken
22 into account where that * burnup is taken into
23 account. For gap release, we have some information *
24 burnup, so it is taken into account. Where there is
25 no information, or few information - okay - experts

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1 have tried to take into account at a given point of
2 view.

3 MR. KRESS: When one takes into account
4 burnup, does one look at the distribution of burnup
5 throughout the fuel and the core, as the core is not
6 homogenous.

7 MR. CLEMENT: Yeah.

8 MR. KRESS: Do you account for this
9 distribution somewhat?

10 MR. CLEMENT: In fact, at the end of the
11 day, in the results we get some pages that can apply
12 probably to the *, because there is a distribution of
13 *. In fact, we're seeing the -- this we'll see in the
14 next presentation, main affect on burnup for the data
15 we have from * experiments, * accelerates the release
16 of *. So also, * compress this phase in time, but
17 when you look at the -- depends then what you want to
18 do with that for -- you know, French case, for
19 instance, we're interested to know what is in the
20 containment if we are obliged to vent the containment
21 because of other venting system. So in that case,
22 maybe it's rather long time after the first emission,
23 so maybe the compression of time is not so important.
24 But if you want to look at shorter *, then this
25 compression of time due to burnup may be of

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1 importance. It depends what you want to do with your
2 Source Term.

3 Okay. Well, this was the first part of
4 our presentation.

5 MR. BOYACK: And there is plenty of time.
6 Don't feel like you have to rush.

7 MR. CLEMENT: Questions now? The next one
8 is * from VERCORS and PHEBUS. I can stop now.

9 MR. BOYACK: Yes. And feel free to take
10 as much as you need.

11 MR. CLEMENT: Okay.

12 MR. BOYACK: There's no rush.

13 MR. CLEMENT: Okay.

14 MR. POWERS: I guess in this issue of
15 heterogeneity of the core, the issue of heterogeneity
16 of the core that was raised as a question is
17 interesting, because I suspect that when the Source
18 Term Code Calculations were done, that the -- an inter
19 core was assumed.

20 MR. KRESS: Right. It was, but I don't
21 think they even thought about burnup and how it's
22 distributed throughout the core.

23 MR. POWERS: Well, you shortly thought
24 about inventory.

25 MR. KRESS: The inventory, it is accounted

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1 for in inventory. They need to factor in the burnup,
2 and the fuel management scheme and so forth there, so
3 it is in the inventory, but it's the only place it
4 shows up.

5 MR. POWERS: Maybe the only important
6 place.

7 MR. KRESS: Well, I don't think so,
8 because if it has the significant affect on the
9 fission product release, you need to treat the core --
10 the different parts of the core separately. I mean,
11 we can't talk about a whole core melt down and burnup.
12 You need to think about what gets released from the
13 different parts of the core, and it might affect the
14 timing, it might affect the amounts, because you might
15 melt down part of the core that says high burnup
16 before it has a chance to release -- that sort of
17 consideration.

18 I think it could affect the timing and the
19 amounts, depending on how much core is at this maximum
20 burnup level. You know, when I was doing my
21 calculations, I recognized that I needed a
22 distribution of burnups, and to factor that into the
23 calculation, but I didn't have it, so I couldn't do
24 it. And I'm regretting not having such a
25 distribution, because I could -- if I had the

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1 distribution of burnup in the line up, I could have
2 factored it into my model, but I didn't have it, so I
3 didn't.

4 MR. BOYACK: Okay. Any other questions or
5 comments before we begin the presentation? Okay.

6 MR. CLEMENT: Okay. So that involves
7 fission product release from fuel, and many
8 experimental data. So experimental data coming from
9 the first series of VERCORS tests, so in fact we have
10 the six VERCORS Tests, from one to six. And the other
11 series of VERCORS, VERCORS RT and HT Test, that is
12 currently still in progress, so * facilities,
13 measurements and *. RT2 and RT7 test is a MOX Test,
14 and HT1 is a high burnup test.

15 MR. KRESS: Did these tests vary the
16 burnup?

17 MR. CLEMENT: For the two MOX tests?

18 MR. KRESS: Yes.

19 MR. CLEMENT: Not for burnup. For other
20 things, but not for burnup. And also, that this
21 probably you will know, there are some results of *.

22 Okay. So these * core tests have
23 obviously the true classical objective * kinetics and
24 total * fission products that also are denied in the
25 structural material, so as a function of a fuel

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1 temperature and also the atmosphere that could be
2 either reducing, or oxidizing, or in between, or that
3 could change during the course of an accident and it's
4 simulation. So * Sources also, and the chemical * gas
5 phase. So this first series has been performed from
6 1989 through 1994.

7 Maximum temperatures were about 2600
8 Kelvin, so that we're higher temperature than in the
9 previous HEVA Program. So basically, we make
10 experiments with the three * pellets that are taken
11 from our nuclear * plants, * is kept so we keep the
12 radiative cladding and three pellets.

13 There are * pellets * depleted uranium.
14 uranium in the upper part and the lower part. You see
15 on this scheme this is * within its cladding * uranium
16 pellets, and this is a radiographic of the same thing.

17 Okay. Then this sample is *, so in the
18 past it was * in Grenoble. In order to create short
19 life fission products, that more or less for an
20 instrumentation and detectability question, you have
21 much better measurements if you are able to make * gas
22 spectrometry on short life fission product. So this
23 imposes a constraint between the time of re-
24 irradiation in the reactor and the time of the
25 experiment that must be less than 400 hours in order

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1 to have a good detectability. So in the past, this
2 was easy because the radiation and experiment
3 performed on Grenoble. Now irradiation is performed
4 in *, but they managed to do that. They make a short
5 transportation. The * show this before, so it's quite
6 classical system, so you imagine that you have three
7 pellets here, so inside a ceramic tube, and then you
8 have a * that is heated by the high frequency furnace.
9 Steam hydrogen, or a mixture of steam and hydrogen are
10 injected here in the bottom.

11 What is material in this series of tests
12 goes through an impactor that is not only an *
13 detectors. They are also * bits of stainless steel to
14 trap fine aerosols. So then it goes this way through
15 *. Okay. Then to condenser, then this way you have
16 a possibility to go * gas chromatography. Here you
17 have a volume in which pass all the noble gases that
18 you can measure on line by gas spectrometry, and here
19 you have a contract for noble gases, so * the system.

20 MR. KRESS: Your fission product release
21 measurement, is that second --

22 MR. CLEMENT: Okay. We have one online
23 detector on the fuel. Okay? One online detector on
24 the impactor, one online detector on the gas capacity.

25 MR. KRESS: And the one on the fuel would

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1 be driven what's still in the fuel, you think?

2 MR. CLEMENT: Yes. It measures what is
3 staying in the fuel. In fact, of the three pellets,
4 it's looking at the upper pellets.

5 MR. KRESS: And you used the change in
6 that to get --

7 MR. CLEMENT: Yes. That's right.
8 Okay. The same thing that's just written, so steam
9 hydrogen injection system that is superfitted at the
10 inlet, so the heating system that can go up to 2600
11 Kelvin, cascade impactor, filter, gas capacity and
12 cold trap.

13 Okay. So * there is an optical pyrometer
14 for measuring the temperature of the crucible. It
15 doesn't measure exactly the temperature of the fuel,
16 so calibration has been necessary.

17 MR. KRESS: Do you run a temperature ramp
18 rate up and then hold it constant?

19 MR. CLEMENT: No, you will see that -- in
20 fact, these experiments the first temperature plateau
21 which was a low temperature in order to oxidize the
22 Zircoloid cladding, minimizing the interactions, and
23 then it's ramp. Ramp was sometimes interrupted by
24 small plateaus, but basically it's ramp.

25 Okay. So as I said, three gamma

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1 spectrometers. One on the fuel rod, one on the
2 impactor, and one for measurement of noble gases.

3 MR. KRESS: But what is the temperature
4 ramp rate? Do you --

5 MR. CLEMENT: 1K per second.

6 MR. KRESS: So it's like Adiabatic decay
7 heat levels.

8 MR. CLEMENT: Yeah. Okay. There are also
9 post-test analyses, so the fuel is embedded in epoxy-
10 resin, and then we have x-ray measurements,
11 longitudinal gamma-scanning of the fuel. That's
12 important to have the final inventory. In fact, not
13 only the fuel is gamma-scanned, but all the apparatus
14 * and all of the * of what is in the fuel, where is
15 it, where are fission products deposited and so on, so
16 this is a bone gamma-scan of all components,
17 ceramographic examination to see if there are changes
18 in the microstructure of the fuel after the transient,
19 and physical chemical analysis of samples from the
20 loop, mainly by scanning electron microscopic, so here
21 is the answer to your question maybe. Ramp. No.
22 Yes. Ramp temperature, 1K per second. That's here.
23 Okay. So in fact, you can see that most
24 of these were tests were not at high burnup except the
25 VERCORS 6, that goes up to 60 gamma day per ton of

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1 uranium. Temperature is in the range of 2500, 2600
2 Kelvin.

3 Okay. The atmosphere is changed. You
4 have here the flow rate of hydrogen and here the flow
5 rate of steam. In that case, you have some oxidizing
6 conditions. Here we have only hydrogen, so we have
7 more oxidizing conditions.

8 Okay. For each * about what have been
9 seen I'd say as examinations of the fuel after the
10 test, so the fuel does not have the same morphology,
11 so we have looked in more detail in the VERCORS 3 to
12 VERCORS 5 image, and the VERCORS 6. So let me show
13 the pictures. So this gives you a -- this is -- this
14 gives you an idea of the degradation of the pellets at
15 the end of the experiment, having in mind that things
16 were at temperature lower than uranium melting point,
17 that there was already the fuel degradation. So in
18 VERCORS 3 through 5 it was maintained, but it was
19 severely damaged in VERCORS 6.

20 The upper and central pellets have become
21 much thinner, so they have been consumed on the outer
22 side. I'm not sure it can be seen on the view graph.
23 No, it cannot be seen.

24 MR. KRESS: What is your crucible made of?

25 MR. CLEMENT: In these experiments it was

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1 either Zirconia or Radio Thoria. Radio Thoria. And
2 therefore, partially melted in the VERCORS 6
3 experiment. These were * some morphology, changed
4 morphology, that is what you can see in VERCORS 4,
5 with a hydrogen environment, and VERCORS 5, so you can
6 see the morphology of the cladding. And here you can
7 see the interactions between the cladding and the
8 fuel. You have here, in fact, in this region rather
9 higher *. You can see in such tests, the kind of
10 porosities we can see in the periphery core zone of
11 the fuel, so some morphology *. So the zone * in the
12 periphery was a higher * burnup. Okay? This is what
13 you can see *.

14 MR. KRESS: The grains are about 15
15 microns?

16 MR. CLEMENT: 15 microns *, yeah.

17 MR. KRESS: Is that both at the start and
18 the --

19 MR. CLEMENT: I don't think those -- when
20 fuel remains in tact, I think the grain size does not
21 change too much.

22 MR. KRESS: It doesn't have enough time to
23 go --

24 MR. CLEMENT: Yes. It's a high
25 temperature, but a short time so --

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1 MR. KRESS: Okay. Did it change in
2 burnup?

3 MR. CLEMENT: Grain size, I don't --

4 MR. POWERS: Well, basically --

5 MR. CLEMENT: Basically yes, but not --

6 MR. POWERS: What you have is you burn
7 fuel, you get some initial grain size growth in the
8 first few megawatt days per time.

9 MR. CLEMENT: Uh-huh.

10 MR. POWERS: And then you pin the grains
11 and they can't grow, don't grow, until you get up to
12 the point that you induce restructuring. And then you
13 go from grains that are like it says on the order of
14 15 microns to grains that are on the order of a tenth
15 of a micron.

16 MR. KRESS: They get that small.

17 MR. POWERS: Oh, yeah. In the
18 restructure, as I'm --

19 MR. LEAVER: That occurs, restructuring, at
20 about what?

21 MR. POWERS: Well, now you're getting into
22 a complication of nomenclature. We tend to think
23 about burnups over some finite amount of the core.
24 Then you've got to think a little bit about the fact
25 that there is a burnup radio profile across a given

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1 pellet. Okay. If I look at the local burnup, the
2 particular region where the restructuring actually
3 occurred, I think it's actually a fairly sharp event,
4 right around 70 gigawatt days per ton. Okay? And
5 it's very detectible.

6 That is somewhat a function of what the
7 linear power rate is, and that's a complexity. And to
8 go into that complexity, we have to discuss gas
9 bubbles, and then lots of things like that. But you
10 can take locally about 70 gigawatt days per ton.

11 Now what that is, to translate from local
12 to a more global measure, depends on whether you're
13 talking about PWR Fuel, or BWR Fuel, what kind of
14 burnable poisons you have, how much gadolinium is in
15 it, things like that. Okay? But roughly, 50 gigawatt
16 days per ton is the pellet average.

17 Now things we -- you know, once you
18 persuade yourself that that restructuring, that fine
19 microstructure that he shows, that I'm sure that Ralph
20 will show more of, whether that has a significant
21 impact or not, then you've got to discuss how thick it
22 is, and how deep it goes and what happens to it as you
23 go through this temperature transient that you ascribe
24 to the accident. All interesting stuff.

25 MR. CLEMENT: Okay. Some *, so we'll just

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1 summarize quickly. If you look at the * the last
2 experiments, are no surprise for volatized fission
3 products, you are between 99 and 100 *. What is
4 notable difference was what is taken in 1465 is
5 barium-release. That is in this experiment important,
6 so --

7 MR. LEAVER: Barium?

8 MR. CLEMENT: Yeah, barium.

9 MR. BOYACK: Just before the one you want.
10 The orange one. Yeah.

11 MR. CLEMENT: About here, up to 80
12 percent, or 55 percent, or 29 percent release of
13 barium, so that's one difference with what is 1465.
14 But this is consistent with * HIVI Test. Values are
15 sometimes different, but it's -- globally it's
16 consistent. Other points we can see * when it's
17 oxidizing. Okay. That's not a surprise.

18 We saw that release of tellurium *. We
19 have to wait for the cladding being oxidized, but this
20 was null also. Concerning the actinides, actinium is
21 more released than uranium, that is more released than
22 plutonium. That's the order. That *.

23 Getting back to volume now, I'd like to
24 show you how this graph, the volume actual
25 distribution, so this is a distribution of the fuel

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1 before the test. This is the fuel after the test.
2 Okay. That's * volume on this, sorry. But what is
3 important is when we look at both the volume that was
4 staying here - okay - what is important is that not
5 all the volume is still in the fuel, so this is
6 thermograms, and emission thermography, so in effect,
7 imagine you have the fuel here, and volume has been
8 spread like that in a radial direction, so not all the
9 volume that went out of the fuel was really released
10 from the test section, but some went out.

11 This could be important, for instance, we
12 are speaking about the suspension or evaporation, if
13 you have things like that, that this could be
14 important.

15 MR. LEAVER: What is the -- this is the
16 pellet?

17 MR. CLEMENT: This is the pellet, yes.

18 MR. LEAVER: And what are the white lines?

19 MR. CLEMENT: The white line is probably
20 an original diameter of the pellets, so then it was
21 eroded here.

22 MR. LEAVER: The original diameter of the
23 pellets?

24 MR. CLEMENT: Yeah. It was eroded *.

25 MR. LEAVER: For the cladding?

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1 MR. CLEMENT: The cladding was probably
2 here.

3 MR. LEAVER: Yeah.

4 MR. CLEMENT: This was erosion of the *.

5 MR. LEAVER: Okay. And there's no cladding
6 on this pellet.

7 MR. CLEMENT: No. No. You will see that
8 on another experiment where it is maybe more clear.
9 Okay. So conclusions, at 2600 Kelvin, so no surprises
10 for iodine. Normal gas * cesium, tellurium and
11 antimony, so nearly * delay for tellurium and
12 antimony, but trapping on the unoxidized cladding.
13 For semi-volatized, there is molybdenum *, rhodium.
14 The significance of this is that could be about half
15 of these -- of the release -- of the volatized *. For
16 the same experiment, you are able to release about
17 half here of what you will release here, so it's
18 significant. High sensitivity through oxidizing or
19 reducing conditions, for instance, molybdenum * and
20 oxidizing in volume * in reducing conditions. And
21 also a significant retention close to the fuel. I
22 mean, we have -- as you have seen, we have this gamma
23 measurement that is on line measuring what is in the
24 fuel. And you have the other gamma measurements that
25 are measuring what is * in the impactor and *, so we

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1 know that it is an important retention, and this is
2 also gamma scan.

3 Continue for *, so for strontium,
4 lanthanum, * between 3 to 10 percent of initial *,
5 deposit very close to the fuel. Zirconium * so they
6 are already linked to the fuel. Negligible *. Okay.
7 Only some molybdenum and lanthanum measurements have
8 been measured in another experiment *. That is the
9 only one on which a significant amount of lanthanum is
10 measured. So this is in good agreement with the other
11 tests, so HIVI and PHEBUS-FP with the exception of
12 volume.

13 MR. KRESS: Well, was VERCORS 6 an
14 oxidizing environment or a reduced --

15 MR. CLEMENT: VERCORS 6 was --

16 MR. EVRARD: You have the table with the
17 condition.

18 MR. CLEMENT: I have the table but it's so
19 much *.

20 MR. SCHAPEROW: Yeah. I think that was
21 the most oxidized.

22 MR. CLEMENT: VERCORS 6, where is VERCORS
23 6?

24 MR. LEAVER: That was .5 tighter than
25 the --

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1 MR. KRESS: So it's oxidizing.

2 MR. LEAVER: I think we need to think
3 about that, because if we're looking at fission
4 product release in some of the sequences, the question
5 is --

6 MR. EVRARD: Co-mixing conditions.

7 MR. KRESS: Yeah. Is it doing oxidizing
8 conditions or doing reducing conditions? I think it's
9 more likely to be doing reducing conditions. I'm
10 not --

11 MR. LEAVER: Release.

12 MR. KRESS: Yeah. You need -- right. You
13 need to run the whole four codes to determine whether
14 the release comes from --

15 MR. LEAVER: Yeah. There's a table
16 listing all the conditions.

17 MR. KRESS: My question is what is it do
18 in real accidents.

19 MR. CLEMENT: All right. Coming back to
20 test with high burnup, so we have for the time being
21 two tests, VERCORS 6 and VERCORS RT5. I may not have
22 spoken about VERCORS RT5 because there were some
23 experimental difficulties, so it's really difficult to
24 measure what was released during this test, so the
25 test analysis has been postponed.

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1 MR. KRESS: Okay.

2 MR. CLEMENT: Maybe in the future, we'll
3 come back to it, but it's much more difficult. And
4 when the future test is done in 2002, with a *
5 radiation *, so we know that to complete this
6 database.

7 Okay. General comments. In fact, we
8 observed what we call in the VERCORS the fuel
9 relocation at the given level of temperature. We
10 observe online with this gamma spectrometer that is
11 looking at the upper pellet, when you look, for
12 instance, at elements like europium or things like
13 that, for which your release is very low. You observe
14 that given time and temperature a collapse of the
15 fuel. That is called fuel relocation. So with
16 increasing burnup, this relocation appears at lower
17 temperature. Yes?

18 MR. SCHAPEROW: On the -- there is a
19 cladding around?

20 MR. CLEMENT: There is a cladding around,
21 yes. But I mean, the cladding is fully oxidized.
22 There's no more --

23 MR. SCHAPEROW: No support.

24 MR. CLEMENT: Yeah, no more support. And
25 also, it might have interactions at such temperature,

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1 or that's probably a good explanation. So the release
2 of volatilized fission products appear earlier than in
3 lower burnup tests. But I would say when you reach
4 this relocation temperature here, that's nearly
5 everything has been released * burnup test. So that
6 was I was calling compression in time.

7 MR. KRESS: That may be -- I'm sorry.
8 That may be -- the reason for that complete release we
9 need to keep in mind may be because you're using a low
10 ramp rate and heat up.

11 MR. CLEMENT: Yeah.

12 MR. KRESS: So you're there a long time
13 before you ever get --

14 MR. LEAVER: Time and temperature.

15 MR. KRESS: So time and temperature is
16 important.

17 MR. SCHAPEROW: Which test was the one
18 that compares -- if you want to do an isolated look at
19 burnup, would it be comparing VERCORS 5 with VERCORS
20 6? Would that be the --

21 MR. CLEMENT: Strontium *.

22 MR. LEAVER: 5 is 38.3.

23 MR. EVRARD: I would say it's difficult
24 because there's no specific test we've -- where the *
25 done of * so there is a difference in the

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1 * --

2 MR. LEAVER: Right. Right.

3 MR. EVRARD: -- of plateau and *.

4 MR. LEAVER: Right.

5 MR. EVRARD: That's so easy.

6 MR. KRESS: As long as I can get the same
7 atmospheric conditions, then I could compare it.

8 MR. LEAVER: It's not clear that the --

9 MR. KRESS: I can take care of the
10 temperature.

11 MR. LEAVER: The atmosphere is not the
12 same though.

13 MR. KRESS: Yeah, that's what I need to
14 know.

15 MR. LEAVER: Yeah.

16 MR. CLEMENT: I have lost my table. I
17 have lost my table.

18 MR. LEAVER: You had that one table that
19 had --

20 MR. CLEMENT: Yeah.

21 MR. LEAVER: I was going to ask you to
22 hold that one out.

23 MR. KRESS: There it is.

24 MR. CLEMENT: Okay. So the VERCORS 6 *
25 not small comparable with this one for the atmosphere.

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1 Okay. For VERCORS 3 --

2 MR. LEAVER: Okay. And 3?

3 MR. CLEMENT: The duration of plateau is
4 not the same for the atmosphere.

5 MR. LEAVER: That's a good one. That's 3
6 and 6. Yeah. Were those the two that you said on
7 that other slide that you were comparing, 3 and 6?

8 MR. CLEMENT: No, it was not a direct
9 comparison, no.

10 MR. LEAVER: It wasn't?

11 MR. CLEMENT: No.

12 MR. LEAVER: It was just a general
13 comparison.

14 MR. CLEMENT: Yes, a general.

15 MR. LEAVER: Yeah.

16 MR. CLEMENT: Okay. So --

17 MR. LEAVER: But that seems significant
18 that he's really concluding that this is faster which
19 this is a surprise, and -- but it's complete in both
20 cases, so --

21 MR. KRESS: Yeah. It's complete in my
22 mind because you hold it a long time.

23 MR. LEAVER: Right. Right.

24 MR. KRESS: The faster is not a surprise
25 to me --

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1 MR. LEAVER: No.

2 MR. KRESS: -- because I've been saying
3 that all along.

4 MR. LEAVER: Right. Right.

5 MR. EVRARD: But I think there's a way to
6 * temperature if the * on the table for *.

7 MR. KRESS: Yeah, but the reactors
8 generally go through two ramps. One of them is this
9 1 degree K, which is mostly an Adiabatic heatup. Then
10 you light off the clad.

11 MR. LEAVER: Right. It takes off like a
12 rocket.

13 MR. KRESS: And then it changes an order
14 of magnitude or more.

15 MR. LEAVER: Exactly.

16 MR. KRESS: So you have two ramps that you
17 have to worry about, and you have to worry about how
18 long you're in each one of them.

19 MR. LEAVER: Right.

20 MR. CLEMENT: So for summary, low
21 volatiles - okay - there is a question mark here
22 because it appears not so important, but * not so
23 important *, and maybe it's an affect of this low
24 relocation temperature. You don't have time to
25 release all of these fission products, but we are so

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1 sure we can make this conclusion. A conclusion if you
2 * about that now. So this was VERCORS series, and now
3 we have the series that is being run now. That is
4 VERCORS RT and HT, so RT stands for -- HT stands for
5 high temperature, RT I don't remember whether it's --
6 I don't know.

7 MR. GIESEKE: Never mind.

8 MR. CLEMENT: The RT tests are quite
9 simplified tests. We just want to look at release
10 from the fuel - okay - so we just put all of the fuel
11 * filters in which we trap everything that is
12 released.

13 MR. LEAVER: Release of transuranics.

14 MR. CLEMENT: Everything that is released.

15 MR. SCHAPEROW: Those are RT. That's
16 right. Yeah.

17 MR. CLEMENT: Transuranics.

18 MR. LEAVER: Yeah, that's what it was for.

19 MR. CLEMENT: Thanks.

20 MR. LEAVER: Right.

21 MR. CLEMENT: Thanks.

22 MR. LEAVER: It's on this other slide.

23 MR. CLEMENT: Yeah. And we make also
24 chemical analysis of the different parts of the
25 circuit in order to have the mass balance, and to know

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1 where things are depositing.

2 HT Test also -- we also look at the
3 retention in the circuit in the simplified way. I
4 mean, over the test * you have a thermal gradient
5 tube, so we --

6 MR. KRESS: Do you have --

7 MR. CLEMENT: A thermal gradient tube.

8 MR. KRESS: Do you have a thermal gradient
9 tube bottle? Dana would like to see that.

10 MR. CLEMENT: We make calculations of
11 vapor condensation.

12 MR. POWERS: But that's --

13 MR. KRESS: That's not good enough.

14 MR. CLEMENT: In fact, that's an important
15 point. And in fact, in -- it is on this HT Test that
16 we first tried to see if our calculations are okay or
17 not, because it's a simpler continuation than other
18 ones, on which condensation peaks are well measured in
19 the thermal gradient tubing. We are now in the
20 process of looking at * . Okay.

21 MR. SCHAPEROW: Why you say this is a
22 simpler configuration? In what way is it simpler?

23 MR. CLEMENT: Well, let me show --

24 MR. SCHAPEROW: I'm sorry. I guess I
25 missed that.

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1 MR. CLEMENT: I will show the next slide.

2 MR. SCHAPEROW: Oh, okay.

3 MR. CLEMENT: So this is the * the same
4 kind of furnace, and here on this filter you measure
5 everything. * pyrometer you measure the bottom and the
6 top. You have online gamma spectrometry on the short
7 column on the impactor. Then you go to condensers,
8 drivers and cold traps, so it's quite simple *. You
9 see here the furnace itself. You adhere the * tube.
10 And here the * filtering system that is *. The same
11 in *. Okay. So the heating system over there.

12 MR. KRESS: When you use your thermal
13 gradient --

14 MR. CLEMENT: Yes.

15 MR. KRESS: -- in your pyrometer, with
16 your -- I guess you're using a glass --

17 MR. CLEMENT: I didn't --

18 MR. KRESS: What does it look is what I'm
19 getting at? Do you have a --

20 MR. CLEMENT: We look at -- we know the --
21 what is the temperature * along with thermal gradient
22 tube, and we look at the peaks of vapor condensation
23 along with thermal gradient tube.

24 MR. KRESS: I was thinking about where it
25 looks at the fuel itself.

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1 MR. CLEMENT: No, no.

2 MR. KRESS: How does that --

3 MR. CLEMENT: The gamma spectrometer?

4 MR. KRESS: Yeah. No, no, no, no. The
5 optical pyrometer.

6 MR. CLEMENT: The gamma --

7 MR. KRESS: The optical pyrometer, that
8 gauges the temperature of the fuel --

9 MR. CLEMENT: Optical pyrometer, in the
10 lower part it's looking at the bottom of the crucible
11 in which is the fuel.

12 MR. KRESS: Uh-huh.

13 MR. CLEMENT: And the one that is looking
14 from above is looking at the upper source of * --

15 MR. KRESS: You have one looking in the
16 ends.

17 MR. CLEMENT: Yeah.

18 MR. KRESS: You have a hole this way?

19 MR. CLEMENT: No. No, no.

20 MR. KRESS: Fiber optics.

21 MR. CLEMENT: Fiber optics, yes. They
22 resist for a while and then we have to change them.
23 Okay. So you speak now about the true RT Test with
24 MOX. We'll come back to the HT Test after that. So
25 RT2 and RT7, so there was one question about burnup.

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1 It's very similar, 45.6 here, and 43 here. Same kind
2 of fabrication. This one was probably -- may *
3 oxidizing atmosphere and this one in reducing
4 atmosphere. Okay.

5 So fuel degradation, you can see here 1
6 through 5, so in the RT 7 Test, so this one, was
7 reducing atmosphere. The relocation of the fuel was
8 observed at 2700 Kelvins. In the RT 2 Test it was
9 observed 500 Kelvin lower, 2200 Kelvin. Okay.

10 So the only idea is that the interaction
11 between material would have been different in both
12 cases, because fuel doesn't * temperature. Also
13 interaction between fuel have been different. Maybe,
14 you know, *, maybe some remaining Zircaloy.

15 Okay. Anyway, * tests on this relocation
16 temperature problem is -- we think that it will be
17 performed * if possible before the end of 2002,
18 because it's quite an important difference, and we
19 want to try to understand why * would have been --

20 MR. KRESS: But in your test when your
21 fuel relocates, it's not molten you said.

22 MR. CLEMENT: That's why I say it
23 relocates, and I don't say it's molten.

24 MR. KRESS: Okay. Does the fission
25 product release stop --

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1 MR. CLEMENT: There is --

2 MR. KRESS: -- or does it continue?

3 MR. CLEMENT: Maybe it's a coincidence
4 that there is -- because that's the next chart.
5 Involve the two tests of this * fuel, the two tests,
6 whether approximately the same temperature history up
7 to this point here.

8 MR. KRESS: Uh-huh.

9 MR. CLEMENT: There is fuel relocation,
10 and up to this point there is fuel relocation.

11 MR. KRESS: Okay.

12 MR. CLEMENT: Look at cesium release.

13 MR. KRESS: A chemical --

14 MR. CLEMENT: Cesium is denied for this
15 test with his relocation temperature, so it's earlier
16 -- for this test was low relocation temperature. The
17 * two coincidents but we * for both tests.

18 MR. KRESS: Yeah. And it was all gone in
19 both cases before relocation.

20 MR. CLEMENT: Yes. Okay. So it's * of
21 such * because it's not so easy to understand. Maybe
22 more in detail * questions of morphology or things
23 like that, I don't know.

24 MR. LEAVER: But it has nothing to do with
25 UO2 --

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1 MR. CLEMENT: I mean, I cannot imagine
2 that you have relocation at very low temperature
3 without nuclear action between UO2 and other material.
4 You know, when you take * then you would --

5 MR. LEAVER: So there's no clad in this.

6 MR. CLEMENT: There is cladding.

7 MR. LEAVER: Oh, there is cladding.

8 MR. CLEMENT: There is cladding, but the
9 cladding -- there is a low temperature plateau at 1500
10 Celsius, and the duration of the plateau is enough
11 for, I would say oxidize completely the cladding. But
12 maybe there is some interaction, I don't know. This
13 is the only explanation I can see for things like
14 that, different interactions. And also, fission
15 product may play a role. That's -- you know that if
16 you have some pressure in the gas bubbles and so on,
17 that is different in both cases. This could play a
18 role with the interaction *. That's maybe an
19 interesting * for barium.

20 You were asking me how do you use the
21 gamma spectrometer with the fuel. Okay? So this is a
22 view of the signal of the gamma spectrometer for the
23 fuel in RT 7 Test that's inverted, so that in fact,
24 the signal in reality decreases, it is inverted so
25 that this is *. Okay?

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1 Where * exception of barium, that's a blue
2 one. You have here *, and this is just a signal of
3 gamma spectrometer. What we can see here is the first
4 barium movement that is going from the center to the
5 periphery, and then with your gamma spectrometer you
6 have a much less shielding for measuring your volume,
7 and you have a greater signal of barium that doesn't
8 correspond to the release * original movement. And
9 then the release from the test section *. Only there,
10 so this is just to show you that there are very
11 peculiar behavior.

12 MR. SCHAPEROW: Is that because barium is
13 a beta emitter or something?

14 MR. CLEMENT: Barium is a?

15 MR. SCHAPEROW: Well, is it a beta
16 emitter? Is that why --

17 MR. CLEMENT: Oh, it's a gamma emitter
18 both. I mean, it's emitter anyway, yeah.

19 MR. SCHAPEROW: So the other fission
20 products don't go through that migration.

21 MR. CLEMENT: No, no. But measure is
22 gamma rays, not the beta.

23 Okay. This is a view of the gas release.
24 krypton, xenon. What we observe, this is quite
25 classical, is that for each temperature ramp here

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1 before a plateau, you have a big spike in the gas
2 release. You can see other temperature ramps, the gas
3 release increases. Then it stops. Same here, so it's
4 not -- gas release is different from iodine or cesium
5 releases. It's not the same mechanisms. You have
6 this spikes and release during the temperature
7 changes.

8 MR. EVRARD: You have the final release *.

9 MR. CLEMENT: Yeah, and the final release
10 corresponds to fuel relocation. That's what --

11 MR. LEAVER: And the orange curve is
12 temperature?

13 MR. CLEMENT: Yeah, temperature. So this
14 is really associated with degradation *.

15 Okay. Concluding the RT2 Test. Okay.
16 Now in RT2 Test, the release of volatile FPs earlier
17 than RT1, that RT1 was made with * fuel. Okay? For
18 the -- on the contrary, RT7 we have a delayed release,
19 so for the RT2 Test, * release with the UO2 fuel, but
20 this is not confirmed by the other MOX Test. I'm
21 sorry for this confusion, but that's related.

22 Okay. Now we are in the process to make
23 * interpretation, because we don't have yet all the
24 measurements for these tests. In particular, the
25 actinides measurements, we don't yet have the results.

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1 This is important for MOX fuel *.

2 MR. BOYACK: Does your detailed
3 interpretation have something to do with this, also
4 running some of your computer codes, and trying to
5 understand --

6 MR. CLEMENT: There are two points. When
7 I say the interpretation, in fact the analysis of
8 experimental results is not terminated because not all
9 are available *, and then we analyze this test with
10 our computer codes. Yes.

11 MR. BOYACK: Okay.

12 MR. CLEMENT: That could be *. If we just
13 want to look at if what the current status of the code
14 that is used in ASTEC, that is ELISA, is okay or not,
15 we use ELISA for comparing with the experiment. It's
16 a kind of validation process. If you want to
17 understand more detailed features, for instance,
18 fission products are released earlier because there
19 are * what is the size of the bubbles and so on, there
20 we use an FPR. It depends on the goals.

21 MR. KRESS: Your model you said was a lot
22 like the one that's in Victoria?

23 MR. CLEMENT: Yeah, I think so.

24 MR. KRESS: It's a diffusion based model.

25 MR. CLEMENT: Yeah.

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1 MR. KRESS: Have you tried to use the data
2 to back up the uraneous type of coefficients?

3 MR. CLEMENT: In fact, we use -- we use in
4 fact the model of diffusion, so it is diffusion
5 coefficients that are depending of temperature, and
6 also of the pure oxidization, so this is taken into
7 account. In fact, as I said before, for these the
8 fission coefficients, they have been adjusted in
9 experimental research in the first series, because *
10 so we don't take into account other possibilities, so
11 * coefficient *, you know, that should be. Okay.
12 Probably for high burnup fuel and we use a * model
13 like ELISA, probably you will have to use a second
14 population of volatilized Fps, that the beginning * no
15 more in the grain, but in the grain boundaries. That
16 could be a simple way of using simple codes for *.
17 Because here it is not enough to modify the fission
18 coefficients. You have to take into account whether
19 the repartition efficient * grain outside or grain in,
20 so that's not truly an avenue.

21 Okay. So * to the VERCORS-HT, so here is
22 the fuel. Okay. Here is the * with gamma detector.
23 The thermal gradient tube. Then the flow is developed
24 with either * an aerosol filter that traps everything,
25 or at a given time on an impactor * granular *

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1 measurement. Okay. Then we have, I think, the gas
2 capacity here for measurement of noble gases. Then
3 the cold trap, and gases can be sent to gas
4 chromatography, so while * to this part of the system
5 for the transport.

6 Okay. This is a view of VERCORS-HT1 for
7 high temperature tests. Okay. So the release is
8 still high, like * 100, volume 4900, so quite
9 important. And I said before for the first time,
10 important for release of ruthenium, 8 percent, so that
11 -- and also europium, 9 percent. So this is the first
12 time we have quite important * of this low volatized,
13 but this experiment was at a rather high temperature,
14 and I'm sure HT1, I think at higher temperatures.
15 Okay.

16 MR. LEAVER: For a while for 1.

17 MR. CLEMENT: For a while, yes.

18 MR. POWERS: Well, having very high
19 temperatures for a while is of interest, if we ascribe
20 to the belief of some that there's a protracted period
21 in which you have molten fuel on the lower head being
22 retained there because of the time it takes to conduct
23 heat into the lower head.

24 MR. CLEMENT: Yes. I mean any way in
25 the --

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1 MR. POWERS: You will note I did not say
2 I was a subscriber to that.

3 MR. CLEMENT: No, and just on your point.
4 I mean, when the fuel is liquified so it goes down,
5 that's clear. Remind that in these experiments you
6 got online measurements of all these images, so you
7 can make your * at the stage of the experiment that
8 you want. Okay. Because just look at before this
9 important relocation * and say okay, in that case it
10 goes to the lower head. I am not going to * for this
11 phase. You can pick the release -- the time you want,
12 because this is a view of the fuel relocation. This
13 is a gamma scanning initial state, okay. And this is,
14 I believe, is zirconium 95 so that stays in the fuel.
15 You see the * went down, and there -- if there was
16 nothing to stop it - okay - it would have went --

17 MR. KRESS: This might be a good time to
18 break. This -- I've been of the opinion a long time
19 when fuel liquefies it becomes liquid, that the
20 fission product release turns off and quits. And I'm
21 looking for some validation of that opinion by
22 experiments. Not only relocates, because it can
23 relocate and still be in the solid state.

24 MR. POWERS: I'm sure that you don't mean
25 that.

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1 MR. KRESS: I -- what I think happens,
2 Dana, is that you end up creating a pathway for the
3 fission product to get out that's a further distance,
4 because you're no longer dealing with grains. You're
5 dealing with a bulk liquid, and that the diffusion
6 coefficient through this bulk liquid is different than
7 the diffusion through the solid state. And that
8 basically, it turns off because it gets such a -- a
9 much slower rate.

10 MR. POWERS: Yeah. You just mean the mass
11 transfer goes to --

12 MR. KRESS: The mass transfer goes to
13 zero.

14 MR. POWERS: Well, it goes slow. You
15 don't mean it turns off.

16 MR. KRESS: Well, low enough to say it
17 just quits releasing.

18 MR. POWERS: Oh.

19 MR. KRESS: And that kind of gets --

20 MR. POWERS: That's a big off.

21 MR. KRESS: Yeah.

22 MR. POWERS: The trouble is with that
23 view, is you say it turns off, people will forget that
24 when it goes down a rod button and things like that,
25 the mass transfer goes very high. And it's only when

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1 it's in a stagnant pool that you mean the mass
2 transport --

3 MR. KRESS: Yeah. It doesn't --

4 MR. POWERS: Yeah.

5 MR. KRESS: But that's --

6 MR. GIESEKE: It's moving then. It's a
7 release, I would think.

8 MR. KRESS: Yeah, but that's --

9 MR. GIESEKE: Because you're refreshing
10 the surfaces. You're moving it all around.

11 MR. POWERS: You better say yes, because
12 he's got PHEBUS data that shows every time they
13 relocate fuel they get a big burst of aerosol coming
14 through.

15 MR. KRESS: I will believe that, but if it
16 ever gets to a pool, then I think it quits.

17 MR. POWERS: Yeah. I mean it didn't quit
18 down. It's closed down.

19 MR. GIESEKE: Yeah. It slows down.

20 MR. POWERS: All right. And it may be
21 even worse than you think because you've got to have
22 this relatively low convection within the pool, but
23 then you have this frozen or crust --

24 MR. LEAVER: The crust has a big impact on
25 that.

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1 MR. CLEMENT: Okay. So this gives you an
2 idea of the fuel movements. Okay. This is -- okay.
3 It's the same for lanthanum and europium. Okay. It's
4 not so important now. Okay. This gives you a --
5 that's a thermal gradient tube so * response to the
6 temperature, that you can see on this scale. And here
7 you have cesium deposits, iodine deposits, and
8 tellurium deposits, so you can see the peaks are
9 clearly identified, so we are now trying to interpret
10 that. cesium behaves differently, as you can see. If
11 you look at tellurium, this really looks like a
12 beautiful vapor condensation peak with a -- something
13 quite sharp, then a * and so on.

14 MR. KRESS: But it's an iodine compound
15 though.

16 MR. CLEMENT: It's an iodine compound,
17 yes.

18 MR. LEAVER: 800K.

19 MR. CLEMENT: Here it's up to -- maximum
20 is up to 750K. Okay. The tellurium peak is less
21 beautiful but maybe there are trophics. I don't know.
22 We have to look at that. Okay. And for cesium,
23 something else happened. It's not only vapor
24 condensation. Okay. So either we have several
25 species of aerosol depositions here, but all we have

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1 the vaporization of some cesium species, the
2 deposition and then the vaporization, and everything
3 is deposited that way.

4 MR. POWERS: What's the tube made out of?

5 MR. CLEMENT: Huh?

6 MR. POWERS: What's the tube made out of?

7 MR. CLEMENT: The tube is made -- I don't
8 remember. It's metallic *. I don't remember. In
9 fact, I think that's -- if you look at the other
10 kinetics of cesium we have probably the suspension of
11 cesium in this experiment. This is probably what *.
12 Okay.

13 Okay, talking about transport. We measure
14 also what arrives in -- * what arrives in the filter
15 that is at the end of the experiment. So you will go
16 to iodine, cesium, molybdenum. This is *, so that
17 these experiments can be really used to assess the
18 models for the transport in the vicinity of the * in
19 a simple configuration. Okay? So we should be able
20 to calculate such a simple continuation before
21 completing more complicated ones.

22 Okay. So main conclusions, so for the
23 volatile fission products the release was total about
24 2600 Kelvin, so *. In fact, if it continues a
25 transient of release of volatile *, deposition may --

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1 all things remain in the * in the thermal gradient
2 tube. And for the semi-volatiles FP, 50 percent of
3 release of * in molybdenum, so it's quite important
4 and * taken into account for the chemistry efficient
5 product in the RCS. They might interact with other
6 fission products. Okay. The deposition in the upper
7 part of the furnace, thermal gradient tube in the *
8 have been measured.

9 For low volatile - okay - with ruthenium,
10 neptunium, cesium in 5 and 9 percent, more significant
11 release for lanthanum, as I said before, europium.
12 lanthanum was about 8 percent, and most of these
13 fission products were deposited in the upper part of
14 the furnace. I mean, the low volatile fission
15 products are deposited much closer to the fuel than
16 the volatile ones. And no release for zirconium. So
17 watch for the recent test and future test in VERCORS,
18 so we have performed the FP-3 Test in June 2001, with
19 a 47 gigawatt day per ton fuel in oxidizing
20 atmosphere, and silveranium, cadmium was added to the
21 system just to cause the impact on the transport of
22 fission product * fuel. Okay. Analyses ongoing.
23 Future tests, tests will be performed next year. HT-2
24 in April, so we're using atmosphere. That was
25 injection of silveranium cadmium. UO2 was four cycles

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1 radiation. RT-6 in September. UO2 very high burnup,
2 six radiation cycles. And we are discussing
3 presenting the possibility to perform an air injection
4 just at the very end of the test, in order to see if
5 we see * or revaporization of the deposited ruthenium.

6 Okay. So that's all for VERCORS.

7 MR. EVRARD: The VERCORS facility will be
8 closed --

9 MR. CLEMENT: Yes.

10 MR. EVRARD: -- at the end of 2000,
11 because the VERCORS facility will be closed in the *,
12 and to * plan for future experiment in *, but not
13 before 2005. I think that's -- I mean, with this
14 smaller device *. But it could be interesting, I
15 think, for going more for * in a MOX fuel, because I
16 think we are * very much on MOX so far.

17 MR. CLEMENT: Okay. Should I go on on
18 PHEBUS or --

19 MR. BOYACK: Yes.

20 MR. CLEMENT: Yes.

21 MR. KRESS: Well, you know, one thing this
22 points out is we need to decide by some sort of
23 exercise of the codes as to whether we think our
24 release for the Source Term is going to be taking
25 place in oxidizing conditions or reducing conditions,

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1 because it makes significant difference, particularly
2 on some of the lesser volatiles. So we'll have to --
3 but that's a function of which sequences we want to
4 look at, and do the calculations of where we think the
5 fission product occurs in the sequence as it
6 progresses. I think that's one of the points we need
7 to think about.

8 MR. LEAVER: Yeah. I mean, it looks like
9 that's almost more important than whether it's MOX or
10 UO2.

11 MR. KRESS: Probably.

12 MR. CLEMENT: So PHEBUS probably no more
13 than * VERCORS. So four tests have been performed so
14 far, FPT-0 in 1993 which *, so it was a fission
15 product release from a bundle of 25 drops in oxidizing
16 atmosphere, 51 in 1996. The burnup was 23 gamma watt
17 days per ton. Physically the test was quite similar
18 to the FPT-0 * oxidizing atmosphere. Okay. What
19 means oxidizing?

20 In that case, we have during the Zircaloy
21 oxidation phase, 50 percent of more Hydrogen at the
22 outlet of the bundle of the first section, so this is
23 the meaning of oxidizing atmosphere in that case.

24 FPT-2 in October 2000, so 32 gamma watt
25 days per ton of uranium, so * reducing atmosphere. So

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1 reducing means we had steam starvation for Zircaloy
2 oxidation, and we measured one 100 percent Hydrogen at
3 the fuel outlet.

4 FPT-4 in July 1999, so 33 gamma watt days
5 per ton. It was released from debris bed, pre-
6 fabricated debris bed.

7 MR. POWERS: It might be useful to point
8 out how long you measured 100 percent Hydrogen at the
9 outlet.

10 MR. CLEMENT: It was about more than 15
11 minutes, 18 minutes, so it's not -- it's one part of
12 the transient *, so some amount of fission product has
13 been noticed in these conditions. And another part
14 has been noted in oxidizing conditions.

15 MR. KRESS: Is this Hydrogen generated
16 from the plant or --

17 MR. CLEMENT: It was from Zircaloy
18 oxidation.

19 MR. KRESS: It was Zircaloy oxidation.
20 You didn't inject.

21 MR. CLEMENT: No. For instance - okay -
22 you have had in the FPT-2 Test for the high release of
23 molybdenum, so consistent with what I've shown you.
24 But this release of molybdenum did not happen during
25 this phase, but during the peak up phase after when

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1 the conditions were oxidizing.

2 MR. SCHAPEROW: I'm kind of curious too.
3 So what you have is a very slow flow rate of steam
4 into the --

5 MR. CLEMENT: No.

6 MR. SCHAPEROW: And no Hydrogen going into
7 the --

8 MR. CLEMENT: You have very slow -- yes,
9 very --

10 MR. SCHAPEROW: Just steam going in.

11 MR. CLEMENT: We just inject steam.

12 MR. SCHAPEROW: And it turned into
13 Hydrogen.

14 MR. CLEMENT: And * by Zircaloy oxidation,
15 yes. Okay. Well, just like to point out what are
16 the, I would say, the differences with what we've
17 spoken before. Okay. So for volatized * the results
18 are consistent with the picture we have had, * for
19 kinetics and *. Obviously, you have to recalculate
20 with your * actual temperature is * and so on, and so
21 on.

22 Low release of barium, only 2 percent, so
23 this was troublesome because there are a number of *
24 experiments where you release barium in PHEBUS *, so
25 what is our current interpretation. But I say we are

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1 not sure of that. We have made several dynamic
2 calculations in the solid state, adding some oxidized
3 zirconium or oxidized Iron in the UO2 metrics, and
4 calculated the vapor pressure volume of such a
5 mixture, * that it is greatly reduced, so you don't
6 have the proof. That is what we've got by
7 thermodynamic calculations to explain this difference.

8 In fact, in all the * tests you don't have
9 the Iron that you have in PHEBUS * Zircaloy. And
10 depending on the experiment, in VERCORS the Zircaloy
11 is supposed to be fully oxidized so not to interact so
12 much. I think in some tests * there was interaction
13 between Zircaloy and ruthenium.

14 MR. KRESS: There definitely was.

15 MR. CLEMENT: Yes. So maybe it's * but
16 that's *. And for ruthenium we have always this
17 specific *. There is a significant release from the
18 test * matrix, but nearly all what is released is
19 deposited in the upper part of the bundle, and only a
20 few percents are released from the bundle, so these
21 are quite general conclusions. Again, this * the
22 question of what happens if some air arrives on *
23 deposits, would it be fully oxidized and go out?
24 That's a problem.

25 Concerning the fission product transport,

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1 in fact in PHEBUS FP experiment we have simulated *,
2 a steam generator and a cold *. So the temperature of
3 the hot leg was at 700 Celsius, and the conditions of
4 the experiments all of the volatile fission products
5 were transported as aerosol at 700 Celsius, with the
6 exception of iodine. That means that cesium was
7 condensed, * was condensed.

8 We measure low retention in the steam
9 generator. The * are estimate the retention by a
10 factor of about 2 as compared to the PHEBUS-FP
11 experiments, so we go directly to the conclusions.

12 There is some gaseous iodine injected from
13 the primary * to the containment during the
14 degradation phase, and the significant one. It is
15 maximum during the cladding oxidation, the FPT-1, and
16 it is higher in the hot leg that was at 700 Celsius
17 than in the cold leg, that was at * Celsius.

18 You will see later on the -- from the
19 presentation of Jean-Michel Evrard how we have taken
20 that into account in our own Source Term *, but it has
21 been taken into account.

22 Then when iodine comes into the
23 containment it reacts with oxidized silver * to form
24 non-soluble species, and this reduces the * inhibited
25 radiolytic I2 formation in the conditions of these PT-

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1 1 experiment. So most of the --

2 MR. KRESS: Was your silt water stirred?

3 MR. CLEMENT: It was -- was is --

4 MR. KRESS: Was it stirred because the
5 silver iodine tends to settle to the bottom.

6 MR. CLEMENT: Yeah. That is what we have
7 measured. It was sedimented.

8 MR. KRESS: Sedimented.

9 MR. CLEMENT: Sedimented in the bottom.
10 Yeah.

11 MR. KRESS: Slow sedimentation.

12 MR. CLEMENT: It's a rather slow
13 sedimentation, because probably small particles. So
14 most of the * containment during the FPT-1 Test was
15 coming from the *. Then our interpretation is that it
16 reacted with the paints in the atmosphere. This is
17 because at the end of the test we measure mostly
18 organic iodides in the containment vessel. And that
19 is -- was probably * coming from the sun. I think
20 it's solely by reaction with the atmospheric paints.

21 MR. KRESS: And in these tests, you had a
22 -- the steam was condensed in the middle?

23 MR. CLEMENT: The steam was condensed in
24 the middle, and *.

25 MR. KRESS: And that would tend to carry

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1 the iodine towards the -- away from the wall?

2 MR. CLEMENT: Yes. Yes. I mean, you may
3 have reactions of iodine * by different processes,
4 because if you -- when steam is condensed you will
5 have also iodides that will come on the condensing
6 surface, and these iodides may also react with the
7 paints.

8 MR. KRESS: Oh, the condensing surfaces
9 themselves --

10 MR. CLEMENT: Uh-huh.

11 MR. KRESS: Okay.

12 MR. CLEMENT: Just because in a reactor
13 building you condense some painted surfaces.

14 MR. KRESS: Okay.

15 MR. CLEMENT: Okay. This will give you
16 some * stopped it by that, but okay. So the experiment
17 was conducted with -- this is the temperature in red.
18 This is the Zircaloy cladding oxidation, and here is
19 the end of the experiment. Here is the nuclear power.
20 So just to show you some data, so here, for instance,
21 is the xenon measured release from this experiment.
22 So this first picture is * Zircaloy cladding
23 oxidation. In fact, during the course of the
24 experiment, at that part we have had the formation of
25 a molten pool, during this PT-1 experiment. Okay? So

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1 a large part of the fuel that was in the upper part
2 went into the lower part. And we see a decrease of
3 xenon, followed by an increase at the end of the test.
4 In fact here, we have few movements, where hot
5 material were coming down and hitting * fuel in the
6 lower part, and causing this xenon release, so we will
7 go to that for I would say most of the elements. This
8 was a review of the flow rates. This is integrated
9 measurement for iodine. This is the same one for --
10 xenon was different measurements. In fact, *. Here
11 you have * tellurium. You can see that it's quite
12 similar to *, except there is less when is during the
13 oxidation phase starts later on. Okay. That for
14 cesium 137, so * important, and you can see here for
15 cesium, 85 percent at the end of the test, a release
16 from the *.

17

18 Here the release was different kinetics.
19 That's ruthenium. Okay. That's * are negligible, but
20 you can see that the kinetics are not the same as for
21 cesium. It is released later on. This is * of the
22 kinetics, but the release is very low. This one is
23 molybdenum, so 55 percent of the release for
24 molybdenum, and this is uranium, so * in that case *
25 is not correct. It doesn't take into account the

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1 deposits just about the fuel because they were not
2 well measured. For all other fission products this
3 was taken into account, so the kinetic * of uranium is
4 not *. Compare with release of cesium, cesium and
5 uranium, not at all the same.

6 Okay. This was measured also the
7 depositions in various parts of the circuit. Here is
8 the kinetics of -- deposition of iodine in the steam
9 generator, so this is what is measured *, and this is
10 what is derived. This * from the *, so we can see
11 that we have several * phases. The first oxidation
12 phase, that is here, with Zircaloy. Here what we call
13 the main release phase, and at the end of the
14 experiment when we had some fewer movements, what we
15 call late oxidation phase, because in fact, hot
16 material coming in cold regions have oxidized
17 remaining Zircaloy.

18 Okay. We have got the same picture in the
19 containment vessel, so where you can see the
20 repartition of that *, so in the outer part is the
21 total mass reaching the containment. This is the
22 total mass. That is deposited * the same. Then you
23 have what is calculated to be deposited by * settling,
24 which is calculated to be deposited by
25 diffusiophoresis. Okay. And here * iodine into

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1 containment vessel. So *, but these are the
2 measurements, this one.

3 When I say calculated, it's not calculated
4 by calculated by code calculations * from experimental
5 measurements. Okay. Then what is important is what
6 was measured as a gaseous iodine fractions in the
7 containment atmosphere, so these * are a response to
8 the gaseous iodine measurement fraction from the
9 bundle inventory. * one percent, here is your
10 percent. So here at the beginning is the release
11 phase. Then we have this phase here during which all
12 of your solar deposition either by settling or by * in
13 the beginning. So you can see that the concentration
14 is maximum at the beginning, and then is decreasing.
15 Then here we have a specific feature of the previous
16 experiment. We have a large fraction of aerosols that
17 are deposited on the vessel bottom, that are not in
18 sump water. In fact, we wash all these aerosols that
19 are on sump bottom and put them in sump water, and
20 then we start * more than *.

21 Here we can see an increase of * infection
22 and there is * concentration. The curves here
23 corresponds as what is in the sump water from the
24 signal of the gamma spectrometer, so the decrease
25 does not correspond -- the decrease in concentration,

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1 the response to sedimentation, settling of silver
2 iodide.

3 Okay. If we come back to the overall *
4 of * probably need a copy of this table so we could
5 have that, of what having measured as krypton xenon *.
6 iodine, rubidium, cesium, technetium, antimony as
7 volatiles. barium, ruthenium, strontium, * the
8 fission products. So this table, in fact, we have
9 what is in the test bundle zone. Okay. What is in
10 the fuel here, and the upper plenum above the fuel.
11 Then we have what is deposited in the hot leg, what is
12 transported at the measure point of the hot leg, what
13 is deposited in steam generator, and the same for the
14 cold leg. So this gives you an idea of the kind of
15 measurement we get to the end. Okay. And these are
16 other * so neptunium, uranium, plutonium, zirconium,
17 cadmium, rhenium, silver, and strange things. uranium
18 that is an artifact * instrument. And we also measure
19 the * lead that seems completely distributed, but is
20 probably a pollution, but we have the same royalist
21 kinetics as fission products, so that's probably a
22 coincidence. So this gives you some ideas about *
23 FPT-1 and * FPT-1 *.

24 Let's say some words about the first *
25 FPT-2, so similar as far as FPT-1 for the overall

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1 release. Then things are found, not surprises. Xenon
2 release starts before cesium and iodine. Tellurium
3 release starts after the end of cladding oxidation,
4 and molybdenum has not been released during this
5 cladding oxidation where we had 100 percent Hydrogen,
6 but during the oxidizing following heatup phase. * of
7 barium, so we are doing this reducing phase. And *
8 trapped in the hot leg. In precedent experiments it
9 was not trapped or maybe *. In that case, we have
10 changed the conditions in the sump water and iodine
11 was largely soluble in sump water, but the PH of the
12 experiment was alkaline so it changed many things.
13 Gaseous iodine concentration in the containment
14 similar to FPT-1 in the short term, and lower in the
15 long term.

16 Give an idea of experiment for this is
17 versus time. This is a measure of the *
18 concentration, so was 100 percent here. This is
19 iodine concentration in the containment as measured,
20 so with one part of the release during the reducing
21 atmosphere, and one part in the oxidizing atmosphere.

22 The last curve here gives you an idea of
23 the aerosol release. That's quite *. That's an
24 optical monitor in this, so you can see an important
25 peak here at the end of the oxidation phase. And

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1 another important peak, and say near the end of the
2 experiment. This is * time before. We have seen
3 progression of our model molten pool, a * of our
4 molten pool in the experiment. So again, as in
5 previous FPT experiments, you have always an important
6 relation -- you have always important relations
7 between what happens on aerosol fission product, and
8 what happens on fuel degradation.

9 MR. LEAVER: This is -- the main
10 difference is the reducing?

11 MR. CLEMENT: As compared to * for the
12 fuel fission product release, yes. Conditions for the
13 containment were different. The overall mass flow
14 rate was also lower, so that we have had more deposits
15 in the RCS, but that's logical. And also, from a
16 chemist * point of view, there was Boric Acid injected
17 in the system.

18 MR. LEAVER: And the sump chemistry was
19 the same?

20 MR. CLEMENT: Sump chemistry was
21 different, no.

22 MR. LEAVER: It was different.

23 MR. CLEMENT: In FPT-1 it was -- PH was
24 acidic, and temperature was low at the end of the
25 experiment, 90 Celsius and PH-5. Here at the end of

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1 the experiment PH is 9, and temperature is 120, so
2 sump chemistry different.

3 Okay. This is sump chemistry. That's *
4 for first results of FPT-2, so this is a view versus
5 time. Time is rather long of a gamma spectrometry
6 measurements on the sump water. In fact, we have two
7 gamma spectrometers, one looking at the bulk, and one
8 looking at the bottom to see what has been settled.

9 Okay. When we look at the gamma
10 spectrometer that goes at the * this gives an idea of
11 the solubility, for instance, here and here also is
12 settled down * here during this phase. You have a
13 constant value that corresponds -- that gives us the
14 fraction of iodine but that is soluble.

15 When you look at the other spectrometer,
16 that is this one, you look at what is settled *
17 partitioned here. Then we make this washing phase,
18 and we have a rapid increase, and then a rapid
19 decrease, then a *. When we stopped the experiment
20 with decreasing the temperature * changes in the
21 solubility of iodine, so this gives you an idea of the
22 data on which we are working and presenting. So this
23 was my last slide. I'm finished.

24 MR. BOYACK: Any questions or comments on
25 that?

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1 MR. POWERS: Other than it's spectacular.

2 MR. CLEMENT: Thank you.

3 MR. POWERS: It's an amazing set of tests.
4 It showed us things that we believed, and it showed us
5 things that we didn't know about. For example, the
6 one we didn't know about, of course we didn't know
7 that silver was going to chomp on iodine in the
8 containment, and never took it into account in any of
9 the modeling. The other --

10 MR. LEAVER: That happened in the lot
11 though, didn't it?

12 MR. POWERS: What did you say?

13 MR. LEAVER: Did that happen in the lot?
14 Wasn't there silver iodide observed in the lot? I
15 think there was.

16 MR. POWERS: Whether it was observed or
17 not, nobody took it into account.

18 MR. LEAVER: Yeah.

19 MR. POWERS: And never recognized how
20 pervasive an effect it would be. The other thing that
21 has always struck me that the test showed, the PHEBUS
22 Test showed especially, is that motion of the fuel,
23 changing of the flow within the core, and changing of
24 the gas composition within the core are at least as
25 important as changing temperatures on fission product

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1 release. And we build simplified models that have
2 fission product release driven by temperature, just
3 isn't true, and we want the details of the timing. It
4 probably doesn't make a huge difference for the
5 volatiles if all you're interested in is the integral
6 releases. If you're interested in timing and things
7 like that, and the progression, and you do get
8 interested in those things when you're dealing with
9 behavior in the containment, our models are just not
10 up to the chore. And it suggests that they just need
11 to recognize mass transport, what PHEBUS is driving
12 through to. Unfortunately, it's extremely complicated
13 mass transport, so I'm not sure how you recognize it.

14 The -- on the things that it confirmed,
15 probably -- there are lots of things that it really
16 did not support. That is, you get a lot -- you get a
17 substantial fraction of the nobles, you get a
18 substantial fraction of the cesium and iodine. We see
19 a little movement of ruthenium and tellurium which
20 unfortunately is orthogonal to our intuitions on these
21 things, and we're still sorting that out.

22 It also confirms the fact that once you
23 get into the containment, you do get mixed aerosols;
24 that is, the aerosols are very quickly becoming the
25 same composition, kind of a uniform composition.

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1 That's very important because that's an assumption
2 built into every one of the aerosol models, that if we
3 didn't have confirmation of that, the aerosol
4 physicists would be slitting their veins because the
5 alternative is really really intractable. The iodine
6 very quickly come gaseous iodine concentrations,
7 whatever they may be very quickly come to a steady
8 state. That too is a very important confirmation
9 because it's just that details of the kinetical
10 processes are not so important as long as you get the
11 sources and syncs correctly calculated. And of
12 course, that in itself is a problem, because you've
13 got paints, and steels and things like that that are
14 complicated, but if you get the sources and syncs
15 right, what goes in with the atmospheric chemistry is
16 not so nearly -- It's a mixture of things. It's just
17 exactly which one integral test to do for you, confirm
18 things and tell you about things that you should have,
19 if you'd been smarter and paid attention, looked and
20 would have then extrapolated it to reactor accidents.
21 You would probably have better models.

22 I will comment also that one of the
23 biggest benefits that comes out of the tests is that
24 you get a lot from the expendable results, but you get
25 a lot more because they have these meanings with

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1 programmatic groups of lots and lots of people getting
2 together and putting eyeballs on the planning of the
3 tests and the test results, and those insights that
4 come out of the modeling probably are at least as good
5 as the experiment results themselves.

6 MR. BOYACK: Okay. Thank you. Anybody
7 else? Any other comments? Now there was a third part
8 of the presentation.

9 MR. EVRARD: Yes.

10 MR. BOYACK: And how long approximately do
11 you think that takes?

12 MR. EVRARD: I would say maybe a half an
13 hour.

14 MR. BOYACK: No, no, no. It's not too
15 long. It's just a matter of when we have lunch.

16 MR. EVRARD: Maybe a little more.

17 MR. BOYACK: You think a half hour? Well,
18 I think if it's the half hour, we would go ahead and
19 have the presentation and we'll take a lunch break.
20 There's still food down there at 20 after. Right?

21 MR. SCHAPEROW: It's up to you. You're
22 running the meeting.

23 MR. BOYACK: Why don't we go ahead through
24 your presentation then.

25 MR. EVRARD: Okay.

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1 MR. BOYACK: If we get to 1:00, we'll
2 stop.

3 MR. EVRARD: So the last part of the
4 presentation is related to the -- to our work on the
5 reassessment of reference * for the application of the
6 data we collected *. So in a general point of view in
7 France, we have two types of Source Term. One for
8 design basis accidents, and I think that the main
9 difference with the NRC approach is that for this
10 design by these accidents, we consider only *. That
11 means we consider that there is * of the core, and
12 there's no degradation of the pellets, so the -- only
13 the release of the gap inventory *. And the Source
14 Term are used to design instrumentation. I forgot to
15 mention the qualification of equipment to define
16 accessibility, and to assess *. And we have all the
17 Source Terms for severe accidents in order to design
18 emergency planning for those type of accidents. And
19 for this severe accident we consider the scenario, we
20 are commenting with vessel rupture and with a long
21 term loss of containment integrity. We come back to
22 this point later.

23 So personally, I'm more involved in severe
24 accident, but for the purpose of this meeting, I tried
25 to collect information about what is doing in France

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1 in the field of design basis accidents. So * Source
2 Term for different situations in design conditions.

3 For instance, for a large break * there
4 are two different sets of assumptions. One, to assess
5 what * impact, and for this proposal we consider that
6 there is one sort of cladding rupture of the core, and
7 5 percent release of noble gases, and 2 percent
8 release of volatile fission products. That means
9 iodine and cesium.

10 MR. KRESS: Was that 2 percent and 5
11 percent out of those fuels that compose the 33 percent
12 clad failure, so the whole core --

13 MR. EVRARD: Because yes, that's 5 percent
14 and 2 percent have been accumulated in the gap, and
15 all this amount is released during cladding rupture.

16 MR. KRESS: But released from 33 percent
17 of the tubing.

18 MR. EVRARD: Yes. Yes.

19 MR. KRESS: Okay. That's fine.

20 MR. LEAVER: So five-thirds of a percent
21 of the noble gas -- according to the rate noble gases
22 --

23 MR. KRESS: That was my question. Yeah.

24 MR. EVRARD: Yes. And there are some -- a
25 different assumption for -- to assess * existence.

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1 That mean 100 percent of cladding rupture and 5
2 percent of noble gases and volatile fission product.
3 I don't think that * that assumption. And so far, the
4 Source Terms are applicable to UO2 fuel up to 52
5 gigawatt days per ton, and MOX up to 37.

6 MR. LEAVER: What is the difference
7 between system operability and --

8 MR. EVRARD: That means all the
9 applications and * impact.

10 MR. LEAVER: You mean like filtration
11 systems and things like that?

12 MR. EVRARD: Yes, and instrumentation,
13 and accessibility.

14 MR. LEAVER: Okay.

15 MR. EVRARD: So as we gathered the
16 extension of this assumption to high burnup fuel and
17 MOX fuel, there are different kinds of work in France.
18 The first one is feedback of the duration of fuel, so
19 EDF perform measurements on * in order to determine
20 the gap inventory of fission products. So for the *
21 burnup, so far up to 60 gigawatt days per ton, for
22 UO2, and also for MOX fuel. So this gives data on the
23 amount of fission product cumulated in the gap at the
24 end of the life of * core interactor.

25 There are also an In-pile experiment

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1 program named FLASH, which has been performed in order
2 to measure the fission product release under LOCA
3 conditions. And from this experiment, which have been
4 performed many years ago, one involved * burnup fuel
5 * 50 gigawatt days per ton. At -- the main outcomes
6 of these works is that *. That means below 52 and 37,
7 the volatile fission product contained in the gap is
8 less than 1 percent of the core inventory when you
9 measure the gap inventory in * after the *.

10 It increases up to 5 percent for 60
11 gigawatt days per ton for UO2 fuel, and 40 gigawatt
12 days per ton for MOX fuel. It's around this value, so
13 you observe a rapid increase of the containment of the
14 gap for these values, and the FLASH-5 experiment,
15 which involved the high burnup fuel, appeared to be
16 above * value. It seems to be higher content of
17 fission product * gap for burnup of 50 megawatt days
18 per ton, so the assumption is that a part of the
19 volatile fission product * are also being released
20 during the transient * the amount * the gap also a
21 part of the fission product *.

22 So EDF also performed some calculation
23 with the * code which simulates the fuel * fission
24 product production and *. And if we consider that all
25 of the amount of fission product accumulated is

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1 grained * supposed to be released. This -- the
2 conclusion of this calculation is that about 10
3 percent of the noble gases of the inventory of the
4 water could be released, and this could increase up to
5 20 percent for most. So this information coming EDF
6 and * between EDF and *, so this information only for
7 the purpose of the work of this group.

8 MR. LEAVER: Could you repeat what you
9 just said. I didn't understand it. Something to do
10 with PDF and IPF.

11 MR. EVRARD: So this * from EDF.

12 MR. LEAVER: In the last bullet?

13 MR. EVRARD: Yes, all this information.

14 MR. LEAVER: Okay.

15 MR. EVRARD: Is the work performed by EDF
16 to * about high burnup and MOX fuel, and the extension
17 of the use of this fuel * property of EDF.

18 MR. LEAVER: Would that suggest that -- is
19 there some rethinking going on about the release
20 fractions for the design basis accident as a result of
21 this information?

22 MR. EVRARD: Excuse me?

23 MR. LEAVER: The first slide that you
24 showed had a design basis accident in which you were
25 releasing 5 percent for the 33 percent that had clad

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1 trouble. Now this data suggests maybe that number
2 should be a bit higher, at least that's what I think.
3 Is that -- so is there any thinking going on about
4 possibly changing that?

5 MR. EVRARD: Yes. The discussion is about
6 how -- up to which limits we can authorize high burnup
7 and MOX fuel. And if we go below * change the
8 assumptions for Source Term use. And there are also
9 programs and progress with MOX fuel by EDF with two
10 parts. One part is to -- is out-of-pile experiments
11 in Grenoble, which is a program -- the * Program which
12 tried to measure the release under LOCA condition from
13 the pellet, and from the gap. And maybe in the future
14 in-pile experiment like FLASH on MOX fuel, but that's
15 that tests that have been decided so far.

16 Okay. So those are the information I have
17 about high burnup in fuel during design basis
18 accident. So the second part is relative to severe
19 accidents, so I want to make a short history of the
20 reference Source Term for severe accident in France.
21 So in 1975 to `80, there were first studies in severe
22 accident, and the definition of * Source Term, and
23 then to S-1, S-2 and S-3. S-1 is * accident I would
24 say was early rupture of containment, and * the
25 environment.

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1 S-2 was a delayed release, a long term
2 release, but without any filtration. And S-3 was a
3 long term release with filtration by the soil, for
4 instance. And so we -- I can give you the values of
5 this Source Term. So for each one, you have a large
6 release of noble gas for sure, but also of iodine,
7 about 60 percent of iodine, and 40 percent of cesium.
8 For S-2, it was about 3 percent of iodine, and for S-3
9 it was about .8 percent of iodine.

10 MR. LEAVER: Is this release from
11 containment or from the fuel?

12 MR. EVRARD: From containment, yes.

13 MR. LEAVER: From containment.

14 MR. EVRARD: It's where the Source Term *
15 containment.

16 Okay. So following the severe accidents,
17 there are the -- there was implementation of emergency
18 procedures, including a system of * of the containment
19 building, and there * of S-3, taking into account this
20 procedure of filter *. So the -- for the emergency
21 planning, we have considered that * was S-3 Source
22 Term, and that we means that we suppose that early
23 rupture of containment have a low probability, and can
24 be excluded. And for the long term rupture of
25 containment, there will be either the filtration by

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1 the filter venting system or the filtration by the
2 soil is case of basement melt through, for the
3 emergency planning design and the purpose of this S-3
4 Source Term.

5 So from * we have performed a study to
6 assess the S-3 Source Term. In order to consider the
7 new knowledge on the release and on the * fission
8 product, and associating materials to take into
9 account the improvement, implementing these plans, and
10 as mentioned by Bernard Clement, this work is best on
11 a deterministic approach, best on a limited number of
12 accident sequences, which can be considered as * of
13 all the spectrum of accidental sequences. And only
14 long term containment rupture would consider * with S-
15 2, S-3 *.

16 So the accident sequences we have
17 considered are three large * LOCA sequences, which are
18 the AC sequence in * terminology, with the limestone
19 concrete. That means it involved an initial failure
20 of containment spray, and the * until sump temperature
21 reach about 130 degrees for it's core melt, with *
22 containment *.

23 The second sequence is an AHC sequence
24 with also a limestone concrete, with initial failure
25 of * and a failure of containment spray * circulation

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1 water, so it's involved an early core melt and the
2 release through the venting system of the containment
3 ribbing. And the last one is an EC sequence with a
4 siliceous concrete, initial failure of * and
5 containment spray, and due to the choice of siliceous
6 concrete, we have releases through the basement.

7 So as concerns the * of these sequences,
8 we consider that these sequences are * of the last
9 spectrum of sequences considered by the * assessment,
10 because as a * factor which are taken into account,
11 are not the facts that a large break is considered,
12 but is due to other assumptions. The first one is
13 delay before core uncovering, which is due mainly to the
14 delay before * failure, and not to the *. The
15 unavailability of containment spray, the
16 unavailability of steam generator cooling, and not to
17 have the facts that the break is considered in the hot
18 leg.

19 We are also performing complimentary
20 calculations, that means small break and station
21 blackout to confirm the previous ways * calculation.

22 There are two main points amongst others
23 which have been considered and developed in this
24 study. The first one is related to fission product
25 release from the fuel and from * system, and the

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1 second one is *, so I will focus on those two points.

2 So the first one was based on the critical
3 review and the * of available experimental result,
4 again from HEVA-VERCORS experiments, from also HI/VI
5 experiments, from * test, that means PHEBUS-FP, and
6 from TMI-2. And this leads to a selection of
7 recommended values * from the gap, from the core, and
8 at the break of the RCS by a group of experts. So I
9 will give you the conclusion of this group of experts.

10 So the value which have been considered
11 for the gap release, the classical ones, means 5
12 percent for noble gases, and 2 percent for iodine and
13 cesium.

MR. LEAVER: Now where is that
14 -- that's the same number of the --

MR. EVRARD: Yeah. So at the moment of
15 the study, we didn't consider especially high burnup
16 and MOX fuel at that point, but in the proposal * you
17 will see that the main point is the release of iodine
18 and * of iodine, so the release of iodine is
19 considered total from the fuel, so -- and the impact
20 of the Source Term on the environment is *. So I will
21 say that the impact of the high burnup and MOX, seems
22 very limited to these conclusions.

23
24 The release from the fuel inside, from the
25 fuel are the following, so we take 100 percent of the

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1 release for noble gases, also for iodine in burnup.
2 About the same for cesium, and for rubidium, for
3 tellurium, antimony and *. We didn't find any
4 significant release for *. We considered a release of
5 10 percent for strontium which is * release *
6 experiment. About 50 percent for barium. As
7 mentioned by Bernard Clement, the significant
8 difference between the VERCORS and PHEBUS result *
9 maximum value. And we obtained a value of 10 percent
10 of ruthenium, for ruthenium. I think there is a good
11 agreement between PHEBUS and VERCORS for -- in this
12 experiment. 30 percent for ruthenium, again from
13 VERCORS results. 90 percent for molybdenum and
14 technetium, values taken from VERCORS and PHEBUS
15 results. And 10 percent for Lanthanides and europium,
16 and cerium.

17 MR. LEAVER: Certainly, they're much
18 better than TMI. That was -- you mentioned TMI was
19 one of the -- part of your review.

20 MR. EVRARD: Yes.

21 MR. LEAVER: Yeah. And you looked at the
22 number --

23 MR. EVRARD: * The value of * different
24 from lanthanides and europium. And 10 percent for
25 europium and cerium and neptunium, 1 percent for

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1 plutonium, also 10 percent for uranium, and that's
2 all. And to -- during the calculation we * kinetic *,
3 we consider first the release of volatile fission
4 products, between the beginning of core degradation
5 and a point which is an arbitrary fraction of the
6 total interval between the beginning of core
7 degradation and *, and a second release of less
8 volatile fission product between this point and *,
9 which is a very arbitrary assumption. And the
10 continuous release of * material.

11 So as we got the assumption for release
12 fraction at the break, we observed that the experiment
13 there was an important deposit for low volatility
14 fission product near the core. And we made the
15 assumptions that the experimental deposition in
16 VERCORS and so with PHEBUS were envelope of the *
17 deposition in the upper structure of the vessel
18 interactor, because this structure -- the geometry of
19 the structure interactor is much more complicated than
20 in the experimental facility, so we can imagine that
21 the deposit in the reactor will be much higher, so
22 that was the assumption. So the conclusion was that
23 we considered no deposition for * volatilized elements
24 *. Deposited fraction of 30 percent for volatile
25 elements like cesium, rubidium, tellurium, *. A

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1 deposited fraction of 18 percent for element like
2 strontium, barium, ruthenium and so on, and a
3 deposited fraction of 20 percent for uranium. So this
4 means to this result 100 percent for noble gases
5 iodine burnup, about 70 percent for cesium, tellurium,
6 molybdenum and technetium, 10 percent for barium, 6
7 percent for rhodium, 2 percent for * cerium, and .2
8 percent for zirconium, 1 percent for uranium, 2
9 percent for neptunium, .2 for plutonium.

10 MR. KRESS: Is that 1 percent of the total
11 core inventory you're writing?

12 MR. EVRARD: Yes.

13 MR. KRESS: That's a lot of aerosol.

14 MR. LEAVER: It sure is. That's about
15 2,000 pounds of aerosol.

16 MR. EVRARD: In terms of comparison with
17 the assumption of NUREG-1465, so as mentioned before,
18 the * Source Term were assessment concerning severe
19 accident, so no design basis accident, including
20 partial core melting. So we consider in general more
21 higher release fraction for volatile and semi-volatile
22 in our study. As a * we consider * core concrete
23 interaction. The long term in-vessel release have
24 been taken into account in the IPSN, which we consider
25 very, very few deposition in the reactor coolant

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1 system. Particular articles we consider a break in
2 the hot leg so there's no *. And for the moment, we
3 didn't consider the affect of air in the long term.
4 And but I would say that the total release are
5 comparable for a large number of element, so we've
6 tried to provide the result in this table. So if you
7 compare the total release for IPSN Source Term, and
8 the total release in the NUREG-1465, including gap
9 release, early in-vessel, ex-vessel and late in-
10 vessel, that means applicable to severe accidents, we
11 have not so different values except for molybdenum.
12 We have 12 percent and you have .5. For molybdenum
13 and technetium there is a very large difference. We
14 have 70 percent and you have .5.

15 Also, for -- this is for rhodium, I think
16 it's 6 percent against 25, so in term of global
17 release it's not so different. But the particular
18 point * in-vessel release is very different.

19 I also have a view graph about iodine
20 behavior. I don't know if it's very connected to the
21 discussion today. It's up to you if you want to --

22 MR. BOYACK: You might as well show it,
23 yes.

24 MR. SCHAPEROW: Sure, you came all this
25 way.

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1 MR. EVRARD: Okay. So the other main
2 point of the reassessment of Source Term is related to
3 the behavior of iodine, in particular because PHEBUS
4 experiments have shown new * on the behavior of
5 iodine, so I would try to underline * all the main *
6 we have considered in order to reassess the behavior
7 of iodine. So the first point was that we considered
8 that a part of iodine release at the break of the RCS
9 was under * force. As mentioned, it is * FPT-0 and
10 FPT-1 Test, so there are many difficulties * to this
11 application. There's the PHEBUS Test break * cold leg
12 of the reactor, whereas it is located on the hot leg
13 of the RCS in the assessment of Source Term
14 assumptions, so we can try to reconstruct the -- what
15 would happen if the break were in the hot leg from
16 data from PHEBUS, but it was difficult. And there is
17 a complex chemistry in the SCS due to the * release of
18 many * which interact --

19 MR. KRESS: In PHEBUS, the fuel
20 temperature is driven by fissioning.

21 MR. CLEMENT: It depends during *.

22 MR. EVRARD: By fissioning, but during the
23 cladding oxidation there is more chemical power.

24 MR. KRESS: I was wondering what the
25 release of the silver is driven by, since it doesn't

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1 fission, and --

2 MR. CLEMENT: I mean --

3 MR. KRESS: It lags in temperature around
4 in the fuel or --

5 MR. CLEMENT: I mean silverized -- okay.
6 When the silver * phase you've got * slowing down *.

7 MR. KRESS: It fails before the fuel
8 starts releasing?

9 MR. CLEMENT: It fails before, yeah.

10 MR. KRESS: Okay.

11 MR. CLEMENT: It fails, in fact, after the
12 cladding rupture, before the --

13 MR. KRESS: Oh, so there's a gap release
14 but --

15 MR. CLEMENT: Yes. And then it relocates
16 at the given level, it fissions or not, and then it's
17 from its temperature that the vapor pressure of silver
18 * cadmium, and so on is released. It's really a
19 process of * down of materials. It is heated up by
20 the surrounding fuel.

21 MR. EVRARD: So thermodynamic calculation
22 about 700 degrees with a * material show that
23 oxidizing atmosphere * with other components more
24 stable than *, getting to a fraction of iodine under
25 * form equal to a maximum of 2 percent. We did see a

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1 condition representative of reactor condition during
2 most part of * I think too much lower values, so there
3 is an inconsistency between the experimental result
4 and the result from some thermodynamic calculations.

5 MR. KRESS: Why did you choose 700 degrees
6 C?

7 MR. EVRARD: Because it's about the
8 temperature of -- if the break were at the hot leg I
9 think.

10 MR. KRESS: That would be where the break
11 location is.

12 MR. EVRARD: Yes. Yes.

13 MR. KRESS: Okay.

14 MR. EVRARD: And so we considered that the
15 most reasonable assumption was to retain the value
16 again from the FPT-1 experiment, I think 5 percent,
17 which is already a value considered in previous
18 studies, but I think there is a very large * this
19 value, so it's not a very * assumption.

20 The second point is silver-iodine
21 interaction. For the PHEBUS * shows that the silver
22 at the sump was * for iodine. In other respects *
23 show that AgI is highly stable under radiation, so we
24 have considered that iodine was definitely trapped in
25 the * for 900 megawatts, because enough amount of

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1 silver. On the contrary, for 1300 megawatts, there is
2 not enough silver, so the *.

3 As we got * so the -- we consider that the
4 molecular iodine goes to wet painting surfaces and *,
5 and coefficient which is a function of some
6 temperature. Mainly because the molecular iodine
7 transfer into in-gas painted surfaces. That was also
8 an outcome from PHEBUS experiment, so we consider
9 first all the low * function of water temperature, and
10 function of the highest water temperature reached by
11 *.

12 MR. LEAVER In-gas means not wet?

13 MR. CLEMENT In-gas phase --

14 MR. EVRARD: Yes.

15 MR. LEAVER: It means not wet.

16 MR. EVRARD: Painting in the * part of the
17 containment.

18 MR. LEAVER: Okay, but -- all right.
19 Outside of the sump. Yeah. Well, wet could be the --

20 MR. EVRARD: Yes, the first * sump.

21 MR. LEAVER: Wet means the sump?

22 MR. EVRARD: Yes. Okay. More detail. So
23 one important point is organic iodide * by iodine
24 paint interaction, so we consider that the interaction
25 is a predominant way to * organic iodide in our

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1 reactors. There was no *, so we made another view of
2 experimental data, but this data underline * results,
3 so we made very simple assumption. We don't consider
4 any kinetic. We consider a ratio between organic
5 iodide and iodine tracked on paint in the gas phase
6 equivalent to 10 percent at any time. So 10 percent
7 of the molecular iodine which is trapped from the
8 paint is converted into organic iodide. And this is
9 a value of 10 percent or present the * fractile of
10 representative experiment. That's a conservative *.

11 This is a picture of the result of
12 representative experiment on this formation of organic
13 iodide by venting, and so we consider it a value of 10
14 percent which is the -- in the upper part of the cloud
15 of points.

16 As concerns the 1900 megawatts, we
17 consider the organic iodide * by homogenous reaction
18 between molecular iodine and Methane. So in this
19 reactor the * loads are partly made with boron carbide
20 so they could produce * during the oxidation of boron
21 carbide. So in this one also there are *, so in the
22 study it's been assumed that all the carbon was
23 converted into *. So when we consider this
24 assumption, estimated * of * and iodine, * 10 to the
25 minus 4, and 5, 10 to the minus 8 mole per liter.

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1 Under this condition * indicated that about 5 percent
2 of iodine could be converted into organic iodide.
3 Okay. This is a value which I didn't consider.

4 Another point is absorption into concrete
5 in the annulus space between the inner wall and the
6 outer wall of the containment for 1900 megawatts
7 because on this reactor there is a double containment.
8 This is a part also which has to be considered, so the
9 volatile iodine may be in contact with the bare
10 concrete of the annulus space. And so there is no
11 result on this *, so we consider that there was no
12 action with concrete of iodine.

13 MR. POWERS: Most concretes when they are
14 placed are placed with both an air entraining agent
15 and a curing compound on top. Both of those were
16 organic, and they are unsaturated organics. In a
17 radiolytic environment, wouldn't one expect the iodine
18 to react with those organics?

19 MR. CLEMENT: (Translating into French).

20 MR. EVRARD: Okay. So I would just give
21 the * of this study. So for long term containment,
22 which I'm taking into account * of aerosol in
23 molecular iodine by the * venting system, or the soil.
24 Short term radiological impact is mainly due to the
25 organic iodide, and produced by the *. But the amount

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1 of organic iodide released is of the same order * S-3
2 Source Term, so we found that they were the same *
3 fraction of a percent released, but the mechanism
4 which have been considered on the iodine * are quite
5 different than those which have been considered 20
6 years ago, so maybe *.

7 The assumption made for iodine * seems
8 conservative, and for the radiation * program, like
9 PHEBUS-FP, but also experiments on * CAIMAN, CHIP and
10 EPICUR. There was * amount of aerosol released from
11 the containment in the severe accident has been
12 largely reduced by a factor of 10 to 100, and this is
13 mainly due to the implementation of pre-filter in the
14 * venting system, so the long term impact of severe
15 accident is, therefore, largely reduced with these new
16 assumptions. That concludes my presentation.

17 MR. BOYACK: Probably what we ought to do
18 is if there any comments, we ought to pick those up
19 after lunch. What I propose to do is this, if you
20 could have somebody bring us back up at 20 after 1.

21 MR. SCHAPEROW: All right.

22 MR. BOYACK: And that means for sure we
23 can get started by 1:30 on our discussions, but you'll
24 need to have somebody shepherd us up.

25 MR. SCHAPEROW: Yeah. Okay. I'll be

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1 there. I'll be downstairs in the lobby at 1:20. I
2 want to reiterate what the security procedures are for
3 people.

4 MR. BOYACK: Yes.

5 MR. SCHAPEROW: I think especially Bernard
6 and Jean-Michel might not be familiar with them.

7 MR. BOYACK: The real key here is that
8 once you get in the elevator space, from any place on
9 that we have to be escorted, so somebody will take us
10 downstairs. There is a cafeteria downstairs on the
11 first floor. We can eat there, stay in the lunchroom,
12 but as soon as we come in from the lunchroom back into
13 the elevator space, we have to be escorted. And we'll
14 be picked up again at 20 after 1:00, and brought back
15 up to this room.

16 MR. SCHAPEROW: Yes. And there are
17 restrooms right at the other end of the elevator in
18 the lobby right here. Every floor has got restrooms
19 next to the elevators.

20 MR. BOYACK: Okay. So we'll come back.

21 (Whereupon, the proceedings went off the
22 record at 12:39 p.m. and went back on the record at
23 1:33 p.m.)

24

25

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(1:33 p.m.)

MR. BOYACK: Okay. Let's resume, and Ralph Meyer is going to talk to us about burnup fuel.

MR. TINKLER: Hey, Brent, I'd like to ask a question regarding the French presentation of Mr. Evrard. You talked about the contribution to organic iodide from paints, and I'm just trying to understand a little better about the situation with paints in the French reactors. These epoxy, these organic paints, is it primarily painting on the containment wall itself that's the paint of interest in this particular inventory?

MR. EVRARD: It's the painting on the concrete wall.

MR. TINKLER: Is it all containment, the containment building, or all interior walls, or all of the above?

MR. CLEMENT: I think it's on all the walls. I remember when we make the scaling factor for the Federal simulation of containment vessel --

MR. TINKLER: Right.

MR. CLEMENT: -- we have introduced this part of painted surface on which there is condensation, but we have also introduced one part on

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1 which we don't have condensation, just *, and you are
2 not condensing the steam on all the surfaces of the
3 containment, so * --

4 MR. LEAVER: You have steel lined
5 containment.

6 MR. CLEMENT: On the 900 --

7 MR. TINKLER: No.

8 MR. LEAVER: You do not.

9 MR. TINKLER: Well, the 1300 megawatts are
10 online.

11 MR. CLEMENT: On the 1300 there is
12 no --

13 MR. TINKLER: Right. Well, 900
14 already --

15 MR. LEAVER: Okay.

16 MR. TINKLER: That's why I was wondering
17 whether it was --

18 MR. LEAVER: Even on the 900 you've got,
19 obviously, interior --

20 MR. TINKLER: Yeah. And there's less need
21 to coat those surfaces than there is on the unlined
22 internal surface.

23 MR. CLEMENT: In fact, * designed at that
24 time and tested for what we call in France, design
25 basis accident.

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1 MR. TINKLER: Right.

2 MR. CLEMENT: So that * moderate Source
3 Term base * with the contamination of the paint, so I
4 think everything is -- on internal *.

5 MR. TINKLER: And I know you're also
6 looking at polymeric liners on the inside of the 1300
7 megawatt reactors too, the same issue. Okay.

8 MR. MEYER: Okay. Ready to go?

9 MR. BOYACK: We are ready to go, Ralph.
10 Thank you.

11 MR. MEYER: I want to go over some
12 features of high burnup fuel both in the design and
13 the operation that could have some impact on Source
14 Term, but I will say right up front that having gone
15 through this and thought about it, my own conclusion
16 is that there's not likely going to be much of an
17 affect of burnup on the Source Term. And you don't
18 have to take that at face value, but I just show you
19 were sometimes, you know, you --

20 MR. KRESS: We can go home now.

21 MR. MEYER: You give the conclusion up
22 front, and then you get back to the conclusion at the
23 end, so how I'm going to try and do this is by looking
24 at a few things. First, just to mention a few aspects
25 of the design, because there have been some changes in

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1 the fuel design in order to reach the higher burnups.
2 And then show you some results of some calculations,
3 look at some micrographs of high burnup and not so
4 high burnup fuel, and then a couple of concluding
5 comments about possible impact on the Source Term.

6 In designing fuel rods for high burnup,
7 several things have changed, and I have a couple of
8 slides with numbers on them. But the cladding for
9 PWRs has largely changed now from straight Zircaloy to
10 zirconium alloy with some niobium in it, and sometimes
11 also some tin. Zirlo is being supplied now exclusive
12 -- I mean, it's all that Westinghouse is supplying.
13 They're not supplying -- did I say Zircaloy? I meant
14 Zirlo. Zirlo is now the entire product line of
15 Westinghouse, and Framatome has introduced M5 here in
16 the U.S.

17 In addition to that, I want to mention
18 the plenum size because plenum volumes have increased
19 quite a lot. And we've seen plenum lengths ranging
20 from 5 inches to 15 inches, really large plenum
21 volumes. And I would say that the plenum volume and
22 the fill pressure which are -- work together as design
23 variables to make sure that at end of life the rod
24 pressure is not too high in relation to system
25 pressure. So plenum volume and fill pressure you can

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1 think of as designer variables. I mean, they change
2 all the time, just depending on what particular core
3 they're trying to fit, so there is no single value of
4 plenum volume of fill pressure which are going to have
5 an affect on something important to us at high burnup.
6 Those change quite a bit.

7 The -- I put this in so you have it in
8 your handout. This shows the composition of several
9 cladding alloys, Zircaloy, Zirlo and M5, along with
10 two Russian alloys, Alloy E-110, which is the standard
11 VVER cladding that's been used for years in Russia, is
12 very similar in its basic composition to M5. And
13 alloy E-635 is a Russian alloy that is not used,
14 although has been under development for many years in
15 Russia, and it's similar in composition to Zirlo.

16 I looked to see if absorber materials were
17 changing much, and there's not a lot here in terms of
18 change. Of course, concentration in amounts of
19 burnable poisons have increased. The BWR fuel
20 generally use gadolinium, urania gadolinium, mixture
21 right in the fuel, and those concentrations are now
22 approaching 10 percent gadolinium. There's still in
23 the PWR silveranium cadmium is still used as a main
24 control rod ingredient. There had been hafnium rods
25 that Westinghouse introduced some years ago, and

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1 they've discontinued that, so I don't know if you
2 would find any or not, but certainly in terms of
3 thinking about what's going to be in the chemical soup
4 down there, hafnium control rods is not in the picture
5 any longer.

6 There are a number of control rods, as we
7 saw in the earlier presentation, and PWRs, which is
8 principally silverinium cadmium with some B₄C also in
9 the same rod, just as a sort of axially zoned absorber
10 material.

11 Westinghouse has used pyrex glass and B₄C
12 in burnable absorber assemblies, and more recently,
13 they have begun using burnable absorbers right in the
14 fuel rods, but unlike in the BWR case. This is a
15 coating of boron, zirconium bolide, I guess, on the
16 idea of cladding to form an integral fuel burnable
17 absorber. But, you know, there's already boron
18 around.

19 There's an erbium absorber that's being
20 tried out now, as sort of a substitute for a
21 gadolinium absorber. I mean, it's mixed right in with
22 the fuel, and takes lower concentrations of erbium to
23 do the same job that the gadolinium does, so you might
24 find a little erbium in the soup.

25 By and large, I think you have from the

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1 absorber materials, the same materials that you
2 thought you had before. A lot of silverinium, cadmium
3 in PWRs, and gadolinium in BWRs.

4 These pretty pictures come from a report
5 that we're about to publish. We had a summer student,
6 as we did a lot of calculations with FRAPCON last
7 summer, and we've written a report with a lot of
8 typical design information about PWRs and BWRs in the
9 U.S., along with these calculations. And we're about
10 ready to publish it, and that's where these figures
11 come from. And the only point I wish to make from
12 this figure is that in the BWRs, as we've moved to
13 longer cycles and higher burnups, the larger rods in
14 the smaller arrays have disappeared in favor of some
15 smaller rods. There are no more seven by sevens.
16 Eight by eights are on the way out. Most of the BWR
17 fuel is nine by nine, and ten by ten. And just as a
18 point of calibration, we found as we were going
19 through and looking up all of these properties this
20 summer, that BWR nine by nine fuel rod is virtually
21 identical to a PWR fifteen by fifteen fuel rod.

22 In fact, one manufacturer, we could tell
23 by looking at the numbers, is using the same cladding
24 to the same pellets in the two products. But this is
25 useful in terms of trying to bring these two

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1 populations together in your mind, because they are
2 very similar.

3 In the PWRs, there's essentially no
4 change. PWRs are pretty much stuck with the geometry
5 that they originally chose for the plant. It would be
6 a big effort to redesign, or to refabricate control
7 assemblies where you slip the rods around a little in
8 order to accommodate a different geometry.

9 MR. POWERS: Could you change their heads?
10 Is that going to get revisited?

11 MR. MEYER: Well, that's an interesting
12 question. I know that BNW, in fact, had some, at
13 least conceptually, plans to convert fifteen by
14 fifteens to seventeen by seventeens. As to whether
15 any of these BNW Plants with the new heads would make
16 that change, I have no idea. I've heard nothing on
17 that score. It's possible, but no one is talking
18 about it.

19 So then quickly to summarize the design
20 changes, large plenum volumes chosen along with fill
21 pressures in order to have operating fuel rod
22 pressures that are not much above the reactor system
23 pressure. New cladding alloys for PWRs, some but not
24 much change in control materials, and small diameter
25 fuel rods in BWRs.

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1 Now some of those design changes will have
2 significant affect on the loss of coolant accident,
3 which you're interested in. During the design basis
4 part of the event where we're looking mechanistically
5 at the behavior of things, and so I'm not suggesting
6 that these changes in features that I'm going to talk
7 about don't have an affect on the accident behavior.
8 But when it comes down to getting the Source Term
9 itself, is where I question whether these changes are
10 going to have a big affect.

11 Okay. Now let me run through a few of the
12 calculations, and I'm not going to go into any great
13 detail, but I will tell you that the two sets of
14 calculations that I will show you were fuel rods that
15 started out at 9 kilowatts per foot, and then ran at
16 a constant power of 9 kilowatts per foot out to, in
17 this case, 50 gigawatt days per ton. You see the
18 point right there where the center line fuel
19 temperature starts dropping off, is where the power
20 started ramping down to an end point of 5 kilowatts
21 per foot.

22 We had to ramp the power down at some
23 point in the cycle, because with the given enrichment,
24 and our constraint of completing the lifetime in
25 approximately four years, resulted in this scheme.

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1 And it's just a scheme that we adopted, but it's a
2 fairly typical one that's used for a lot of
3 calculations. So what you see here, the features that
4 you see, and I don't need to belabor these, but this
5 first peak in temperature is a fuel densification
6 peak, and then as the fuel density stabilizes and fuel
7 swelling starts to expand out and fill up the gap, you
8 eventually close the gap, and gap closure occurs about
9 here. And now temperature starts increasing again as
10 the thermal conductivity degrades, so these -- there's
11 a lot of wiggles to these curves. And if you go back
12 and look at the phenomena that occurring during normal
13 operation, then you can understand most of these.

14 The one point that I want to make from
15 this slide to remember again is that the maximum
16 temperature, and maximum stored energy may not occur
17 at beginning of life. You see, there's a second peak.
18 Now in this particular case, it's a little lower.
19 Well, this one isn't. This temperature is a little
20 higher than the initial temperature. This is the
21 stored energy which you use in a LOCA calculation, and
22 it looks like the stored energy is not quite high as
23 the first peak, but this is just one calculation at 9
24 kilowatts per foot. And so, the point is that there's
25 a lot of burnable poison used that holds down initial

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1 reactivity, and so peak power can occur much later in
2 cycle than beginning of life.

3 It used to be we just assumed everything
4 was limiting at beginning of life, and you can't make
5 that assumption safely with these high burnup fuels.

6 MR. POWERS: We hear interest among the
7 PWR community in trying to achieve the same kinds of
8 proper upgrades that are going on in the BWR
9 community. If -- I mean, the strategy on that is very
10 unclear right now, I'll admit, but do you think that
11 they will be operating at higher linear heating rates
12 than this 9 kilowatts that you've quoted here?

13 MR. MEYER: Well, 9 kilowatts per foot is
14 not a limit. It's only a number that I picked for
15 this illustration. The -- I think in the PWRs,
16 they're limiting, or their heat rates are controlled
17 by the loss of coolant accident analysis, and the only
18 way that I can see that that would increase is if you
19 found some way to reduce the prediction of peak
20 cladding temperatures in your LOCA analysis. And
21 this, of course, is one reason why there had been such
22 keen interest in Risk Informing 50.46, and making
23 other changes which may not come to pass. But, I
24 mean, that's the source of the interest in that.

25 I don't necessarily see -- I don't see any

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1 increase. I mean, you're asking me for an opinion.
2 My opinion is I don't see any big increase in linear
3 heat rate coming for either the Ps or the Bs. The
4 trend, in fact, has been to bring down the linear heat
5 rate, particularly in the Bs, by going to more and
6 more rods in a bundle. You can get the assembly
7 power, the bundle power up, but the individual rod
8 heat rate is down.

9 This is fission gas release and rod
10 internal pressure for that same PWR calculation. The
11 -- if you start looking at every wiggle in the fission
12 gas release curves, you're going to go crazy on this.
13 But I'll tell you that this model has some thresholds
14 in it, and this sharp increase at this burnup
15 corresponds to hitting one of those thresholds in the
16 gas release model.

17 MR. POWERS: Which model was used to
18 calculate this?

19 MR. MEYER: This is a model, I think, they
20 call the MASSIH Model. I, personally, don't know a
21 lot about the model. I think it's a bunch of things.
22 I'm going to unkindly say plugged together, because
23 you're going to see some really strange behavior in
24 the BWR calculation on the fission gas release. But
25 the thing that I do know is the people who put this

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1 together are sitting on top of tons of fission gas
2 data, largely from Halden, but from other places, and
3 they see these funny features that are threshold
4 effects. You don't get anything out until you reach
5 the tons of temperature, and it starts kicking up
6 really well. There is some pressure sensitivity so
7 that the difference in pressure between the PWR --
8 system pressure between the PWR and the BWR, because
9 the rod pressure is adjusted to the system pressure,
10 has an affect, so that you don't see, even for the
11 same temperature in calculations for a B and a P, you
12 don't see exactly the same fission gas behavior. But
13 I do believe the model, in spite of its rather
14 unsophisticated final appearance, is well calibrated.

15 MR. POWERS: That's -- I mean, that
16 fundamentally is the challenge, that you can calibrate
17 these things with extremely simplified physics in
18 them.

19 MR. MEYER: Yes.

20 MR. POWERS: And in fact, we use them all
21 the time. And we've essentially -- same bubbles
22 exist, and then -- but don't do anything.

23 MR. MEYER: Yeah.

24 MR. POWERS: And that seems to raise
25 questions, does one indeed reach thresholds of burnup

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1 where this neglected physics suddenly turns on, and it
2 would affect up or down the final numbers that you're
3 giving.

4 MR. MEYER: Well, this threshold is not a
5 burnup threshold. I think it's a temperature
6 threshold.

7 MR. POWERS: Yeah, but they're a function
8 of --

9 MR. MEYER: It's a function of other
10 things. The comfort that you should take here is that
11 the test program that's cranking out these data is
12 well ahead of industry burnups, taking data up in the
13 range of 100 gigawatt day per ton fuel rods.

14 MR. LEAVER: Whose test program is this?

15 MR. MEYER: This is Halden.

16 MR. LEAVER: In Norway?

17 MR. MEYER: Yeah, that's it.

18 MR. LEAVER: Is the NRC helping to fund
19 that, or have some involvement in it in any way?

20 MR. MEYER: Yeah. Two -- well, several
21 U.S. organizations are members or associate members.
22 The NRC is a full member. We pay a big fee annually
23 to support a large joint program. EPRI is an
24 associate member. Westinghouse has taken over CE's
25 associate membership, and I think Global Nuclear Fuels

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1 has taken over GE's associate membership under the
2 fuels part of GE.

3 MR. LEAVER: So this is to measure -- at
4 least some of the tests are designed to measure
5 specifically these kinds of affects in Lightwater
6 Reactor fuel like we burn in the United States?

7 MR. MEYER: Yes. Yes. Absolutely.

8 Now this is a calculation of oxide
9 thickness that was also a burnup at three elevations
10 in this same case. I don't want to pretend that we
11 can do straight up calculations of oxide thickness
12 because we're using an older simplified EPRI model
13 that doesn't have enough parameters in it to really
14 accommodate variations in water chemistry and all
15 kinds of things, but it calculates ball park numbers,
16 and it shows a trend that I want to show here.

17 First of all, there is a strong increase
18 as you go from the bottom of the core to the top of
19 the core because temperatures in the PWR core are
20 increasing. And of course, there's an increase in
21 time as you go out in burnup. For calibration, the HP
22 Robinson Fuel that we received this year at Argonne in
23 our test program, has a maximum oxide thickness of
24 about 110 microns, which is a little off-scale on this
25 figure. And it has a burnup of 72 gigawatt days per

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1 ton, so that point is somewhere up here.

2 I also have -- this is kind of interesting
3 and fairly recent. This is actual profile of oxide
4 thickness in a Zirlo clad fuel rod that is going to be
5 tested in Cabri next spring. It's a rod that has a
6 burnup. I think the burnup here is about 73 gigawatt
7 days per ton, and it was a Zirlo rod manufactured by
8 ENUSA in Spain, and burned in the Van Deos plant. And
9 so you see peak oxide thickness, even in this Zirlo
10 rod, of 100 microns.

11 Now everyone in the industry would say
12 well, gee, this is pretty high for a Zirlo rod. We
13 don't expect most of them to be up that high, but the
14 point is, you can get substantial oxidation on Zirlo,
15 as well as on Zircaloy.

16 Now the BWR is a little different. I'm
17 showing here the same 9 kilowatt per foot series for
18 the BWR, just sort of a match to the PWR one that I
19 showed. It -- okay. So it's -- in this calculation
20 the power starts down at 40 gigawatt days per ton
21 instead of 50, that's a difference. That was input so
22 here's the fission gas model which is -- it's very
23 hard to understand all of the features of this result,
24 but you see the number is in the right ball park. But
25 one thing you're going to notice here is that the fuel

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1 rod pressure in the BWR didn't drop off when the power
2 dropped off, because in the boiling water reactor, the
3 local temperatures are not a function of the local
4 power. It's boiling more or less at a constant
5 temperature, so the burnup temperature stays up there.
6 And also, in the boiling water reactor, for that
7 reason, there is very little axial grading in oxide
8 thickness. It's at least in the range that we plotted
9 here for two and a half feet from the bottom to nine
10 and a half feet from the bottom. The temperature was
11 nearly constant and produced the same oxidation level.

12 It's also rather lower than in the boiling
13 water reactor. We have a fairly high value calculated
14 here, but that really is just the way we set the
15 calculation up. We have Limerick rods up at Argonne,
16 and the Limerick rods have a burnup of about 57
17 gigawatt days per ton, and a maximum oxide thickness
18 of only about 10 microns.

19 So the observations that I thought might
20 be relevant to Source Term considerations were that
21 the peak power can occur later in life. The gas
22 release, which I'll call here the gap release, does
23 show a strong burnup enhancement. In the examples I
24 show, the rod pressure did not exceed the system
25 pressure, but in higher power calculations that we ran

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1 it did exceed system pressure. And also, cladding
2 oxidation at the top of the core in PWRs can be very
3 high, but in BWRs it's relatively low at all
4 elevations.

5 Now I want to look at a few
6 microstructures, and I don't want to spend too much
7 time on these, but I think there are a couple of
8 interesting things to see.

9 This is a Surry rod at 36 gigawatt days
10 per ton, and I'm going to say that this rod looks like
11 a low burnup fuel rod. And I have two charts to show
12 here. The fuel has no major change in microstructure.
13 It's pretty uniform all the way across. It's got big
14 cracks in the fuel pellet. And if you look more
15 closely at the gap between the cladding and the
16 pellet, now in this, the cladding is the light colored
17 phase, and the pellet is over here. This dark gray
18 area here is, in fact, an open gap. There's a very
19 small amount of oxide, zirconium oxide on the ID of
20 the cladding, but not much, and the gap is open.

21 Now the rest of the micrographs that I'm
22 going to show --

23 MR. LEAVER: When you say -- Ralph, you
24 say the gap is open?

25 MR. MEYER: This is the gap. Now you

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1 can't tell from looking at that gray area there that
2 that's open, but we can tell by going in with a
3 microprobe or a scanning microscope that there's
4 nothing there. That's just filled up with epoxy melt
5 from the metalography melt.

6 I'm going to show you some others where
7 it's not open. Now that was at 36 gigawatt days per
8 ton, and this one is just 50, so we've just gone from
9 roughly 40 to 50 gigawatt days per ton, and now we
10 have a fuel rod that looks like a high burnup fuel
11 rod. It still has the large pellet fragments, but
12 it's developing a porous rim. And I'm going to show
13 you now the same fuel rod closer up, and see what we
14 can tell from this.

15 Okay. Start on this side. This is the
16 fuel, and this is the rim region. It has a lot of
17 fine porosity compared to over here toward the center
18 of the fuel where the pores would be larger and less
19 dense. The cladding is the light region in the
20 picture, and this gray phase in between is, in fact,
21 zirconium oxide. And it's all stuck together. It's
22 bonded to the cladding, so you've got this porous rim
23 structure on the pellet, a heavy layer of zirconium
24 oxide, and then the zirconium cladding stuck together.

25 Here is another similar view. The

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1 interesting thing here is that when the fuel cooled
2 down, you know, the pellet is going to shrink more
3 than the cladding, and so you have to open up some
4 open space, and it actually cracked the rim to
5 accommodate the shrinkage, so the shrinkage in these
6 high burnup fuel rods on cool down is accommodated by
7 opening up the gaps between these big pellet
8 fragments, or creating some new fragments in the
9 pellet, because the pieces of fuel out by the cladding
10 are bonded very strongly to the cladding. And I can
11 just say as a practical matter that in the laboratory
12 when we try and defuel a piece of cladding, it's
13 virtually impossible.

14 You can't do it mechanically. We drill
15 out the bulk of the fuel, and then etch the rest of it
16 with -- I don't know what, nitric acid or something.
17 Why doesn't it eat the cladding? I -- well, tell me,
18 Chemist Dana, what do we -- how do we pull this off?
19 We dissolve UO₂ without touching the zirconium.

20 MR. POWERS: You want to dissolve the UO₂
21 without touching the zirconium?

22 MR. MEYER: Yeah.

23 MR. POWERS: Well, nitric acid with a
24 small trace of oxidant like an iron would do it for
25 you.

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1 MR. MEYER: Okay. Then that's what we
2 use.

3 MR. POWERS: You don't mind etching the
4 clad a little bit, a little HF helps.

5 MR. MEYER: This is the Limerick fuel.
6 It's 57 gigawatt days per ton. There's some things I
7 could point out from this microstructure that I think
8 I'm not going to bother with, because you can -- if
9 you stare at this one, you begin -- you can see some
10 rim structures in here. This one is beginning to
11 restructure a little.

12 Remember the old LMFBR fuels, you get a
13 central hole, and a columnar grain region, and equiax
14 grain region. Well, this is starting, just barely
15 started to restructure. And in this case, it's not
16 quite centered.

17 MR. KRESS: All your grains are square.

18 MR. MEYER: It's a --

19 MR. POWERS: Those are blocks. We're
20 going to give you --

21 MR. MEYER: It's a body centric cubic
22 material.

23 MR. POWERS: Good answer.

24 MR. MEYER: Yeah. Okay. Here's a closer
25 view that shows a lot of these micro cracks near the

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1 surface where it's shrinking --

2 MR. LEAVER: What's the burnup on this?

3 MR. MEYER: 57 gigawatt days per ton. And
4 a third one. This is showing the microstructural
5 changes across the radius. I don't think that they're
6 particularly interesting. And again, out near the
7 cladding, here is a tightly bonded fuel with
8 essentially no zirc oxide in the gap. You remember,
9 the BWR cladding doesn't oxidize very much on the
10 outside, and it doesn't oxidize very much on the
11 inside, but it still is bonded to the pellet.

12 And then finally, we found this picture
13 from a Halden report, that shows close porosity on one
14 face, and interlinked porosity on the other face.
15 It's like how does it do that, but this is the
16 evolution from that at high burnup where the pores
17 link together, and create the easier pathways for
18 migration of the fission gases to a free surface.

19 Okay. So in summary, the high burnup
20 affects begin to appear in the 40 or 50 gigawatt day
21 per ton range. There's tight bonding between the
22 pellets and the cladding. The outer regions of the
23 fuel pellet is porous. This is the rim region. It's
24 gassy. It's got micro cracks in it. There's a lot of
25 oxidation in the PWR fuel, but little in the BWR. And

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1 the porosity becomes interlinked at high burnups.

2 Now you wanted to focus on the loss of
3 coolant accident, and I didn't prepare a lot on that,
4 but if you want to talk about cladding behavior during
5 loss of coolant accident, we can do that. I think
6 there's a limit to the relevance of that to Source
7 Term. And let me just go over this very crudely.

8 During the loss of coolant accident, you
9 have a high temperature transient. The cladding
10 balloons and bursts at a relatively low temperature,
11 around 850 or 900 degrees Centigrade. We expect that
12 this tight bonding between the cladding and the pellet
13 is going to affect the ballooning deformation, and
14 we're about to test that at Argonne, but haven't yet
15 run such tests, so I can't say for sure at that time,
16 but it's very likely that that burnup affect will have
17 a big affect on the ballooning process.

18 MR. POWERS: Would it be relative to the
19 temperature you expect the clad to balloon and burst
20 is the monocladic tetragonal phase change at zero
21 to --

22 MR. MEYER: I've -- it's -- I'm pretty
23 sure it's entirely in the lower temperature, one of
24 those. Which is which?

25 MR. POWERS: The monocladic.

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1 MR. MEYER: Okay. Because I -- Harold,
2 you may recall. I think the other one occurs at like
3 1600.

4 MR. SCOTT: It sounds high, but I can't
5 remember right now.

6 MR. MEYER: Yeah. I think it is. It's
7 higher than this. This is occurring right smack in
8 the middle of the phase transformation in the metal,
9 in the Zircaloy, or the Zirlo or the M5, but I didn't
10 check the oxide number.

11 MR. POWERS: When we go through the
12 monoclinic and tetragonal for the clad that is
13 oxidized on the inside, so you have a distinct ZrO₂
14 region. You're not working with some cubic solution,
15 won't it delaminate at that point?

16 MR. MEYER: I don't know. But again, I
17 doubt that it makes any difference for the following
18 reason. What you probably have in mind is the affect
19 that this oxide coating has on the oxidation rate.

20 MR. POWERS: No, I'm strictly thinking in
21 terms of your bonding.

22 MR. MEYER: Yeah.

23 MR. POWERS: And when I go through this
24 phase change which is a densification phase change,
25 something's got to give. And the place to give, given

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1 the nature of the phase change, is that it's going to
2 shatter the grains of the zirconium that's going to
3 amount to a delamination.

4 MR. MEYER: Yes. And what's the
5 consequence?

6 MR. POWERS: Well, now we have a
7 continuous flow path from the top to the bottom of the
8 rod at the periphery, just like we've always assumed
9 it would be.

10 MR. MEYER: You're talking about internal
11 gas communication?

12 MR. POWERS: Yeah.

13 MR. MEYER: Yeah. We kind of expect that
14 during the ballooning deformation, that we may open up
15 some gas communication.

16 MR. POWERS: If you don't balloon because
17 of the bonding, then the ballooning just occurs later
18 in time when you go through the phase change, wouldn't
19 it?

20 MR. MEYER: No, I don't think so. I think
21 the -- I thought you might get on this subject so I
22 went quickly and pulled out some other things.

23 Basically, what we have here is plastic
24 instability that occurs right at the point of the
25 uniform elongation.

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1 MR. POWERS: That's in the metal.

2 MR. MEYER: In the metal.

3 MR. POWERS: I mean the --

4 MR. MEYER: I thought -- I just don't see
5 where you're going with this. What --

6 MR. POWERS: We've got zero UO2 layer.

7 MR. MEYER: Yeah.

8 MR. POWERS: -- between the clad and the
9 UO2.

10 MR. MEYER: Yeah.

11 MR. POWERS: It's tightly bonded because
12 --

13 MR. MEYER: Okay.

14 MR. POWERS: -- there's a nice solid
15 solution between the UO2 and the zirconium.

16 MR. MEYER: Yeah.

17 MR. POWERS: Okay. Now I take the
18 zirconium off, and I go through a phase change which
19 changes the molecular volume.

20 MR. MEYER: Uh-huh.

21 MR. POWERS: Okay. And in particular, the
22 densification. Okay. Something -- either we're going
23 to put this oxide under incredible tensile strength,
24 or it's going to fracture.

25 MR. MEYER: Yeah.

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1 MR. POWERS: At that point, don't you
2 delaminate the clad from the fuel pellet?

3 MR. SCOTT: The distance might be --

4 MR. MEYER: But what's -- okay.

5 MR. POWERS: It's going to be equal to the
6 volume change.

7 MR. MEYER: But I mean, bursting happened
8 600 degrees earlier, and peak cladding temperature
9 came 400 degrees earlier or 200, whatever the number
10 was. I mean, you're way out there. You have no
11 pressure containment in the rod any longer. It's
12 already vented.

13 MR. POWERS: Sure. Now how can it vent?

14 MR. MEYER: It ruptures in the range of 8
15 to 900 Centigrade.

16 MR. POWERS: I've got a big gas volume up
17 here.

18 MR. MEYER: Yeah.

19 MR. POWERS: I've got an incredibly high
20 resistance, full pathway to where your burst is.

21 MR. MEYER: Okay. Well, I know there's a
22 flow resistance, but I don't think the resistance is
23 infinite.

24 MR. POWERS: Do you have perfect
25 communication?

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1 MR. MEYER: What?

2 MR. POWERS: Do you have perfect
3 communication?

4 MR. MEYER: No, but we don't have zero
5 communication, and so I think all we need is one hole
6 in the cladding, and it will vent.

7 MR. POWERS: That's pretty much zero
8 resistance, isn't it?

9 MR. MEYER: It's just not infinite
10 resistance. It's any resistance but infinite. This
11 is a long term transient. It's going to sit up there
12 for minutes before the temperature sails up to the
13 temperature where the oxide is going to change face.
14 Maybe more -- maybe tens of minutes. I don't have my
15 time scale here. Can you help me out, Harold?

16 MR. SCOTT: Minutes?

17 MR. MEYER: From the time you -- well,
18 you're in a severe accident now, and you have to tell
19 me how long it takes because the design basis accident
20 is going to be over by design when we get 17 percent
21 oxidation, or thereabouts, at 1200 Centigrade. And at
22 this point, it's been there a long time, to accumulate
23 that amount of oxidation minutes, and it ruptured at
24 850, plus or minus 50 degrees C, and somehow now a
25 severe accident is going to develop. You're going to

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1 fail to cool and quench, and the temperature is going
2 to go on up. I think by that time, it almost
3 certainly have no pressurized rods remain.

4 MR. POWERS: Why is that?

5 MR. MEYER: Huh?

6 MR. POWERS: I'm still lost. Why is it
7 not still pressurized?

8 MR. MEYER: They all burst.

9 MR. POWERS: It broke down here. You got
10 a high resistance flow pathway to a plenum up here.

11 MR. BOYACK: You two have different
12 perspectives. You say it's got resistance, therefore
13 it will pressurize very slowly or not at all. Ralph
14 feels like it's porous enough or the cracks are such
15 that the resistance path isn't all that --

16 MR. MEYER: If it's a high resistance,
17 it's still going to leak, just as long as the
18 resistance isn't infinite.

19 MR. POWERS: The timing, the --

20 MR. MEYER: Got a long period of time.

21 MR. POWERS: Somehow I guess I'm missing
22 your point. What difference does it make that the
23 clad is bonded to the fuel?

24 MR. MEYER: It's going to make a big
25 difference in terms of the design basis LOCA

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1 calculation.

2 MR. POWERS: How so?

3 MR. MEYER: Because it's going to affect
4 the strain. I mean, this is hypothesis now because we
5 -- the test hasn't been run, but I'm pretty sure that
6 these rods are not going to balloon with this large
7 ballooning strain that you get for cladding where
8 there is no bonding. And so, the ballooning strain is
9 used in the analysis to calculate a flow area
10 reduction for the thermal hydraulic calculation, and
11 that will be different.

12 Now when it comes -- when you go beyond
13 this and you get into a severe accident, then I don't
14 see the relevance of this type bonding. It's just
15 stuff that's going to melt.

16 MR. POWERS: Because right now there is an
17 enormous amount of problem for us if there's no flow
18 path, because then the only release we're getting it
19 down around the location until such time as we get rid
20 of the clad.

21 MR. MEYER: This is the -- I think this is
22 the only place you're going to get the gap release, is
23 from that single point of rupture.

24 MR. POWERS: Well, I think maybe you
25 changed the definition what you mean by gap release

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1 when you changed the timing on the rod. But even more
2 than that, between the temperature of the rupture and
3 the temperature I bust my clad open broadly, I need a
4 pathway to get release out of the thing if it's
5 bonded.

6 MR. MEYER: It --

7 MR. POWERS: There's no way to get fission
8 products out, transport down along the gap is zip,
9 unless I rupture it.

10 MR. GIESEKE: This -- each of you guys
11 give me a number. We're going to fail the cladding,
12 and I'm just going to say there's zero pressure
13 outside. How long does it take for that rod to be
14 pressurized?

15 MR. MEYER: I'm going to give you a
16 number, a minute.

17 MR. GIESEKE: A minute? See he's saying
18 that fast.

19 MR. POWERS: Yeah, that's essentially an
20 open gap.

21 MR. GIESEKE: So you're talking the same
22 as the gap.

23 MR. POWERS: Yeah.

24 MR. GIESEKE: See, that's why you guys
25 aren't understanding each other. You're saying it's

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1 going to go slower than that, I think.

2 MR. KRESS: If he pressurized it quickly,
3 I don't see how the bonding affects the strain.

4 MR. MEYER: Well, the strain, the
5 ballooning strain, that happens very quickly. I mean,
6 the ballooning strain happens -- the strain happens
7 before the burst.

8 MR. LEAVER: He's saying that the bonding
9 is going to reduce or delay the -- hold it together.

10 MR. KRESS: He's pulling the clad out.

11 MR. LEAVER: Exactly. You strain it.

12 MR. KRESS: But if the gas can get down
13 there that fast, that's not -- that bond is not going
14 to help much. It's fighting against the gas pressure
15 is what it's doing, and I think the gas pressure is
16 going to just come down to it, strains and all. It's
17 like tearing something loose. You've got a crack
18 you're driving up, and that gas pressure is going to
19 overcome any kind of bonding.

20 MR. LEAVER: Well, I guess he's saying the
21 experiment hasn't been done yet, but --

22 MR. KRESS: Well, if the experiment is
23 done right, I don't think it's going to affect your
24 strain.

25 MR. MEYER: Okay.

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1 MR. LEAVER: But I guess more importantly,
2 you're saying for purposes of this discussion, this
3 Committee's objective, is your view, right or wrong,
4 is that high burnup affect in terms of the Source Term
5 for severe accidents is minimal. That's what I hear
6 you saying.

7 MR. MEYER: That's right. I haven't made
8 all the points yet to fully come to that position, and
9 I may get challenged most severely on the last two
10 points that I'm going to make, but --

11 MR. BOYACK: Is it fair to say that there
12 is really no experimental data that would tell you one
13 way or another? You'd have to -- and will the Halden
14 data help at all?

15 MR. MEYER: Halden -- well, actually,
16 Halden is planning a LOCA Test, but we will conduct
17 our test at Argonne long before the Halden Test. We
18 are probably six months away from running this test.
19 The apparatus is fully constructed, and it's been
20 checked out with un-irradiated material. It's being
21 moved into the hot cell, and the test will be done
22 first with Limerick fuel. We'll run a number of them,
23 but they are sections of fuel rods that have the fuel
24 left in tact. The sections are about 15 inches long.
25 They will be pressurized. Dana will have pressure

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1 gauges at both ends of the rod, at the end with the
2 plenum and at the end without the plenum. And the
3 whole purpose of that design is to be able to see how
4 quickly the gas can flow from the plenum into the fuel
5 rod.

6 MR. BOYACK: So in this case, there is an
7 answer out there.

8 MR. MEYER: I think so. I think we
9 can --

10 MR. BOYACK: In the future.

11 MR. MEYER: Now this doesn't go to the
12 oxide phase change in delamination because we're not
13 studying that high temperature region, but at least in
14 the temperature range up to 1200 Centigrade, where you
15 will get ballooning rupture, depressurization, and
16 rapid oxidation, we should have all features present
17 in the test, although some of the temperature flows
18 will be in the wrong direction, and that's where the
19 -- I mean, we're heating from the outside and that's
20 where the Halden Test will come in and see if there's
21 any problem with that. They'll do a nuclear heated
22 test.

23 MR. POWERS: Aren't you going to have to
24 -- what you have to do after you observe the
25 depressurization and then say now how does that scale

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1 up seven and a half feet.

2 MR. MEYER: How does that what?

3 MR. POWERS: How does that scale to seven
4 and a half feet? It depends on the mechanics of the
5 bond.

6 MR. LEAVER: You've got 15 inch rods.

7 MR. MEYER: It's about 15 inches. The
8 Halden rod is about twice as long, so we have a better
9 chance. We're very aware of this.

10 MR. POWERS: Are you going to have a rod
11 spacer, a rib spacer?

12 MR. MEYER: We're talking about having --
13 we're not going to apply any intentional mechanical
14 constraint in the axial direction. The Japanese have
15 done a large number of tests where after heating up
16 and allowing the test section to elongate, they then
17 grab it in an Instron machine, uphold it during the
18 cool down. And it has a huge affect on the amount of
19 embrittlement that you need to severe the rod during
20 cool down. We're not going to do that.

21 We do have a lateral constraint which is
22 very much like a grid in the Argonne Program, and in
23 the Halden Program we're talking about putting a grid-
24 like structure at the upper end of the test specimen
25 in order to affect the flow, the coolant flow in that

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1 region.

2 MR. POWERS: But you know positively that
3 if you get ballooning, grid spaces make a difference
4 out before that ballooning propagates. Now if you
5 don't get any ballooning it doesn't matter, but --

6 MR. MEYER: I -- you know, from what we
7 know about the ballooning process 20 years ago, I
8 don't think you have to count on a grid spacer as the
9 thing that's going to upset the uniform temperatures
10 and limit --

11 MR. POWERS: It puts another constraint on
12 it. A grid keeps the balloon from going any farther.
13 There's 65 tests that they did that showed that.

14 MR. MEYER: That showed what?

15 MR. POWERS: That showed that the grid
16 spacers -- I mean, you've got these really strained
17 structures right around the grid spacers.

18 MR. MEYER: Whose test are you -- what
19 country?

20 MR. POWERS: U.S., Dine Hanford.

21 MR. MEYER: Harold is going to --

22 MR. SCOTT: The water will collect near
23 the grids and that'll sort of cool, so that may make
24 some affect. Let me just suggest in the limit, his
25 scenario that the gas doesn't communicate, as soon as

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1 the plenum temperature gets up to 850 C, then the
2 plenum is going to burst, and then your LOCA, your
3 severe accident LOCA, that's maybe an extra couple of
4 minutes. Right? If there's no ECCS coming in, you
5 know, the rod gets up to 900 C. It doesn't balloon
6 because there's no communication, but a few minutes
7 later the plenum is at 900 C. Now it bursts, so I
8 don't think it really matters whether it bursts a
9 minute or two earlier, or a minute or two later. But
10 I think these experiments with grids -- I mean, how
11 long were Hindell's balloons, maybe a foot long?

12 MR. MEYER: Yeah.

13 MR. SCOTT: We've never seen balloons more
14 than three or four inches long, except for those.

15 MR. MEYER: Hindell's -- for the record,
16 Hindell's balloons Harold referred to as -- what was
17 his first name, Ed?

18 MR. SCOTT: Ed.

19 MR. MEYER: He was in Britain and he did
20 some tubes heated in a furnace. And they were heated
21 very uniformly, and he could blow -- we call them
22 sausage balloons, really long extended balloons. Our
23 conclusion was that the local temperature variation,
24 just by the normal variation in pellet centering, and
25 chipping and other things were perfectly adequate to

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1 localize the ballooning. And in all of the tests that
2 we did with internal heaters, we got localized
3 balloons and not the long balloons, so we're not
4 trying to readdress the questions of the 1970s and
5 1980s, but to inquire does burnup have an affect on
6 this.

7 MR. BOYACK: Is there any short paper or
8 presentation materials that just capture the series of
9 Argonne tests that are planned? The reason I ask
10 that, of course, is one of the things, we don't need
11 to propose things that are already covered. And it
12 would be nice to know what is covered by the Argonne
13 test.

14 MR. MEYER: We had -- did we have a
15 presentation at Water Reactor Safety Meeting a year
16 ago? So I think this past year we called it the
17 Nuclear Safety Research Conference in November, and in
18 previous years it was called the Water Reactor Safety
19 Information Meeting. And there have been
20 presentations for the last two years by Argonne
21 National Laboratory. This year they presented some of
22 the oxidation kinetic results on the Limerick rods.

23 Now we publish transactions which are two
24 paged summaries, and proceedings which are full length
25 papers. The proceedings, the full length paper is for

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1 the meeting that was just held in October of this
2 year. That has not yet been published, and will not
3 be published until some time early next year, so
4 that's why I was inquiring about the one before that.
5 You can find a full length paper in the proceedings
6 for the Water Reactor Safety Meeting of 200.

7 MR. BOYACK: And that would cover the
8 matrix?

9 MR. MEYER: That would cover -- that
10 should -- I think it covers the whole thing. You
11 might get a pretty good overview in the transactions
12 of the 2001 Nuclear Safety Research Conference, but
13 that paper was -- the most recent paper was focused
14 mostly on the oxidation kinetics measurements on the
15 high burnup Limerick fuel rods.

16 MR. BOYACK: Harold, is it possible for
17 you to look and find the last paper that was
18 available?

19 MR. MEYER: Oh, sure.

20 MR. SCOTT: You want something that
21 describes the Argonne Program.

22 MR. BOYACK: Yes.

23 MR. MEYER: Yeah. Sure.

24 MR. BOYACK: Thank you.

25 MR. MEYER: I don't know if I'm going to

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1 be able to get off of this line --

2 MR. BOYACK: Without somebody coming over
3 a rail and strangling you, you mean.

4 MR. MEYER: Just keep in mind that during
5 this design basis phase of the accident that the fuel
6 pellet temperature, at least the center line
7 temperature is actually declining, and it's just
8 equilibrating. You've lost most of your heat
9 transfer, and so the cladding temperature is rising
10 up, and the center temperature is falling down, and
11 the whole thing stays below 1200 C.

12 I know this old CORSOR model is old and
13 over-simplified, but I think the concept is still
14 useful. You can tell me if it isn't, to think of the
15 severe accident Source Term releases as a two step
16 process. And the first step is that it's got to get
17 out of the solid material to a free surface, and then
18 the second step is it's got to make it from the free
19 surface up into whatever atmosphere is above the core
20 material at that time.

21 For the volatile species, the rate
22 limiting step is movement through the solid material.
23 And they get to the surface, and they're already at a
24 temperature where they are vaporized, and away they
25 go.

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1 For the non-volatile species, it's the
2 other way around. They get to the free surface
3 quicker than they vaporize because they have low vapor
4 pressures. Now why do I take such a simplistic view
5 of things, and that is because by and large, the non-
6 volatile species come out more or less at the same
7 rate, a lot more rapidly than the others. And the
8 less volatile species come -- have release fractions
9 that line up in the order of the vapor pressure of the
10 species of that element, the species that we believe
11 exist. And this was work done back in the early 80s
12 by, was his name Reynolds from the University of
13 Virginia, and Dick Lorenz and others have put these
14 data together. And all I did was to take this
15 apparently ranking by vapor pressure, and go look up
16 all the vapor pressures, and recast this old CORSOR
17 model with uranium expressions for those vapor
18 pressures, and some adjustable coefficient in front of
19 it.

20 Now so the point here then is that if you
21 don't change the chemical species of the element, as
22 a result of going to high burnup, then its release
23 from this high temperature core debris is going to be
24 the same as it was at low burnup.

25 And my next slide was lifted from a memo

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1 that Richard Lee gave me, and his memo mentions Dana
2 and Carl, and there's Richard. And it says, by and
3 large, that the UO2 matrix is not saturated with
4 fission products, rare earths and transuranics are
5 soluble up to a couple of percent and so forth, and
6 hence, no new chemical species are expected. So if
7 you get no new chemical species as a result of the
8 high burnup affects, I don't see that you would have
9 a net result on the severe accident Source Term. This
10 is not the gap release, Steve, for some other
11 considerations. This is the severe accident Source
12 Term.

13 And then finally, it's my final slide. In
14 the high burnup program plan that we issued a couple
15 of years ago, we engaged in a little speculation and
16 came to a conclusion that we didn't think that the
17 high burnup process would have an affect on the Source
18 Term. And our rational went along these lines. If
19 anything, there is a reduction in the amount of
20 unoxidized zirconium because you've got a little more
21 corrosion going on. And therefore, when you get down
22 to processes like the high pressure ejection, you have
23 less for the fire, and so that -- if anything, that
24 should tend to decrease what gets into the containment
25 eventually.

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1 There's embrittlement of the fuel cladding, but we
2 couldn't see how this would have any affect on the
3 chemistry of -- this high temperature chemistry of the
4 soup that you have.

5 You do get an enhanced gap release during
6 normal operation, but in the Source Term, these gases,
7 the noble gases and the iodine are essentially
8 released fully anyway, so the fact that you get a
9 little enhanced gap release with the high burnup fuel
10 would not seem to have any affect on that.

11 Now for sure, there's a shift in the
12 fission product spectrum. There's a change in the
13 inventory, and when you put the Source Term together
14 with the inventory, you're going to get a different
15 answer. But the Source Term with just a bunch of
16 fractions, and it's just those fractions which I'm
17 trying to address. And after going through all of
18 this, really don't see any strong indication of an
19 effective burnup on those release fractions.

20 I could also say that the ACRS did not
21 agree with that conclusion.

22 MR. KRESS: I can attest to that.

23 MR. POWERS: But what do they know, huh?

24 MR. MEYER: But I never understood their

25 -- MR. KRESS: Look at these French results.

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1 It flies in the face of these French results. There's
2 a burnup limit, you've got more release faster.

3 MR. CLEMENT: I think you are seeing there
4 will be a change in the *. That's clear. You are
5 also seeing that there will be no change in the *. In
6 the final * up to 100 percent. Okay. There will be
7 no change, but the change in the kinetics * was high
8 burnup during the heat up phase will be greater than
9 the change you have with the gap release *, so it's
10 not the gap release what will be the most important
11 change on the kinetics of fission product, volatile
12 fission product release. It's what's happened after.
13 Your volatilized fission product will be released in
14 a much more extent at a much lower temperature. This
15 will make the difference.

16 MR. MEYER: Yeah, I --

17 MR. CLEMENT: More than the gap release.

18 MR. MEYER: I agree with that, but what do
19 you do in NUREG-1465? You just put down the final
20 number.

21 MR. CLEMENT: Yeah. I mean, it depends
22 what use you make for Source Term. For instance, for
23 the use we are making, I mean for the * of emergency
24 procedures to know if we have to evacuate the
25 population or not 24 hours after the beginning of the

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1 accident. Maybe it's not so big a change, but when
2 you make probabilistic * assessment studies, and you
3 have * probabilities, that's another story. If you
4 just look at the final number for volatile fission
5 product - okay - * to 100 percent, that's it. If you
6 want to see what happens in a more probabilistic, then
7 you will have taken *. It depends what you want to do
8 with the Source Term evaluation.

9 MR. KRESS: You know, what's going to
10 happen is instead of the 100 percent of the iodine and
11 cesium being partly coming from the in-vessel release
12 and partly from the ex-vessel release, it's all going
13 to be in-vessel release with the high burnup. And
14 that changes the timing considerably because you don't
15 have to wait now for the melt to get out and interact
16 with the concrete. It's going to come out a lot
17 earlier, so those are two -- you're going to get all
18 of the noble gases, all of the volatiles, and they're
19 all going to be in-vessel releases. I think that's
20 the difference you're going to see, and that changes
21 the timing.

22 MR. MEYER: It doesn't change -- I'm not
23 trying to argue with you here.

24 MR. KRESS: Yeah.

25 MR. MEYER: It doesn't change the timing

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1 of the -- was it Richard that talked about the -- you
2 know, this old study where we looked at the timing for
3 the purpose of the containment isolation valve.

4 MR. KRESS: That certainly won't change
5 the gap.

6 MR. MEYER: There you just look at when
7 this --

8 MR. KRESS: It's probably not going to
9 change the gap.

10 MR. MEYER: -- when does the rupture
11 occur, and it's a very conservative picture.

12 MR. KRESS: Yeah. It's probably not going
13 to change that, I'll agree.

14 MR. MEYER: No, I agree with you. It's
15 going to affect in-vessel and the timing.

16 MR. KRESS: Now NUREG-1465 has a total
17 amount of start time and a rate for in-vessel release.
18 What it's going to do is it's going to change the
19 total amount, and it's going to change that rate.
20 Those are the two things it's going to change, I'm
21 pretty sure.

22 MR. MEYER: Okay. Well, I think --

23 MR. KRESS: But how much it changes is
24 going to depend, in my mind, is what fraction of the
25 core has that high burnup compared to -- you know, I

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1 don't know if -- you know, when we talk about 70,000,
2 that's the peak burnup.

3 MR. MEYER: Yeah.

4 MR. KRESS: And I know it sure has burnups
5 distributed through the whole core. You know, you may
6 not change the average core burnup very much. I don't
7 know. It depends on how much it changes the average.

8 MR. MEYER: But right now we have limits
9 on burnup, and the limit is on the peak rod, so it's
10 average for the peak rod, and that limit is 62.

11 MR. KRESS: Yeah.

12 MR. MEYER: And so, the peak assembly is
13 about 57, 55, 57, and --

14 MR. KRESS: 55, 57 what?

15 MR. MEYER: 55, 57 gigawatt days per ton
16 is --

17 MR. KRESS: Oh, okay.

18 MR. MEYER: -- the average for the peak
19 assembly.

20 MR. KRESS: Yeah, that's just for the peak
21 assembly.

22 MR. MEYER: And now you -- I don't know
23 what the average is for the core, but it's lower than
24 that.

25 MR. KRESS: Yeah.

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1 MR. POWERS: But you want to remember that
2 one of the outcomes could be achieved, and before with
3 the Source Term perspective, there is no reason not to
4 let you go to 100,000. For all of the --

5 MR. KRESS: Yeah.

6 MR. POWERS: I mean, that's -- and I mean,
7 that's not an inconceivable outcome if you say gee,
8 yeah, it comes out a little faster, but -- and I do
9 have a time associated with that in-vessel release.
10 Okay, I narrow that up by 10 minutes, or I make it
11 into two segments. It doesn't make a very big change.
12 Then you'd say at least from a Source Term
13 perspective, there's no reason not to let it go to 100
14 gigawatt days per ton, and they can solve this problem
15 of clad iodizing up on them. They can -- then you
16 could let them go to very high burnups, and that
17 seems a sound social and economic basis to wanting to
18 go, a 100 gigawatt days per ton.

19 MR. KRESS: So I think in terms of high
20 burnups --

21 MR. POWERS: Well, limit it to 75. 75 is
22 very interesting because you can do that without going
23 over 5 percent fairly easily. Well, not easily but
24 you get decreasing returns to scale, but there's lot
25 of reasons to do that, because you can run two year

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1 cycles. There are lots of advantages, economic
2 advantages. There's social advantages too.

3 MR. MEYER: There's no talk in the
4 industry that I'm aware of going beyond 75. In fact,
5 the next increment from where we are now, from 62 to
6 75, is not super valuable in terms of economics. I
7 think it gives some elbow room that the industry would
8 like to have if it could get it.

9 MR. POWERS: It's valuable not from a fuel
10 burnup perspective, but the fact that you're going to
11 your outages. That's where you get the advantage, I
12 mean two year cycles.

13 MR. MEYER: I don't see -- I mean, there's
14 no one that I know is working toward the next
15 increment beyond that.

16 MR. POWERS: Oh, we've got people
17 designing reactors where they want to go to seven year
18 fuel.

19 MR. LEAVER: Ralph, what about the affect
20 of high burnup on oxidation potential in the fuel.

21 MR. MEYER: Ask Dana.

22 MR. POWERS: Yes, we can talk to you about
23 that.

24 MR. BOYACK: Okay. We have a comment over
25 here.

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1 MR. LA VIE: This is Steve La Vie from
2 Nuclear Reactor Regulation, and listening what Dana is
3 saying and what Ralph is saying, it's not the LOCA
4 that's going to keep us from licensing the 75 gigawatt
5 day fuel. It's the fuel handling accident, which is
6 based on only the gap activity.

7 MR. POWERS: Yeah, gap activity has -- I
8 mean, gap activity is really interesting because it
9 was the stepchild in the severe accident analysis, and
10 we said that it existed. There's actually a coolant
11 activity that everybody forgets about that's actually
12 in 1465, but that was a -- that was not only a
13 stepchild, that was an unadmitted bastard son, but we
14 didn't focus very much attention on it. And when 1465
15 came out, lo and behold, what gets all of the
16 attention? It's the gap release.

17 MR. MEYER: Well, I didn't mention -- I
18 don't think I mentioned what was going on on that
19 score, but there is work going on to address the gap
20 activity. There was a --

21 MR. POWERS: But you see, you have
22 problems really even what you mean by gap activity
23 when there's no gap.

24 MR. MEYER: There is distributed free
25 volume, it's just not --

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1 MR. KRESS: You're just defining what gets
2 out --

3 MR. MEYER: -- necessarily out of the gap.

4 MR. POWERS: Free volume release. How's
5 that?

6 MR. KRESS: It gets out when you break the
7 clad, that's the gap right there.

8 MR. POWERS: What did you say?

9 MR. KRESS: It gets out when you break the
10 clad. That's the gap.

11 MR. POWERS: Well, it's not clear to me
12 what that is.

13 MR. KRESS: I know.

14 MR. MEYER: Well, look, we had a model
15 called the ANS 5.4 fission product release standard
16 model, and the advantage of that model was that it had
17 the mathematics in it that you needed to calculate the
18 release fractions for the short lived isotopes,
19 because most everything we talk about are just
20 releases for stable isotopes. And this MASSIH model
21 is just for stable isotopes. And the old ANS 5.4
22 model was done in the late 70s, early 80s. The
23 highest burnup LWR fuel rod in the database for ANS
24 5.4 had 19 gigawatt days per ton on it.

25 MR. POWERS: I thought it was 23, but

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1 it's --

2 MR. MEYER: And the rest of the -- the
3 high burnup data that we had up into the 30s and 40s
4 was all breeder reactor fuel. So that -- ANS
5 reorganized the Standards Committee ANS 5.4, and they
6 are pulling together data, a lot of which are now
7 coming from the Sweep Gas rigs at Halden. They're --
8 over the years they have been running those, and they
9 still have them. And we have two people from the
10 Halden project who are on this ANS 5.4 Standards
11 Committee. Gary Colstadt from the Halden project, and
12 Tony Turnbull who's an independent consultant now,
13 working with Carl Meyer and some others.

14 Now we were going to try to check on the
15 status. Did you have any luck finding out when
16 they're going to finish?

17 MR. SCOTT: No, but they started to
18 collect the data. I think they're waiting to sort of
19 make sure it's going to be the right format, and then
20 the Committee would get this set of data and look it
21 over. And Carl thought it was about maybe three times
22 the amount of data we had before that you were talking
23 about. And you guys are doing some work - right - on
24 Sweep Gas in France, some initial experiments besides
25 Halden, so we have a lot of new information. It's

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1 much better quality, and it's being collected. It's
2 in the collection stage.

3 MR. MEYER: And it's high burnup so -- but
4 this stuff goes slowly, so I would say a year or two.
5 And until that time, you're kind of stuck with using
6 the stable gas release or some cluged up reduced value
7 of that for your assumptions. And the stable gas
8 releases are a little high, so they, you know -- so
9 that's where we are on the gap activity.

10 MR. BOYACK: Anything else for Ralph?

11 Okay. Thank you.

12 What I'd like to do is I'd like to take
13 just a few minutes to talk about the process of
14 continuing on. And then we'll take a break. After we
15 come back, I believe in some way shape or form, Dana
16 and Tom have some information to discuss with us. I
17 was going to share, but I've got -- share with us,
18 I've got -- until I hit the term.

19 MR. POWERS: We noticed that about you
20 guys up at --

21 MR. MEYER: Don't like to share.

22 MR. BOYACK: I'm not supposed to set
23 myself up. I just finally want a PC for all the work.
24 This Mackintosh -- one of the great things about
25 Mackintosh is you can do wonderful graphics.

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1 MR. KRESS: Very good.

2 MR. BOYACK: Yeah.

3 MR. KRESS: I wish mine would do that.

4 MR. BOYACK: And it just has that look to
5 it, so what I wanted to do is I just wanted to get a
6 sense of whether this was a reasonable way to proceed,
7 which is at least the way we've talked about and think
8 we're going to proceed. So let's assume for a moment
9 that we were dealing with noble gases, and we were at
10 the point we were asking ourselves about the
11 applicability of the gap release for noble gas.
12 That's one of the values off the table there, we would
13 start, so that you have this given Source Term. Then
14 we ask ourselves is this Source Term from 1465
15 applicable. If the answer is yes, then what we'd like
16 to do is we'd like to understand why, and record that
17 information.

18 On the other hand, if the answer is no,
19 then the question, I think, naturally comes, well, is
20 the Panel about to guesstimate, estimate, or otherwise
21 specify a new value.

22 Now if the answer to that is yes, then
23 we'd like to know what the value is, and we'd like to
24 know the rational. We would record this. On the
25 other hand, I think at least there's the possibility

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1 that at some point during all those tabular values,
2 the Panel may say we just don't know. And if that's
3 the case, then we once again want to discuss why. And
4 the reason I asked Ralph about the current planned
5 research and so, is because there is some research
6 that's planned and ongoing. We've been talking about
7 that, and over the next year, year and a half, it
8 appears like there's a significant amount of new data
9 that's going to be generated. And so we may just want
10 to acknowledge and highlight it, if that's -- if
11 there's sufficient new research planned. But if not,
12 if there's more research needed, then that was one of
13 the charters of the Panel, which was to identify if
14 you think that there's literally a gap on this Source
15 Term Applicability; that is, we're not able to able to
16 specify a new value, and there's not data or
17 experimental programs underway to generate that, then
18 what is it that's needed to fill the gap?

19 So I believe that's what the -- what we're trying to.
20 Jason?

21 MR. SCHAPEROW: I'd just like to add that
22 two of those blocks, the upper right hand and the
23 lower left hand, again we get -- if the Panel is
24 willing to specify numbers at this point, maybe partly
25 on the basis that this other research is basically to

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1 confirm it, like ongoing VERCORS tests, for example.

2 MR. BOYACK: Yeah. I wasn't trying to
3 give the Panel a way to say no on every point. I was
4 just indicating that this is one of the possibilities.

5 MR. POWERS: I think it's very important
6 to understand that the existing table is really not
7 fundamentally a product of an expert elicitation. The
8 existing table was generated having looked at lots and
9 lots of calculations, and that's -- those calculations
10 presumably did a certain amount of this integration
11 that Tom's worried about, but I don't worry about it
12 at all, because I know before we just did it all as in
13 the light fuel, and didn't worry about the variability
14 of burnup, but maybe you should in this case. So
15 really, you're looking at expert elicitation and
16 adjustment to the table.

17 MR. BOYACK: Yes, and I certainly
18 acknowledge that. The whole process, the effort, the
19 level of effort, the amount of time that's put into
20 this is relatively small compared to the first
21 activity, so I think the objective is to go ahead and
22 extract as much information in a relatively small time
23 period, and then as to how the NRC will use it, other
24 than documented in a NUREG CR, I'm not sure. The
25 intent, I guess, was discussed earlier today in

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1 Jason's presentation. But anyway, this is how I
2 perceive the process. And basically, an orderly
3 process where we go one by one through the table,
4 after having collected whatever set of information is
5 going to be collected, so that was the Jerry
6 presentation last meeting, or our French colleagues
7 this meeting, what you and Tom had to say, Ralph's
8 presentation, and then any discussion that goes along
9 with that. But basically, to work through the tables
10 and then just ask ourselves. It seems to me we end up
11 down one of those three paths on each and every value.

12 MR. GIESEKE: For each and every value on
13 the table, you're saying.

14 MR. BOYACK: Yes. So where I'd say start,
15 given Source Term Applicable, then at that point we'd
16 go through multiple times. We'd go through it for
17 this one, and this one, and this one, and this one,
18 and so on through the table, is my perception of how
19 we proceed. And then we'll find out whether it's
20 doable or not.

21 Any questions or comment about that?

22 MR. LEAVER: Well, there might be another
23 -- you can put your drawing -- I mean, it depends on
24 how you want to label this, but I think one answer to
25 the top diamond there might be we don't know, or

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1 maybe. Is it applicable or not?

2 MR. BOYACK: No, I don't think that's
3 acceptable. I mean, to me, that we don't know or
4 maybe is a no, because you aren't willing to put down
5 a value, so you just work down through the rest of it.

6 MR. LEAVER: Okay. But that might be a
7 little easier to explain than a no no. If it's a no
8 no, then the NRC is sitting there with something that
9 people are saying it's not right, but we don't know
10 what it is. But, you know, it might turn out to be
11 right, if we do the research, and maybe it is right.

12 MR. BOYACK: So let me -- here you're
13 willing to put down a value. Right? Given Source
14 Term Applicable.

15 MR. LEAVER: Right.

16 MR. BOYACK: You come over here, and the
17 question I ask, "Are you able to specify a new value?"
18 That one, seems to me, to be yes or no, not maybe.

19 MR. LEAVER: That's yes or no.

20 MR. BOYACK: Yeah. So --

21 MR. LEAVER: That wasn't the one I was
22 talking about. I was talking about the one up above.
23 The answer to that one might be maybe.

24 MR. BOYACK: Oh. Well, I guess what I
25 could put is yes, and everything else. And that might

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1 qualify --

2 MR. LEAVER: Yes and not yes.

3 MR. BOYACK: Yes and not yes.

4 MR. LEAVER: Well, I mean, that's how you
5 PRA Table too. There's really not a no, it's yes, and
6 not yes.

7 MR. BOYACK: You want me to right down not
8 yes?

9 MR. LEAVER: I think --

10 MR. BOYACK: I understand the point.

11 MR. LEAVER: Yeah.

12 MR. BOYACK: If there's no objection, then
13 let's take 10 minutes. If there anybody that wants to
14 go down and get coffee downstairs?

15 (Whereupon, the proceedings went off the
16 record at 3:08 p.m. and went back on the record at
17 3:24 p.m.)

18 MR. BOYACK: All right. Let's go ahead and
19 resume. And I think the first thing to do as we
20 resume is to give Dana and/or Tom, in whatever order
21 they deem appropriate, the floor. Let them walk us
22 through some material that they generated as a result
23 of discussions last -- or at the first meeting, and
24 basically, their willingness to go ahead and
25 assimilate some information and show us the result.

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1 So, Dana, I believe you're first on that.

2 MR. POWERS: Oh, okay.

3 MR. BOYACK: He's got slides right.
4 Obviously. Okay. Just a moment. Let her --

5 MR. POWERS: If was you, Brent, I wouldn't,
6 but since it's her, I --

7 (Pause.)

8 MR. POWERS: Well, let me start by saying
9 that -- to thank Ralph for his presentation, because
10 you're going to find out right at the beginning that
11 I don't repudiate anything I wrote in the past about
12 the Source Term for severe accident, for high burnup
13 fuel. That in fact, when we look at most of the
14 categories of fission product release associated with
15 the Source Term, you come up and you say well, it can
16 change a little bit at most. In some cases, it won't.

17 For instance, for the life of me, I cannot
18 imagine how ex-vessel releases will change at all,
19 because once you've melted the fuel then the effect of
20 burnups go that you can't detect any more.

21 MR. KRESS: The affect I envision is that
22 it changes the inventory. It's no longer there to be
23 released.

24 MR. POWERS: Yeah. You have to your math
25 balances right. You have to get the sums right.

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1 MR. KRESS: Right.

2 MR. POWERS: Okay. In other words, release
3 fractions better all add up to one, or two, depending
4 on how you count.

5 MR. KRESS: Right.

6 MR. POWERS: When I think about the late
7 in-vessel release, I say it comes up -- it's composed
8 of three things, degradation of residual fuel,
9 revaporization and air ingress. Air ingress was
10 actually not taken into account, and that might
11 deserve some attention at some future date, but I
12 don't think it's part of this agency.

13 The degradation of residual fuel, if
14 there's any affect on burnup here, it's going to be
15 whatever we identify up in here. And this is very
16 likely to be profoundly affected if there's a profound
17 affect on burnup up here, because of the way they
18 organized the cores. And what's residual in the core
19 late in an accident that doesn't melt down promptly is
20 the peripheries, and the peripheries were intended to
21 accumulate high burnup fuel, so there's no direct
22 affect here. It's affected here.

23 Now I cavalierly say there's not much of
24 affect. I remind you that the gap release really was
25 the stepchild of all these things, because it's

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1 trivial in severe accidents base. We didn't care what
2 the gap release was, 1 percent, 5 percent. It made no
3 difference at all. We were dealing with 30 and 40
4 percent, and so we didn't devote a lot of attention to
5 this gap release. And what one gets surprised by is
6 that when 1465 was published, a lot of attention was
7 paid to the gap release, particularly to the timing.
8 But, you know, magnitudes now make a difference, fuel
9 handling accidents which are just gap release events
10 suddenly become a difference, things like that. And
11 so you've got really a couple of phenomena you need to
12 worry about up in here just immediately, and that's
13 what the gap inventory is. And we've never really
14 sorted that out to everyone's satisfaction. And
15 whether you can -- what it means to release gap
16 inventories.

17 Now I remind you that when you think about
18 gap inventories, we tend to think about it as that
19 release that occurs when the clad breaks, and you get
20 a depressurization of the rods. Speaking of the
21 Malinauskus experiments done in the 80s, many years
22 ago, and which they did exactly that. They get the
23 rod up, it broke, things came up, the major damage
24 came out and they called this gap release, and then
25 they had diffusional release.

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1 The gap release in 1465 parlance is a
2 little different. It's first half hour of release, and
3 a half an hour is the time that you go from 800
4 degrees up to 1200 and beyond, so you have to bend
5 your thinking a little bit around on what you mean by
6 gap release here. It's not just the gap inventory.
7 It's what's released in the first half hour.

8 In-vessel release, you -- we've already
9 touched upon the problem there, is that if I release
10 100 percent of the cesium in that portion of the fuel,
11 it melts and falls into the lower plenum. I can't
12 release 200 percent, so I can't change -- it didn't
13 matter what burnup does unless it depresses that
14 release, reduces the number. It's still going to be
15 100 percent.

16 There is a time associated with it, but
17 that's really the time of core degradation and vessel
18 penetration, so that's not going to change very much,
19 one presumes. And there are a lot of things to look
20 at here, but you're going to run into some conceptual
21 difficulties.

22 What I have been trying to do since our
23 last meeting is to look and see is there anything that
24 changes this a lot? Are there things up here that
25 affect the gap inventory that we really ought to think

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1 about, so that's really my focus.

2 I'll focus first on what changed in the gap
3 release, and I'm really not trying to calculate
4 things. I'm really trying to figure out what I need
5 to do to calculate things. What is an adequate model?
6 What's the time interval for gap release.

7 An in-vessel release is anything that
8 affects the releases of the noble gases, cesium,
9 iodine and tellurium, and anything changed
10 qualitatively down here. And we'll discuss things
11 like we see more barium burnup, boron release, will
12 have been released and things like that, whether that
13 might come about.

14 What I will comment is there is an
15 imponderable associated with the in-vessel release.
16 In-vessel releases is associated with core
17 degradation. A lot of it occurs when the clad is in
18 tact. A lot of it occurs when the clad is attacked in
19 the fuel, and a lot of it occurs during candling and
20 melting. And burnup may affect those processes.

21 NUREG-1465 was based on a bunch of
22 calculations that assumed a particular model of fuel
23 degradation. It assumed that candling, as clad
24 interact with the fuel, you form some liquid, you melt
25 it and drain down, pretty much like we saw from the

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1 PHEBUS experiments, not greatly different from that in
2 concept.

3 When you go to high burnup fuel, you're
4 talking about a lot of fission gases in the fuel. A
5 lot of fission gases, as you'll see, that are located
6 at the perimeter of the fuel, causing fuel cladding,
7 and mechanical interactions. You heat them up. Those
8 are the kinds of things that predispose you to get
9 fuel foaming.

10 Fuel foaming was first identified in high
11 burnup, I mean in the fast reactor world. And it was
12 driven by producing a lot of fuel gases, vapors, that
13 caused foaming in the fuel pellets. We started to see
14 it in some of the experiments with light water fuel,
15 but it's driven not by vaporizing fuel. It's driven
16 by the fission gases, and here we've got a lot of
17 fission gases. Is it possible that we fuel foaming
18 here that would change the mode of degradation? And
19 the kinds of foaming that we have seen in some of the
20 experiments is substantial foaming. It expands the
21 fuel pellets by a factor of 2. It would block the
22 flow channels. It would change the flow of gases to
23 steam and Hydrogen through the core. Probably reduce
24 the mass transport to the core region, and let you get
25 much higher fuel temperatures.

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1 I call this the great imponderable because
2 there really is a question of do you get fuel foaming
3 for the high burnup fuels or not. You can do all the
4 calculations you want to one way or the other on that.
5 Actually, the only thing that answers that is go do an
6 experiment on degradation of high burnup fuel and see
7 if you get fuel foaming, and see if it affects things.

8 MR. KRESS: And the problem with it is it's
9 probably driven by noble gases, and a lot of the tests
10 we do on noble gases are not --

11 MR. POWERS: You release them.

12 MR. KRESS: And you then you need to do
13 this experiment correctly to find out --

14 MR. POWERS: Yeah, you've got to be careful
15 with it. And there's just a lot of things you've got
16 to be careful about on doing fuel foaming experiment.
17 Worse than that, it's probably a transitory structure.
18 That is, you foam up. You sit there for a while. It
19 collapses down into a pool. Now a pool formed from
20 fuel foaming, fuel pool formed for candling look about
21 the same. Okay? So you've got to track what's going
22 on in the experiment fairly carefully. You can't do
23 calculations with systems low on Cogema, I have a fuel
24 foaming model, so I'm not going to worry about this.

25 Here is the mental picture I have of high

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1 burnup fuel, and this is a cartoon, trust me not
2 driven to scale. I did that deliberately.

3 MR. KRESS: Did you make this on the
4 Mackintosh?

5 MR. POWERS: I -- Bill Zack put this
6 together for me on the Mackintosh. Actually, it's far
7 better than the Mackintosh could do, which is the air
8 jettison clad with oxides on both sides of it. I've
9 depicted hydrided metal here, just because I like the
10 idea of hydrided metal. In fact, I think --

11 MR. KRESS: Your hydrides are oriented in
12 the wrong direction.

13 MR. POWERS: Yeah, but I couldn't -- I
14 realized that after I had drawn the picture, as a
15 matter of fact.

16 MR. SCOTT: Turn it on its side and you'll
17 get it.

18 MR. POWERS: It doesn't matter. By the
19 time we get to the temperatures it will dissolve back
20 into the fuel, into the clad anyway, and whatnot.
21 I've depicted some oxide on the inside. Ralph tells
22 me this okay for PWR, but he didn't want to see this
23 with any BWR. This is just PWR fuel clad and whatnot.

24 Then over here I have fuel grains like
25 we're used to seeing them. They're 10, 15, maybe even

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1 20 micron type fuel grains. Fission products gases
2 are borne in those fuel grains. When you think about
3 fission gases, you say gee, how much fission gas --
4 you want to bear in mind when we talk about fission
5 gas, we're talking about a lot of gas. Roughly a
6 quarter of every -- one-fourth of an atom is produced
7 for every -- of fission gas atom is produced for every
8 fission event roughly.

9 Tom will ask me what a quarter of an atom
10 looks like. It's a little pie-shaped section, Tom.

11 MR. KRESS: A quarter of an atom is A-T-O
12 or any of them. Pick out one.

13 MR. POWERS: It's one of those, and that's
14 why you have multiple kinds. And it turns out you get
15 about four times the number of xenon atoms as you get
16 Peptide atoms.

17 The fission gases are enormously insoluble
18 in the fuel, and so the fuel is very quickly
19 supersaturated in these gas atoms. And you say well,
20 obviously, nucleate bubbles here. Try to calculate
21 the nucleation rate for bubbles in fuel. It goes as
22 the exponential of the cube of the surface energy.
23 You aren't going to homogeneously nucleate gas bubbles
24 in this fuel in my life time. Okay. And the reason
25 bubbles nucleate is because you get fission tracks in

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1 here, and that generates little tiny bubbles, one to
2 ten nanometer type bubbles in the fuel.

3 Then we have here the high burnup
4 structure, HBS for those of us in the know. And this
5 is the restructure region where you have little tiny
6 fuel grains. Instead of these big 10 micron grains,
7 .1 to .3 micrometer grains, and great big gas bubbles,
8 one, two, even four micron.

9 MR. KRESS: I know what the B.S. stands
10 for, but what does the H stand for?

11 MR. POWERS: It's a whole lot of B.S.

12 MR. MEYER: What was wrong with our I.M.?
13 Really. Nobody got a name for it.

14 MR. POWERS: Yeah. Well, kind of. Ralph
15 raised a real good point. You see this here. What
16 characterizes this here? The fuel has restructured.
17 If I take an x-ray of the diffraction pattern of the
18 fuel over here and the fuel particles here, what's the
19 difference? This is much purer uranium dioxide. It
20 has a lattice parameter. It seems to reflect only the
21 Alpha damage to the lattice, smaller than the lattice
22 structure that I would have over here. It contains no
23 fission gases. This has fission gases that are
24 saturated in.

25 MR. KRESS: What are those little black

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1 dots?

2 MR. POWERS: Say this again?

3 MR. KRESS: What are those little black
4 dots?

5 MR. POWERS: The black dots are the fuel
6 grains.

7 MR. KRESS: Uh-huh.

8 MR. POWERS: And then I have big bubbles in
9 there. And now what we would like to do is -- okay.
10 This is a structure here. Now how far does the affect
11 reflected in this structure propagate into the fuel
12 here?

13 MR. KRESS: Would that constitute the gap
14 inventory?

15 MR. POWERS: No, I haven't talked about gap
16 inventory yet. These bubbles here don't communicate
17 to anybody yet. We're working on that. Okay. But
18 right now as drawn here, they don't communicate.
19 They're -- I've shown no gap here. This sucker is
20 bonded. Now are there pathways through that bonding?
21 I mean, is that really one -- I don't know. How fast
22 is it can we communicate from the plenum at the top to
23 Ralph's breakdown here? Two-thirds up, two-thirds
24 down? I don't know. It is going to vent in a minute?
25 Ralph tells me it will.

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1 MR. KRESS: Those little shales around
2 those bubbles don't look very strong to me.

3 MR. POWERS: They're pretty strong right
4 now because I'm at low temperature. I'm working on
5 it.

6 Well, to continue on, if I recall this rim,
7 Ralph, I'm going to get what I call the chicken and
8 the egg problem here, which you can see from this is
9 the grains have restructured and you've produced big
10 gas bubbles.

11 The chicken and the egg problem is did
12 restructuring lead to the big gas pores, or did gas
13 pores lead to the restructuring? And maybe that will
14 explain why I call it a high burnup structure and not
15 an event. Me.

16 MR. KRESS: You called it rim at the
17 bottom.

18 MR. POWERS: I called that little piece
19 there the rim because that's where all the
20 correlations are written in. And I -- here are just
21 some features of the rim.

22 When does it form? LOCA burnups around 72
23 gigawatt days per ton. Pellet average burnups around
24 51. They depend a lot on the power --

25 MR. KRESS: You say LOCA versus pellet

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1 average. You're talking LOCA at the edge of the
2 pellet.

3 MR. POWERS: The average for the region
4 that we call the high burnup structure. Okay?
5 Because presumably it's extraordinarily high at the
6 very front face of the pellet, and it falls off
7 exponentially across that rim, and then it's actually
8 kind of falling out across most of the rest of the
9 fuel. There's not much plutonium.

10 Okay. Where this thing -- if we just run
11 our fuel a little hotter, we'd never see this. Okay?
12 So it does depend on how hot the fuel is. The width
13 of that rim region, that high burnup structure,
14 roughly linear with burnup. Now the question is --

15 MR. KRESS: You've got the actual model
16 there.

17 MR. POWERS: Well, it's an actual
18 correlation.

19 MR. KRESS: Correlation.

20 MR. POWERS: And this is the non-
21 conservative correlation. There's also a conservative
22 correlation here. This tells you how big it is.

23 MR. KRESS: Uh-huh.

24 MR. POWERS: And this is in terms of LOCA
25 burnup here, indicates you plug a number in. Okay?

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1 If you want to relate LOCA burnup and the rod average
2 burnup, roughly you want to clad by four-thirds.

3 MR. KRESS: Do I get a negative by using
4 the rod burnup?

5 MR. POWERS: Yeah, you can. For low
6 burnups you'll get negative numbers there, in which
7 case it's zero. Okay. We don't have gripping grains
8 for them on the outset.

9 Okay. And the question, you know, is
10 restructuring lead to gas bubbles, or do gas bubbles
11 lead to restructuring? This has been a debate in the
12 literature over the last three years, and there are
13 competing models on this. Jeff, for instance, got one
14 that says oh yeah, restructuring gives you bubbles.
15 Most of the rest of the world says no, it's the other
16 way around. Here are just some more features of the
17 rim region.

18 MR. KRESS: Does it matter which one?

19 MR. POWERS: If we're going to predict it,
20 it does. And I'll make an argument that says yeah,
21 and things get worse when you go through transient.

22 MR. MEYER: Keep in mind that the LOCA
23 power in burnup in the real area time.

24 MR. POWERS: Yeah, it's extraordinarily
25 high at the surface. It falls -- it's roughly

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1 exponential across it, and so when I correlated
2 linearly like that it's a lot of averaging. And in
3 fact, most people now a days believe it's linear like
4 that only up to burnups of like 70 gigawatt days from
5 the pellet as a whole, and after that it starts taking
6 off on you in a more exponential fashion.

7 MR. KRESS: In general, the 70 gigawatt
8 days per ton, what fraction of the pellet diameter is
9 that?

10 MR. POWERS: Well, that's what you're
11 calculating with the rim.

12 MR. KRESS: How high does that number come
13 out to be?

14 MR. POWERS: Well, it's a few microns at --
15 for 60 gigawatt fuel, and as you approach 80, it goes
16 up to 1,000 microns. I mean, so you can get to --

17 MR. KRESS: But it's an insignificant part
18 of the radius essentially.

19 MR. POWERS: It's a small part of the
20 radius. It's a huge fraction of the --

21 MR. KRESS: It's --

22 MR. POWERS: I mean, it starts getting big
23 on you quickly, as you go up beyond 70 gigawatt days
24 per ton.

25 MR. KRESS: Is it a real significant

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1 fraction of fission product inventory in the fuel?

2 MR. POWERS: Yeah.

3 MR. KRESS: That's where I'm worried.

4 MR. POWERS: It's roughly -- I mean --

5 MR. KRESS: Because most of the models I
6 use, assumed the fission products are pretty evenly
7 distributed. Now you're saying most of -- a lot of
8 them are out near the rim.

9 MR. POWERS: At 60 gigawatt days it's small
10 for an average. Pellet average is 60 gigawatts, the
11 rim region is real small. Okay? Now you get across
12 70, 75 with the pellet a whole, it starts getting
13 pretty big.

14 Porosity in this region is about 20
15 percent. Big time porosity in the high burnup
16 structure at the rim region.

17 MR. KRESS: This is dating --

18 MR. POWERS: Yeah. Interestingly enough,
19 this rim material has a higher fraction of toughness
20 than the bulk fuel. How can this be? The stuff is
21 porous, and then you think about it. When you grain
22 size is small and your pores are big, all the cracked
23 tips blunt. Okay. If you have little pores and big
24 grains, then pore act as stress risers and cause the
25 cracks to propagate. This stuff is fracture tough,

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1 and so all those fragments of fuel that you're used to
2 seeing, well, they're getting blunted out by this
3 restructuring zone.

4 MR. KRESS: How does it measure in the
5 fracture toughness of this?

6 MR. POWERS: Actually in -- first in their
7 hardness. It's got --

8 MR. KRESS: With the hardness.

9 MR. POWERS: And then they did a stress
10 propagation of the fractures out from the indenter,
11 and got K1C values.

12 MR. KRESS: And just like you do with
13 the --

14 MR. POWERS: Yeah. And the grains in the
15 region, they don't have any krypton and xenon in them,
16 or at least not very much. And relative to bulk,
17 they're enriched in cesium. Okay. cesium goes up, so
18 now I wish I had Ralph's little picture of his fission
19 product release, but you think about diffusion models
20 for cesium, little tiny grains, big porosity. Well,
21 does that lead to release fractions?

22 MR. KRESS: Shows them way up high.

23 MR. POWERS: Yeah. So food for thought.
24 Right?

25 MR. KRESS: Uh-huh.

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1 MR. POWERS: Okay. A few high burnup
2 structures. Like I said, if you were to run the fuel
3 hot, higher linear powers less tendency to form rim
4 structures. Okay. And that's because you can't form
5 any bubbles. The fission gases will be dissolving in
6 the fuel rapidly. And in fact, you probably can't
7 propagate this rim structure completely across the
8 fuel. As you get through the hotter and hotter
9 regions, they just won't form any more. The
10 predominant amount of evidence is the restructuring of
11 the fuel is caused by the formation of big gas
12 bubbles.

13 MR. KRESS: Is there a limit to the rim
14 structure in normal operating temperatures, because of
15 the temperature grading?

16 MR. POWERS: Yeah, I think so. I don't
17 think anybody has ever gotten there, but I think it
18 is. Okay. What we restructuring is doing is you're
19 creating a bubble, and creating a huge string field
20 around it within the lattice. And what that lattice
21 wants to do is it wants to relieve that string energy,
22 and it does that by forming dislocations. And pretty
23 soon you get a net of dislocations, and you get what
24 are called dislocation cells. And then the cells say
25 I don't like to have a lot of dislocations around me.

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1 I'm going to form a new ring, and you get this
2 restructuring.

3 MR. KRESS: Thermodynamics 102 is it?

4 MR. POWERS: Well, certainly didn't cover
5 it any thermodynamics I've ever done, but that's
6 essentially what you're doing, is you're putting
7 energy into the system to try to relieve the super-
8 saturation. The bubbles, in fact, are over-
9 pressurized. They're creating a huge string field
10 around it. The lattice has got to react to this
11 eventually at some point, and it does it by creating
12 dislocations. Dislocations --

13 MR. KRESS: It wants to minimize its --

14 MR. POWERS: It's trying madly to reduce
15 it's energy. It produces these dislocations. At the
16 point where dislocations start becoming entangled, and
17 you get a net of them, and the easy way out of that
18 high energy state is to a new ring. Even though per
19 se that, you know, if I compare the energy below the
20 little grains to one great big grain, well, the low
21 energy stays one very big grain, but in this high
22 dislocation.

23 Okay. This stress fuel is driving. Now I
24 ask you this question. We put the fuel in to a
25 temperature transient. We're ramping up the

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1 temperature, at not too outlandish of a rate compared
2 to say the reactivity insertion. Put unreasonable
3 weight, or pressurizing the bubbles, aren't we going
4 to be inducing more stress around them? What would
5 cause this rim region to grow? I don't know the
6 answer to that. It seems like an issue to think
7 about.

8 What this kind of mechanism says is the
9 affect of this high fission rate at the perimeter is
10 going deeper where you see this actual rim structure
11 on the outside. And then it can't propagate under
12 some kinds of transients, so it might be more
13 pervasive than just the little rim that you see.

14 It looks to me like all of this leads you
15 to say gee, for low burnups around 60 gigawatt days
16 per ton, it's an interesting but not very
17 consequential thing. As you start going beyond 60,
18 and you start getting, you know, substantial changes
19 in the fuel structure. So the question comes down, we
20 want to calculate the fission product release from
21 this stuff, and we sure like this Booth type
22 approximations. And I throw CORSOR into a Booth like
23 approximation, as well. And is that an adequate
24 approximation for this? Even -- especially when you
25 realize if I apply Booth, little tiny grains, I'm

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1 going to get some much more rapid release of things
2 like cesium and iodine.

3 There are alternatives available to Booth,
4 more sophisticated treatments of the material that do
5 count for burnup. They have been calibrated for
6 calculating behavior during normal operation. That
7 is, they've been parameterized for normal operation,
8 and not -- nobody has attempted to apply them to an
9 accident transient. Okay. There's no reason you
10 couldn't.

11 The other issue that arises here is in the
12 Booth type approximations, you're saying the release
13 is limited by transport to a surface, and then vapor
14 pressure. That transport through the porosity to some
15 vent pathway is a zero resistance sort of thing. And
16 with these relatively highly damaged fuels, that may
17 not be true, and we may need to put an additional
18 resistance in. And people have spent some time
19 developing those.

20 There are a lot of phenomena associated
21 with these alternatives, and my point on this slide is
22 not to say that you need to take these into account.
23 Just to simply say there are a whole lot of phenomena
24 that are models that have not traditionally taken into
25 account, to calculate how things -- how bubbles

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1 behave, gas bubble migrate in this fuel. And in
2 particular with Booth models, we basically say the
3 bubbles are pinned. They don't move. They're fixed.
4 And then what's happening is that you're really
5 getting transport of fission products via atomic
6 mobility to a free surface. Okay? Everybody has
7 known that's not really true, that the bubbles are
8 fixed. They're just kind of fixed.

9 The other thing that's not true is the once
10 formal bubble, an atom in that bubble isn't there
11 forever, that in fact, it's continuous, it's a dynamic
12 surfing. They're redissolving and coming back in.
13 And FRAPCON, I just -- nothing against FRAPCON. I
14 picked FRAPCON out of the list. All of the models
15 have some subset of these phenomena that they don't
16 include. FRAPCON recognizes that fission bubble --
17 fission gas bubbles at the grain boundaries can
18 redissolve. And this is FRAPCON and one of its
19 incarnations. I have no idea which one. But here are
20 all these other mechanisms that are not included.

21 MR. MEYER: Excuse me, Dana.

22 MR. POWERS: Yeah.

23 MR. MEYER: It matters whether it's 2 or 3,
24 because 2 did not have high burnup affects that kind
25 of form, 3 does.

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1 MR. POWERS: Okay. This is definitely 2.

2 MR. MEYER: 2 has been out of print for a
3 number of years now.

4 MR. POWERS: But that's the last one I
5 read, Ralph.

6 MR. MEYER: I think we'll get you an
7 autographed copy of 3.

8 MR. POWERS: You've already given me an
9 unautographed copy.

10 MR. MEYER: Oh, okay.

11 MR. POWERS: But that doesn't mean I've
12 read it. It's a big document, Ralph. Give me a
13 break. I read the high points of it. I didn't go
14 through and look at mechanisms, and it's not my point.
15 That I'm just saying there are lots of mechanisms that
16 if you want a more sophisticated treatment, you've got
17 to do a lot.

18 Well, Ralph made the point that if you
19 don't change the chemical form of things in the fuel,
20 you're really not going to change the fission product
21 release during the in-vessel phase very much at all.
22 And you'll get the inventory affect, but you're not
23 going to get -- see things that were at .0025
24 fraction release jumping up to 10s and 15 percent
25 fraction release if you don't change the chemical

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1 form. And chemical form, it's clearly a function of
2 temperature. And presumably our release models
3 reflect that temperature. It's a function of oxygen
4 potential, and what we use right now must surely
5 reflect that oxygen potential in fuel up to a certain
6 level of burnup. But does the burnup affect things
7 any further?

8 Well, yeah, it does. And the first thing
9 burnup does, it does affect the defect structure, and
10 I simply cannot resist laying out the defect structure
11 for these fuels. I just love this stuff. This is
12 great. This looks like real science, doesn't it?

13 This is how you calculate the oxygen
14 potential in defective fuel. Abnormal uranium atoms
15 getting oxidized in what the literature calls small
16 polarons. You will spend weeks trying to find out
17 what in the world do they mean by "small polarons".
18 And all it means it's a 5 valent uranium, on a uranium
19 site, rather than 4 valent uranium on a uranium site.
20 They also have large polarons which are 3 valent
21 uranium on a uranium site. You have vacancies on the
22 oxygen site.

23 MR. KRESS: You're knocking off electrons.
24 Is that what you --

25 MR. POWERS: Yeah. You're taking the

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1 electron off, putting it on an oxygen atom, sticking
2 the oxygen atom into an interstitial site. And oxygen
3 in interstitial locations can combine with vacancies
4 on the oxygen lattice to form oxygen.

5 MR. KRESS: Right.

6 MR. POWERS: Then you get this kind of an
7 interaction. plutonium on a uranium site interacting
8 with uranium on a uranium site can form a small
9 polaron, and a trivalent of plutonium atom, and I have
10 highlighted that one because that has a lot to do with
11 what the oxygen potential is in the LOCA region.

12 MR. KRESS: These things are going both
13 ways.

14 MR. POWERS: Oh, yeah. These are all
15 equilibrium. Yeah. There's no irreversibility in the
16 defect structure. Then you form these defect
17 complexes, and defect complexes are -- people that
18 like to do this like me just get really excited about
19 defect complexes, because this is where our little
20 xenon atoms like to sit.

21 MR. KRESS: You've got all those little
22 things conglomerated together.

23 MR. POWERS: Sure. Yeah, they charge
24 relative to each other.

25 MR. KRESS: They charge relative to each

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1 other, and they just hook on.

2 MR. POWERS: Yeah, these hook up together.

3 MR. KRESS: And that's where the xenon
4 likes to go?

5 MR. POWERS: Yeah. It just love -- xenon
6 is like --

7 MR. KRESS: Why would xenon want to be
8 there?

9 MR. POWERS: Because xenon is huge. It's
10 enormous compared to everything else in here.

11 MR. KRESS: So it's like a vapor, it's like
12 a surface tension affect?

13 MR. POWERS: Well, it just can't sit on a
14 lattice site because it's too small. Okay. So it's
15 looking for something big, and these things are big.

16 MR. KRESS: I see, so that's why it likes
17 it there.

18 MR. POWERS: Yeah. And this is just the
19 general lanthanum species here that hooks up to form
20 these things.

21 MR. KRESS: That's almost analogous to a
22 gas surface tension on a solid, isn't it?

23 MR. POWERS: Well, it's almost exactly that
24 because it's the forces from all the surrounding atoms
25 are just getting very, very repulsive and keeps trying

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1 to push the xenon out.

2 MR. KRESS: Okay.

3 MR. POWERS: And they choose charge pellet,
4 and mass pellets, and out of this you can get an
5 oxygen potential.

6 MR. KRESS: You've got to have a rate cut.

7 MR. POWERS: No. This is equilibrium
8 stuff.

9 MR. KRESS: You can do the thermodynamic
10 delivery --

11 MR. POWERS: Yeah, well --

12 MR. KRESS: But you've got to minimize the
13 free energy.

14 MR. POWERS: Yeah. You minimize the
15 energies on these things, the charge balances. And
16 you've got to know the end, and you fit it a little
17 beta to get the delivering constants.

18 MR. KRESS: Okay.

19 MR. POWERS: You've got to know what the
20 concentrations of these things are.

21 MR. KRESS: But you have to assume this is
22 all on equilibrium, which means that the constants
23 are --

24 MR. POWERS: Yeah, because you're just
25 moving electrons. They move like the engines.

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1 MR. KRESS: They really hurl.

2 MR. POWERS: Yeah, they fly around. Now
3 when you do this, you make a couple of assumptions
4 about how cesium and barium behave. You say cesium,
5 well it's a uranate, it precipitates out. It's a
6 different structure so it doesn't engage. You say
7 barium forms a zirconate, and that's boroscite
8 structure. It's insoluble in the dioxide. The rest
9 is zirconium that you form by fissioning. The
10 zirconium is right on the peak for one of the fission
11 curves, and there's a lot of it. It goes into the
12 lattice, and so the -- you run this through and you
13 end up with something that looks like this. The
14 oxygen to metal ratio which dictates the oxygen
15 potential here, and it's an input in your calculation.

16 What you started with has a term that's
17 affected by the fractional burnup. Burnup times the
18 yield of barium and the yield of cerium, plus yields
19 of lots of other things, so to answer your question,
20 Dave, yeah, oxygen potential gets affected by burnup.

21 MR. KRESS: It goes up?

22 MR. POWERS: Yes.

23 MR. LEAVER: It goes up. Yeah. Not too
24 much.

25 MR. POWERS: Well, I said yeah, it goes up.

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1 And two things you have to bear in mind. In none of
2 this modeling did I take any oxygen and react it with
3 the inside of the cladding. Okay. And you have this
4 magic equation. This molybdenum dioxide buffer, and
5 what this is, is molybdenum is present in the fuel as
6 an alloy, an alloy with molybdenum, like technetium,
7 and ruthenium, rhodium and palladium, and it can react
8 with oxygen, perform loading dioxide in the lattice.

9 MR. KRESS: Is that only in mixed
10 dioxide --

11 MR. POWERS: No, no.

12 MR. KRESS: It's in all the fuel?

13 MR. POWERS: Yeah. It happens almost -- I
14 mean, all those little bubbles that I showed you in
15 the fuel particles, they're pinned because that's the
16 preferred location for these allows to precipitate.
17 Okay. They're all over the fuel. In fact, when you do
18 like an electron diffraction of fuel or a transmission
19 electron microscope, these alloys, of course have
20 incredible scattering power relative to the lattice.
21 That's all you see. You can't see anything except
22 those little things sticking up at you.

23 This alloy holds the oxygen potential kind
24 of at the same value. It acts like a buffer, but
25 because it's in an alloy, you can overwhelm this

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1 eventually. As you start pulling the molybdenum out,
2 it becomes lower and lower activity all the time, and
3 so there's a point where this buffer kind of gives up,
4 and that point is up around 75, 80 gigawatt days per
5 ton. Okay. So you're kind of coming up to an
6 asymptote and then it starts going away, if the clad
7 doesn't interact. The clad would act like an infinite
8 sink of oxygen, because there's a lot of it, whatnot,
9 but you've got a lot of things in the way of the
10 oxygen.

11 MR. LEAVER: This is all happening in the
12 rim.

13 MR. POWERS: Yeah. Yeah, well that's what
14 we're talking about.

15 MR. LEAVER: Right.

16 MR. POWERS: It's not out of the rim. I
17 mean that's what we're in right now. The same thing
18 is going on in the bulk fuel, but I just don't worry
19 about it very much right now. Okay.

20 MR. LEAVER: That will change the release
21 of Moly too.

22 MR. POWERS: Yeah. And I think that's what
23 you --

24 MR. LEAVER: Something we need to do.

25 MR. POWERS: Well, and I think that's

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1 something that you -- I mean, everything I've said, I
2 keep saying well, I didn't take this into account. I
3 didn't take this into account, and this -- I think
4 that's where you need the experimental data, to tell
5 you whether to pursue this further than I've done on
6 these obviously carefully thought out and elaborately
7 produced Mackintosh viewgraphs, is that before you
8 invest a huge amount of effort, you need a little
9 experimental data. And we've got some hints here, and
10 we're certainly seeing Moly going up, but not that,
11 you know, suggests hey, this saturation is actually
12 occurring. But I think I'd like to think a lot more
13 before I got too excited about Moly, because you know,
14 things become complicated. And when you try to do
15 things formally and publishable, you end up doing a
16 lot more than my finely produced and carefully crafted
17 Mackintosh --

18 MR. MEYER: Dana, there was about a 20
19 gigawatt day per ton difference between the BWR
20 Limerick fuel that had no ID. oxidation and the higher
21 burnup fuel that had some ID. oxidation, so I don't
22 know if you make a connection there or not.

23 MR. POWERS: Yeah. I saw it in your
24 presentation. I went gosh, that's really weird. I
25 wonder what that tells me. It must be telling us

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1 something, but I don't know what it is right now,
2 Ralph. You got me.

3 Well now some more finely crafted
4 speculation, cesium release. Clearly, cesium release
5 depends on the vapor pressure. We know it's a
6 function of the temperature and the chemical form.
7 What kinds of chemical forms are you going to have?

8 When you think about this, most people say
9 gee, the cesium is really hanging around this fuel as
10 some sort of uranate. And this is a really complex
11 world, because you've got trioxides BCs, and dioxides
12 BCs.

13 MR. KRESS: That's the cesium, that's not
14 cesium matter.

15 MR. POWERS: Yeah, which is most of it.

16 MR. KRESS: Most of it.

17 MR. POWERS: And this clearly is a very
18 strong function of the oxygen potential. If you go
19 through and just do the routine thermodynamics, the
20 species that sticks out to you is actually this class
21 of species called the Zirconates, and there are a
22 bunch of them. I call it CS₂. And O₂, and can be a
23 big number.

24 MR. KRESS: As no vapor pressure always
25 are.

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1 MR. POWERS: They -- once you get up to a
2 big number there's almost no activity of cesium in
3 there at all. That kind of thing, you know, gets you
4 really excited if you're trying to explain why TMI
5 would melt down and retain some of the cesium. I
6 would -- the other one that sticks out at the x-ray
7 guys are the cesium stannates, and they see them when
8 they do x-ray diffraction of the gap region of fuel.
9 They see these cesium stannates in there.

10 Well, of course, if these are what's
11 important, and we switch to M5 fuel, now what? What
12 replaces it? Well, presumably it's -- but they're all
13 strong functions of the oxygen potential. And as you
14 go up in oxygen potential here, then you form more
15 complicated of these species, and reduce the cesium
16 pressure. And it as form and have richer abundance of
17 zirconium, you get the higher ends up here. And as
18 you correctly saw, the vapor pressure is -- it's a
19 huge affect.

20 Well, how about iodine? iodine has always
21 been a problem for us chemically, because we generally
22 concede that there is surely at some time in a fuel
23 rods life must be seizing iodine in the gap region,
24 because I think some guys at Oakridge actually found
25 it by actually diffraction.

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1 MR. KRESS: Yeah. We finally saw it.

2 MR. POWERS: What else could iodine
3 possibly be? Well, there is something -- iodine does
4 cause a stress corrosion cracking and cladding, and
5 there is some chemical species associated with that.
6 Whatever that species is, that could be another
7 species here.

8 The bigger mystery to us is really
9 something Bernard mentioned in his presentation, is if
10 I've got cesium iodide and I've got molybdenum coming
11 off this stuff, I know that this particular reaction
12 wants to go that way, and that tends to free up HI,
13 which at these temperature promptly turns into atomic
14 iodine. So why don't I see more gaseous iodine coming
15 off the fuel? And maybe we do coming off the fuel,
16 and it recombines somewhere in the transport. And
17 assuredly, the people doing PHEBUS calculations in the
18 piping system with gillions and gillions of iodide
19 species, see iodide forming, silver iodide forming the
20 gas, and lots of things.

21 MR. KRESS: You get this second equation
22 without the Moly there, and the gas -- yeah, take the
23 Moly out. And we did that, and it's mostly cesium
24 iodide.

25 MR. POWERS: Uh-huh.

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1 MR. KRESS: And that's -- we did -- we
2 never stick anything else in the gas --

3 MR. POWERS: That's right. That's right.
4 I mean, the way -- I mean, we did that for years, and
5 years, and years. And the thing that -- the
6 innovation that's occurred in that kind of modeling
7 with Victoria code and forgive me, what's the --

8 MR. CLEMENT: SOPHAEROS.

9 MR. POWERS: SOPHAEROS. You know, I try
10 not to think about it. It skips my mind. What
11 they've done is they've been sticking these things in
12 like crazy. And they stick them in as fast as they
13 can --

14 MR. KRESS: Do they have a gas phase
15 chemical equilibrium model?

16 MR. POWERS: Yeah.

17 MR. KRESS: It doesn't do kinetic.

18 MR. POWERS: Some guys have done some
19 kinetics in the gas phase. I get very unenthusiastic
20 about doing kinetics temperatures above 700 degrees
21 Centigrade, because the kinetics hold fast at those
22 temperatures.

23 MR. KRESS: So you just assume everything
24 is in equilibrium at that temperature.

25 MR. POWERS: Yeah. I get very

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1 unenthusiastic about doing equilibrium at temperatures
2 much below 700 degrees Centigrade because the kinetics
3 are all slow.

4 MR. KRESS: The trouble with that was as
5 you come down in temperature and going through the
6 primary system, the equilibrium is continually
7 changing and it's getting slower. And the question is
8 where do you freeze that? And that was always the
9 question we wrestled with quite a bit.

10 MR. POWERS: The volcanologists have
11 wrestled with that equation -- I mean, that question
12 when they're looking at CO2 ratios and the gases that
13 come off volcanoes.

14 MR. KRESS: Uh-huh.

15 MR. POWERS: And you can -- the nice thing
16 about those gases, they're a complete set, so you can
17 actually back calculate it. And it comes in just
18 about 700 degrees Centigrade, just every time.

19 MR. KRESS: Oh, that's interesting because
20 that's where we hit it. That's where we put it on the
21 cesium iodide.

22 MR. POWERS: That's very close.

23 MR. KRESS: Yeah.

24 MR. POWERS: Well, the question I ask is
25 you get this one. This is a nice reaction, and if you

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1 form the cesium Zirconates and cesium uranates,
2 they're a lot better reactions. They go a lot farther
3 to the right, and we don't see a hint.

4 MR. KRESS: So the whole point is you might
5 get a lot of gas iodized if you change this chemical
6 form through high burnup.

7 MR. POWERS: You get a lot more Moly out,
8 you know, you start to worry about that. And now I'll
9 confess my ignorance. I don't understand the
10 tellurium release at all, not zero. I'm totally
11 confused by it.

12 Some contend that tellurium interacts with
13 the clad, and until you oxidize the clad, you aren't
14 going to get any tellurium release. And if that
15 happens, it surely must be formation of --

16 MR. KRESS: Tellurides.

17 MR. POWERS: -- Tellurides because
18 tellurium and zirconium are just not happy campers
19 together. And, of course, if we instead have M5
20 cladding with molybdenum instead of tin, what does
21 that do with that particular mechanism.

22 Other people observe in their experiments,
23 the tellurium didn't come out because the tellurium is
24 still in the fuel. Well, if --

25 MR. KRESS: I don't understand --

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1 MR. POWERS: -- that's volatile, why in the
2 world could -- did it stay in the fuel when iodine and
3 cesium came out? The only thing I could think of is
4 critiquing this a little bit out here, but all these
5 elements form nice lovely, stable, really stable
6 Tellurides.

7 MR. KRESS: They never see each other.

8 MR. POWERS: They have to. These are on
9 the insides of the gas bubbles. That's where these
10 alloys form.

11 MR. KRESS: In the rim region.

12 MR. POWERS: Everywhere you've got a
13 bubble.

14 MR. KRESS: But the only place you've got
15 a significant bubble is in the rim region.

16 MR. POWERS: The rim region. Okay.

17 MR. KRESS: Yeah, so why would it see it
18 before is we never had a rim region.

19 MR. POWERS: Oh.

20 MR. KRESS: Because they never got --

21 MR. POWERS: Well, how come I can't get the
22 tellurium out of my fuel?

23 MR. KRESS: It gets tied up in the clad.

24 MR. POWERS: It wasn't in the clad -- I
25 melted the clad off my fuel.

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1 MR. KRESS: Oh, then you can --

2 MR. POWERS: And I still couldn't see the
3 tellurium.

4 MR. KRESS: Well, every time I did that it
5 came out like you wouldn't believe.

6 MR. POWERS: Well, the question is, is this
7 affected by burnup? Well, I've already told you that
8 as burnup goes, we start pulling this out. We don't
9 really do a whole lot to these things, because we
10 never get high enough an oxygen potential. You do
11 tend to form -- there is some potential for forming a
12 plutonium Palladide and whatnot, and we tie up
13 palladium and compete with the formation of palladium
14 Telluride and whatnot, affected by oxidation.

15 The upshot of this is yeah, I can find ways
16 that look like they have the potential of changing
17 fission product releases. I don't find a smoking gun,
18 except possibly for the molybdenum, because I am
19 saturating out that -- as you burn the fuel and you
20 start saturating that, you just run out of molybdenum.
21 You just run out of the gas.

22 When people in the literature calculated
23 that, they treated the molybdenum as though it was a
24 pure species, so it's acting as constant as a function
25 of burnup, when it's not really. It's actually worse

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1 than that, so you definitely see that coming up. You
2 just run out of gas in the molybdenum, and so you can
3 see reasons for getting molybdenum release, and
4 getting higher oxygen potentials, especially out at
5 the rim region. And you can see things that could
6 shade the other releases one way or another, but you
7 don't see the smoking gun. And that's all I have.

8 MR. BOYACK: Okay. Tom, you have -- are
9 you going to stand up at the front?

10 MR. KRESS: Yeah, because I can talk better
11 here. I can look at your body language.

12 MR. BOYACK: You can turn off the --

13 MR. KRESS: I do not have slides, so you
14 guys could just pretend there are slides up here.

15 MR. BOYACK: You want to hand out the
16 material?

17 MR. KRESS: Not yet.

18 MR. BOYACK: Not yet. He wants to keep you
19 spellbound.

20 MR. KRESS: Yeah. And first, I want to say
21 that I think the stuff that Dana just talked about is
22 wonderful stuff, focuses your attention on what might
23 be important, and why things like PHEBUS and other
24 experiments do what they do. But it also points out
25 why I personally am a very believer in empiricism in

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1 data and empirical models in this business of fission
2 product release.

3 I just don't think we're ever going to be
4 able to mechanistically model all the things that
5 going on.

6 MR. POWERS: Except for the defect
7 structure. You can do really well.

8 MR. KRESS: Yeah, but -- so when I deal
9 with fission product release, I'm relying very heavily
10 on data and empirical correlations of the data. One
11 of the things I use is the Booth model that Dana
12 debunked to some extent. I have a handout which I
13 would like to pass around, which is called, "The
14 Justification of the Use of the Booth Model." I'll
15 pass that around. And there are sides that slide up,
16 and I'm not going to go into them any more other than
17 to say that a lot of these things Dana talked about in
18 terms of movement of bubbles, movement of fission
19 products within bubbles and within grains, changes of
20 grain size, et cetera, can be captured in empirical
21 model if you have enough data. And the data has to
22 include a sufficient range of burnup. And it has to
23 be data that's taken in such a way that when you take
24 that high burnup fuel out of the reactor and put it in
25 a test chamber, that it preserves the things that will

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1 affect the results. And what you miss there, because
2 usually the stuff sits around for years, and things
3 decay away. Your xenons, your kryptons, xenons decay
4 away, and you don't have this gas that may affect this
5 rim affect. You may not get a rim affect that's like
6 the one you have in the reactor, so when I use
7 empirical data to calibrate a model, you have to
8 realize it wasn't -- may or may not be exactly what
9 you get in a reactor. And even in the case like
10 PHEBUS, where you take old fuel and stick it back in,
11 and re-irradiate it to build up the fission products,
12 you're not going -- you're not building up the fission
13 products the same way they were in the reactor, so you
14 get a difference. So these are qualifications to
15 empirical model.

16 And what I've done is taken the things I
17 need to make an empirical model. Does anybody have a
18 blank viewgraph?

19 MR. POWERS: Tom, maybe you better point
20 out to people, especially our visitors from France,
21 that this is written in Tennessee.

22 MR. KRESS: This is written in Tennessee,
23 and it's almost unreadable. What I need first is my
24 empirical model talks about diffusion coefficient,
25 D_0e-Q/RT . And this is an empirical relationship, and

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1 the justification equation writeup I passed around
2 gives you sort of justification for why that would be
3 a good way to do it.

4 I don't intend for these diffusion
5 coefficients to mean diffusions of fission products
6 through grain surface. That's not what I'm talking
7 about. I'm saying when you take everything that goes
8 on in the fuel to get out a fission product in terms
9 of its movement through the various passageway, that
10 this will be a type of equation that will correlate.
11 And I know that because I've used it and correlated
12 fission product with it, and it does pretty good.

13 Now what do I need in order to use that for
14 high burnup? Well, obviously, I need D_0 and I need Q ,
15 all functions of burnup. This is empirical
16 correlation, I need data over a range of burnup, and
17 I need to extract these from the data.

18 Well, the first problem I encounter is you
19 get data where the temperature comes up and goes up to
20 another ramp, goes up, and you get -- that's the
21 temperature. And you get some sort of fission product
22 release of various species. This is maybe the
23 fractional release versus time.

24 Now this may be a particular fission
25 product. Let's call it cesium right now. The first

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1 problem I have is how do I take this curve and get a
2 D0 and a Q out of it? That's the first problem I have
3 for that burnup, because this is the data I have.

4 Well, I've done this, and it's not easy,
5 and what you have it 2 degrees of freedom with the D0
6 and Q, and sometimes you have to -- you can fit this
7 curve with more than one set of these D0s and Qs, and
8 that's the problem. What I attempted to do is use the
9 flat parts to some extent, and I can extract out of
10 that fission product release, I can fit that to a
11 constant temperature, D0 and Q, and I can plot D
12 versus 1/T, and I get a slope. The slope is the Q,
13 and the intercept is the thing. I can do that. I can
14 best fit that to these flat parts, and that's what
15 I've attempted to do to develop my model. And then I
16 go back and use the Booth type equation to show that
17 it fits this curve real good if I do that. So I can
18 get it -- by working very hard, I can a D0 versus Q
19 out of one of these tests, and then I can make this
20 plot. If I have a lot of tests like this and
21 different burnups, I can do this plot.

22 Well, the D0 one in front tends to be
23 linear. It looks like this if I plot it. This thing
24 over the burnup range I have tends to be linear. If
25 I plot the logarithm of the Q versus burnup, that

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1 tends to linear on a logarithm scale, but I've done
2 this for mostly Oakridge tests, but Oakridge tests
3 only run up to about 40,000. And they weren't all the
4 same, so I didn't have maybe two or three points, two,
5 sometimes three, and it's not a good database.

6 I didn't have the French data which I'd
7 love to have the whole thing so I can do this to it.
8 I didn't have the Japanese data. And when I plotted
9 these things, I did get two correlations for D0 versus
10 burnup, and Q versus burnup, and I put up a burnup
11 model into my equations. And that's what's in here.
12 That's my scatter rate. Now the problem is, I don't
13 want you to take this model too seriously, because I'm
14 still working on it, and I did this on the plane
15 almost. Could I have another one of these viewgraphs?

16 MR. POWERS: Tom, if I could just
17 interject, Bill Turnbull. Ralph mentioned Turnbull in
18 connection with the Halden experiments. When he set
19 up his diffusion to coefficient modeling with -- it is
20 a function of burnup, so that he had -- so instead of
21 having strictly uranates, that at low temperatures it
22 came out with a kind of a constant diffusion
23 coefficient at low temperatures, that he had a cut off
24 in the burnup affect at 40,000 -- I mean 40 gigawatt
25 days per ton.

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1 MR. KRESS: Well, that's part of my problem
2 because my data only goes up to about -- now one of
3 the problems with it is, if I use these correlations
4 that the data I have falls on, and extrapolate like --
5 this is like 40,000 a year. If I extrapolate this
6 one goes below. This one is all right. It's on a log
7 scale. This one goes below zero, and it doesn't make
8 any sense, so I know that's wrong, and I need to curve
9 it over. I need -- my correlation is clearly wrong
10 when I extrapolate, so I want you to keep that in mind
11 because what I did was I put these two models which
12 fit the RNL data very well, and fits the -- I fit the
13 Japanese Vega 1 data which at 47,000 megawatt days per
14 ton, so I put that one in my model also, and it fits
15 in very well, so my extrapolation up to 47,000 wasn't
16 bad. But extrapolating up to 70,000 does take this
17 below zero, and I don't know what it does to it, but
18 it takes way down on the slope scale. So my problem
19 is extrapolating the data I have in order to see what
20 affect burnup is going to have on my fission product
21 release model.

22 I did that anyway. I ran the calculation
23 and this is the results of the calculations for three
24 cases, 35 --

25 MR. LEAVER: Is this all one thing?

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1 MR. KRESS: Yeah. And -- it's all hooked
2 together. One case -- three cases hooked together so
3 just -- give me that. I don't want you to take my
4 original, but you can have this one. But what I did
5 was took the model I have for a whole core heatup,
6 which means I don't have distribution of the burnup --

7
8 MR. LEAVER: The entire core, is it
9 whatever --

10 MR. KRESS: -- and decided to on a
11 homogenous heatup.

12 MR. LEAVER: Right.

13 MR. KRESS: So you will see I have a little
14 nomenclature that says fraction of the core assumed to
15 go through this equals 1. What I have to do is I can
16 put in different fractions for that core going through
17 different heatup ramps, and different burnups, but I
18 hadn't done that, so that's another thing that's wrong
19 with this. It's the whole core heating up homogenous,
20 and it's for Surry. It's plant specific, so that the
21 timing is related to reactor itself. And what I've
22 done is with three cases, a burnup of 30,000, a burnup
23 of -- I think I did 47,000, and I did a 70,000, and
24 looked at the release of fission products I get from
25 the empirical model.

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1 And what you'll notice, I've got it for
2 three phases. One of them is for adiabatic heatup
3 ramp. The other phase is ramp driven by the oxidation
4 clad. Then there's a third phase after that where I
5 say that as the fuels melts and candles down, there's
6 something I call a whole time melt which is hard to
7 come by, but I figured out a way to estimate it. And
8 so for -- I've shown the fission product releases
9 fractions for those three phases. And based on this
10 model which needs a lot of work because I need to --
11 I'm extrapolating it outside of its database, and
12 what you'll notice is that the -- when you get up to
13 the high burnups, if I can extrapolate that far, which
14 I know I can, you essentially release all the noble
15 gases, and all the volatiles.

16 Now I have another problem in here. When
17 I release other fission products, I don't have a full
18 set of these empirical relationships for D0 and Q for
19 all the fission products. We just don't get that, and
20 I have another way that I do that called a relative
21 volatility scale. And I use the scale I have for
22 burnups at Oakridge, which are like 35 to 40,000
23 megawatt days per ton. And I just used that relative
24 volatility scale to get the releases in the fission
25 products. There's nothing in my mind that says that

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1 scale might not change also as you go to higher
2 burnups, so what I'm saying there is you don't want to
3 believe what you see for the low volatility elements
4 here because my model is probably not good for those.
5 But what it does show is the timing changes. You get
6 -- at the higher burnups you get volatiles released
7 earlier, and a lot of them get released during the
8 adiabatic heatup ramp at 70,000, whereas previously at
9 lower burnups, nothing gets released hardly during
10 that part except the gap. You have to drive off the
11 oxidation driven kinetics to get much of a release.

12 The other thing you learn with this model
13 is that these rates matter, that the faster you heat
14 up the temperature in whole melt, that you release
15 less fission products, because it's a time and
16 temperature type of thing. And if you heat up real
17 fast and melt, you really inhibit fission product
18 release, as opposed to holding it at just 1 degree per
19 K per second, over a long time, that tends to release
20 it all. Whereas, if you got up to the same
21 temperature real fast, you freeze it in the fuel, so
22 that's a consideration you have to keep in mind when
23 you're talking about a whole core melt.

24 That's really all I wanted to talk about.
25 I can use this model to help us if I had more data at

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1 higher burnups to improve my empiricism.

2 MR. POWERS: I have always been fascinated
3 by the antimony because we pay so little attention to
4 it.

5 MR. KRESS: About what, Dana?

6 MR. POWERS: The antimony, because we pay
7 so little attention to it.

8 MR. KRESS: Well, that's another thing. In
9 using this relative volatility, I anchored my curves
10 with antimony, and we know for a fact that antimony
11 gets tied up in the clad, just like tellurium does, or
12 gets tied up somewhere. And it may be a poor choice
13 to anchor this model with, but the data I used to
14 anchor it was data from fuel that didn't have any clad
15 on it, so that it's a proper anchor if you do that.
16 But you've got to be careful and not use data that has
17 clad on it.

18 I would rather use another anchor with some
19 other data. I just didn't have good data for other
20 fission products and it looks like in some of this
21 French data, they had some pretty nice other fission
22 products used to anchor with. It will be very helpful
23 to me.

24 MR. POWERS: It looks the antimony release
25 in your model, if I'm interpreting things correctly,

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1 goes through a valley, and is a function of burnup.

2 MR. KRESS: No. That's probably one of the
3 problems with the fact that I extrapolated too far,
4 and I got that negative thing.

5 MR. POWERS: Oh, okay.

6 MR. KRESS: And that's what I wanted to
7 warn you about. No, it definitely does do that. It's
8 that negative -- I've got to fix the model so it
9 doesn't through a negative value with D0.

10 MR. BOYACK: Are there any other questions,
11 or comments, or observations regarding either Dana's
12 information or Tom's?

13 MR. POWERS: Well, it seems to me that if
14 I were thinking about burnup affects on releases, that
15 you calculate the minimum affect with your model?
16 Because you're saying all the chemical conditions are
17 the same, and the only thing that's changing are the
18 diffusion coefficients.

19 MR. KRESS: Absolutely. But what I am
20 saying is that if you take the fuel that is going
21 through this burnup, and then freeze it like quenching
22 the -- if you freeze a lot of the chemistry in the
23 fuel, what I don't get then is when you take it back
24 and reheat it, how much have you changed, by letting
25 things stay and set there. And how much have you --

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1 MR. POWERS: Yeah.

2 MR. KRESS: How much do you affect this by
3 whether or not you're in oxidizing conditions or
4 reducing conditions? And my model -- basically I used
5 the data from Oakridge that was in reducing
6 conditions, so that's another thing you need to -- my
7 model is for reducing conditions. And you have to ask
8 yourself what conditions should we be viewing in the
9 actual, you know, design basis accident.

10 MR. POWERS: But I take it, just as the
11 kind of a minimum, a minimal affect.

12 MR. KRESS: Yeah, that would be a good way
13 to --

14 MR. POWERS: Anything else that you added
15 into your model is going to make a bigger affect.

16 MR. KRESS: Bigger affect.

17 MR. POWERS: I mean, you're getting kind
18 of --

19 MR. GIESEKE: It could be counteracting
20 affects.

21 MR. KRESS: I can't --

22 MR. POWERS: Well, it's kind of hard to
23 come up with those, and then you have -- but yeah, I
24 look at your 70 gigawatt calculation, and I look at --
25 and I said gee, you got 1 percent barium release

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1 here. He's got tenths of a percent of ruthenium
2 released, tenths of percent of lanthanum. I mean,
3 these are substantial numbers here. I mean, relative
4 to what you see at the lower burnup, so what you're
5 saying is yeah, I mean there's -- it's non-trivial
6 factor.

7 MR. KRESS: That's right.

8 MR. POWERS: And if that's the minimum -
9 okay - everything else makes it worse.

10 MR. KRESS: Yeah. That's exactly what I'm
11 saying.

12 MR. POWERS: That there's not cause to stop
13 at this point. I mean, it doesn't blow a whistle and
14 say you're wasting your time.

15 MR. KRESS: That's exactly right. And I
16 sure would like to have a lot more data to fit this
17 empirical model.

18 MR. BOYACK: Bernard.

19 MR. CLEMENT: Maybe I have one *. When we
20 tried to calculate the VERCORS experiments with high
21 burnups, with our ELISA model that is basically also
22 diffusion calculations, so it seems that it's quite
23 difficult for high burnup to obtain the measured
24 release with only one single relationship such as the
25 diffusion. It seems that things behave as if we have

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1 several populations of fission products, maybe located
2 in different parts in the fuel, and that we need --

3 MR. KRESS: And that would be a real
4 complicating factor in any empirical data.

5 MR. CLEMENT: I mean, even without going
6 through very complicated models, because * very
7 complicated models, but you have some difficulty
8 comprising *. Maybe there could be some simpler
9 solutions *. I have one possible *, and I apply such
10 things.

11 MR. KRESS: Yeah. I was --

12 MR. CLEMENT: And so a simplified way.

13 MR. KRESS: It could be. Yeah. You know,
14 there's lot of faults in there.

15 MR. CLEMENT: But you also calculated our
16 mechanistic model. For instance, cesium Zirconate,
17 cesium uranates, changing * potential but you have
18 nothing to validate our calculations. That's the
19 problem.

20 MR. BOYACK: I'd like to deal with the
21 question that sets us up for tomorrow. I think what
22 we'll do is finish up about 5 today. There's no sense
23 getting a major start, or trying to get a major start,
24 but there was this question that came up in several
25 presentations about the nature of the environment,

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1 whether it's an oxidizing or a reducing environment.
2 And so I was -- I'm not sure I fully understand that.
3 I understand the question. I'm not sure I understand
4 the underpinnings of that question as to one of these
5 large break LOCA scenarios. And I guess what I'm
6 hearing is that as you go through that transient, you
7 have a change in this environment. And you're trying
8 to ask the question do we use one or the other of
9 these environments for locating the Source Term. So
10 the first question I had, was this issue addressed at
11 all in NUREG-1465, as to the nature of the
12 environment?

13 MR. POWERS: 1465 is based on a bunch of
14 calculations that people attempted to the best of
15 their ability at the time to have consistent
16 scenarios.

17 MR. BOYACK: All right.

18 MR. POWERS: I mean, that was the thrust.

19 MR. KRESS: Yeah, but when you run
20 something like the Source Term Code Package, which to
21 some extent anchored the thinking of NUREG-1150, the
22 -- what the Source Term Code Package does is uses a
23 model for fission product release. It doesn't know
24 anything about, whether it talks -- you know, it's
25 just a model, but it doesn't have any affect on that

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1 oxidizing --

2 MR. BOYACK: Yeah.

3 MR. GIESEKE: So it does make an adjustment
4 in some of the rates when some of the species are
5 oxidized I think. After some time, there's a change
6 in rates, because of the amount that is oxidized
7 presumably. It's pretty simplistic, but --

8 MR. KRESS: We did that for tellurium.

9 MR. GIESEKE: Yeah.

10 MR. BOYACK: Is it essential that we make
11 a decision now at this point when we're trying to
12 discuss 1465 Applicability, Extended Applicability.
13 I don't have the technical basis myself, so I'm trying
14 to ask the questions to get us through the issue.

15 MR. KRESS: Well, if you look at the French
16 data on fission product release of the various species
17 between the various tests, it looked to me like it
18 made a really significant difference as to whether it
19 was oxidized conditions or reducing conditions.

20 MR. CLEMENT: You've got differences in
21 vapor pressures of some semi-volatile fission
22 products.

23 MR. KRESS: Yeah, and that's where it
24 mattered most. And you don't get all the --

25 MR. CLEMENT: Even -- I mean, for instance,

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1 for molybdenum, it's -- the high release is in
2 oxidizing conditions. Okay. So in reducing
3 conditions, the release is not the same, so maybe you
4 can find conditions where not all cesium is cesium
5 Molybdate, if there is cesium Molybdate in the RCS.

6 MR. KRESS: Yeah.

7 MR. CLEMENT: So it might have an indirect
8 affect also in that.

9 MR. KRESS: And my feeling is if you run
10 the MELCOR or cut out RELAP, just cut out for a whole
11 core, for PWR, low pressure accident, what you get is
12 the boildown, and then you start boiling and
13 uncovering the core, and early on as the core starts
14 heating up on its adiabatic ramp. It's cooled a
15 little bit. It's a little less than adiabatic -- that
16 you're in a highly oxidizing condition. Those are
17 mostly steam going by. When you get up to the point
18 where you start significant reaction with the clad,
19 that you're doing it first up high and it's -- and the
20 runaway oxidation is making its way down the fuel.
21 The up high, you're almost completely reducing
22 conditions because it's mostly Hydrogen up here at the
23 top. And that's where the fission products are being
24 released, right into the reducing area. And most of
25 the accident, or reducing the fission products is in

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1 -- my opinion is into a reducing environment. And I'm
2 not sure of this though, and I think it would be
3 helpful if we had some cases. Just maybe you can dig
4 them out of the old reports to see what environment
5 we're talking about, because it may color your vision
6 of whether you get these semi-volatiles to a large
7 extent out, or not.

8 MR. LEAVER: Yeah. I've got a slide here
9 that has some information on low volatile chemical
10 form as a function of oxygen potential. It might be
11 worth just taking a look at this. This is from a
12 nuclear technology paper of about 10 years ago, so
13 maybe there's something better, but this shows --

14 MR. KRESS: I recognize that. Bob Wisner
15 did that?

16 MR. LEAVER: I got this -- I don't think
17 so. It was -- it's actually been in several papers.
18 This is Holland, Zuppetti and Hauger.

19 MR. KRESS: Okay.

20 MR. LEAVER: So I guess this is some TMI,
21 post-TMI.

22 MR. KRESS: Uh-huh.

23 MR. LEAVER: But you can see that the Moly
24 here -- it -- this shaded region is the steam Hydrogen
25 region that you would get during an accident, so

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1 depending on whether you're reducing or oxidizing --
2 reducing might be say down in here, and oxidizing may
3 be towards the top. And you can see that you go --
4 the Moly becomes oxidized here part way up, so this
5 would say that if you're more towards the oxidizing
6 portion of this, that you get higher -- expect to see
7 higher Moly. You see oxide forming and you get higher
8 Moly releases. But everything else is -- well, maybe
9 not everything, but a lot of the other fission
10 products are a long ways away from this. For example,
11 lanthanum and cerium, and strontium and barium are
12 down here, so variations over this region wouldn't
13 affect that. And then ruthenium is quite a ways above
14 it. You almost have to put air in there to get
15 ruthenium oxide which -- and we worry about for late
16 in-vessel, but for the early in-vessel, you wouldn't
17 expect to see that high oxygen potential.

18 MR. KRESS: Those are condensed oxides.

19 MR. POWERS: Condensed oxides. Right.

20 MR. KRESS: And I don't know how you --

21 MR. POWERS: Well, it gives you a
22 misleading view on the formation of volatile oxides.

23 MR. LEAVER: Well, yeah. I mean, the -- I
24 guess this is the region of interest out here. You
25 know, molten.

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1 MR. POWERS: I think the trends are
2 correct, but if you make it -- you just can't come in
3 and say gee, I won't get any ruthenium vapors at all
4 because everything is ruthenium metal in this, that's
5 true, but it doesn't tell you anything about the
6 equilibrium between that metal and say RuO2 gas.
7 There's always some vapor pressure with RuO2 gas.

8 MR. LEAVER: Sure. No, I -- certainly. I
9 was only -- I was just -- this at least gives us sort
10 of a way to think about some of these questions that
11 are being asked about the reducing versus the
12 oxidizing affect, and this is just low ball --

13 MR. CLEMENT I think it's much more
14 complicated because you have to think about oxygen
15 potential within the fuel. And then you have to think
16 that oxygen potential in the gas phase, and then you
17 have to calculate the vapor pressure of a given
18 species over a mixture within the fuel, so it's -
19 that's not so easy.

20 MR. KRESS: I think you're right.

21 MR. BOYACK: I guess, first I appreciate
22 your explanation because it related it back to the
23 mechanistic and unfolding of the scenario, but I guess
24 I heard you say that if you had to immediately make a
25 choice in your case, you would take a reducing

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1 environment. That's representative --

2 MR. KRESS: I would like to have that
3 confirmed, validated by looking -- going back and
4 reviewing -- you know, it's been a long time since
5 I've looked at those core melt calculations to see,
6 and they exist in some of the reports, so I would just
7 like to --

8 MR. TINKLER: What I'd like to say is that
9 I know that we had earlier discussions about low
10 pressure scenarios, and importance of basically tying
11 this to low pressure scenarios with respect to
12 deposition and retention in the RCS. I'm not so sure
13 you want to tie all the chemistry assumptions
14 necessarily to a scenario dependent description
15 though. I think you want this to be a little more
16 general. In my own view, you want it to be a little
17 more general. If you think the affects of chemistry
18 are that pronounced in affecting the volatiles forms
19 of radionuclides, and I think all the evidence
20 suggests that it is, I think you want to cast a little
21 wider net on that particular aspect of it. I don't
22 think you want -- if you think you're going to get a
23 lot of benefits from a reducing environment
24 suppressing the release of semi-volatiles and low
25 volatiles, I'd be cautious about that, because I

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1 think --

2 MR. KRESS: Because this is a design basis
3 accident.

4 MR. TINKLER: Because it's a design basis,
5 and because there are many severe accident scenarios
6 where you'll be reducing for a while. You'll be
7 oxidizing for a while. The extent to which
8 radionuclides are released directly into a reducing
9 environment will also be a function of how well you
10 think you're calculating the flows, bypass flows
11 around hot regions, and then back into the center of
12 the core in the upper axial elevations.

13 I just -- my own view is that unless the
14 Panel feels strong -- and I agree, we should provide
15 -- we'll try to find some information on the nature of
16 it, but I think you might want to consider oxidizing
17 environments in addition to the reducing environments
18 to -- at least to some practical degree.

19 MR. KRESS: Yeah, I think you're right.

20 MR. TINKLER: Okay. Because, I mean -- you
21 know, then you -- I mean, suppose we have scenarios
22 where it's a slower boil off, or a semi-high pressure
23 react, natural circulation in the core.

24 MR. LEAVER: Or you get a little bit
25 injection.

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1 MR. TINKLER: You get a little injection.
2 You know, all that stuff. If that's going to make a
3 factor, a large factor in some of the semi-volatile
4 releases, I'm just not sure you want to pin it all to
5 that.

6 MR. BOYACK: Please stay standing up for a
7 minute now. That was just partly the low pressure
8 resistance.

9 MR. KRESS: Yeah. I remember your comment,
10 and that would be relevant.

11 MR. LEAVER: Yeah. I mean, that point. I
12 think there's two or three other things that could be
13 different too, and this is one of them.

14 MR. BOYACK: So let me see --

15 MR. TINKLER: That doesn't mean I don't
16 think you shouldn't use some of the characteristics of
17 low pressure, perhaps for retention and deposition,
18 although I think you can still keep in mind other
19 pressure scenarios. I don't -- I have my own
20 definition of what that means, but for this particular
21 issue of chemical form and volatility, I think you
22 want to be a little broader in your considerations.

23 MR. BOYACK: If some of you are wondering
24 about the dynamic that's going on here, I'm worried
25 about, or concerned about just getting through the

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1 process once. And to do that process once, to me,
2 means one specification and get through it.

3 MR. TINKLER: Right.

4 MR. BOYACK: Now it may mean that over here
5 to the side we keep a list, and to me, if the Panel
6 wanted to say well, it was either oxidizing or
7 reducing, that would be fine, or high pressure, it
8 just has to be one. And the reason I say I think it
9 has to be one is because as soon as we start to say
10 well, okay, let's do this and that, then we have a
11 hard time getting through the process once, and so it
12 really depends on what the NRC wants, but I do -- I've
13 had this discussion with Jason, quite a few, and I
14 really hounded him on it. But basically --

15 MR. TINKLER: If we could give you one
16 molar ratio for one duration we'd do that too, but one
17 of the reasons people run tests under different
18 conditions is they're not sure exactly how these
19 accidents will proceed, and they want to know how it
20 might be affected by those conditions.

21 MR. BOYACK: I understand all that. Now
22 the question is when we get to the end of Thursday
23 mid-afternoon, can you tell me what you would like to
24 have us leave here at the NRC, or have we soon
25 thereafter leave, because the reality is that if we

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1 put too many optional descriptions, we won't get any
2 of them. That's why I am very serious about at least
3 trying to find one specification, go through the
4 process once. See what the outcome is, recognizing
5 that may or may not be the end that you want to end up
6 with.

7 MR. LEAVER: Let me jump in here. I read
8 the transcripts because I missed the first meeting,
9 and I -- well, I almost read them. I didn't quite get
10 through them, but --

11 MR. KRESS: You went to sleep.

12 MR. LEAVER: There's a very interesting
13 discussion about whether we start with 1465 and do
14 like a Delta of 1465 due to burnup and MOX, or whether
15 we reinvent 1465, or something in between. And this
16 whole subject is hard enough. I mean, I think we
17 can't ignore the things that we've learned since 1465
18 was done. Somehow that has to be captured, but it
19 seems to me that one response to Charlie that might be
20 appropriate here is do the Delta, which is -- which in
21 itself is not easy.

22 MR. BOYACK: No.

23 MR. LEAVER: Okay. And then maybe keep
24 track of things that might also be -- that we need for
25 consideration, that perhaps 1465 either didn't

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1 address, or wasn't explicit on whether it addressed it
2 or not, and maybe what the impact of those might be.
3 But the Delta alone is going to be tough. I mean, I
4 don't even know if we can do that, you know, because
5 I mean, we've got -- we don't have enough data, and
6 maybe it will be a bunch of nos to go into the left on
7 your diagram. And if we try too many things, I just
8 don't think we'll -- we won't give the NRC something
9 that they can use.

10 MR. TINKLER: And that's our first wish, is
11 that we address the Delta. Okay. So whatever warts
12 and flaws are in 1465, and whatever we learned since
13 then, to the extent we can generally reflect upon
14 those things, we would. But, you know, keeping in
15 mind its uses, and the fact that it's a representative
16 Source Term doesn't -- there's not a claim that it's
17 bounded on --

18 MR. LEAVER: It doesn't envelope everything
19 that --

20 MR. TINKLER: Yeah. It's not a claim that
21 it's bound on any particular --

22 MR. KRESS: I tell you what I really could
23 use before I get to that point, and that is what
24 fraction on the core areas at what burnup, when we
25 talk about 70,000 megawatt days per ton, that's just

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1 part of the core.

2 MR. TINKLER: Right.

3 MR. KRESS: Now if I had a distribution of
4 that, that would help me to know the answer.

5 MR. LEAVER: It's a very important
6 question, extremely important question for this group.

7 MR. KRESS: Yeah. So if we could find that
8 out somewhere before Thursday, you would have -- it
9 would help me on this Delta a lot.

10 MR. TINKLER: Okay. Now with respect to
11 producing oxidized environments, the fact that the
12 1465 doesn't specify specifically environment, might
13 cause you to think that it's intended to be broadly
14 applied to different environments, which would suggest
15 that you'd have to at least think about both kinds of
16 environment in that instance, mindful that we've got
17 to keep it --

18 MR. KRESS: Yes.

19 MR. BOYACK: But I could live with that, as
20 long as we could move along with that environment.

21 MR. KRESS: Design basis accidents do not
22 have to be consistent.

23 MR. TINKLER: They rarely are.

24 MR. KRESS: They rarely are.

25 MR. TINKLER: They rarely are. Okay.

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1 MR. KRESS: And I agree. You might have
2 for one part of it, you might have reducing, and for
3 another part of it you might have oxidizing.

4 MR. TINKLER: Right. Unless it's -- I
5 don't know. It's something else to think about, you
6 know, during it certain parts of the Zirc oxidation
7 escalation, it's reducing. But whether or not the
8 fission products emerge immediately at that time, or
9 a little later when it's maybe not quite so reducing
10 in that particular region. Below it might be
11 reducing, but then our ability to calculate flows in
12 this core thermohydraulically, and the flows that will
13 be seen by the fission products emerging into the
14 stream -- well, I don't -- that's a tall order.

15 MR. KRESS: Yes. Beyond our capability.

16 MR. TINKLER: And, you know, even with our
17 improved calculations, thermohydraulical modeling of
18 the core is still pretty coarse, pretty coarse, so --

19 MR. KRESS: Yeah. And my fall back on
20 those conditions is to try to bound it to some extent.

21 MR. TINKLER: To try to what?

22 MR. KRESS: Bound it to some extent.

23 MR. TINKLER: Well, you've got to be
24 careful when you do that though. I mean, you get --
25 you go too far in that direction, you end up with

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1 something that's probably too far in that direction.

2 MR. KRESS: Yeah. And upper bound is
3 everything gets released.

4 MR. TINKLER: Yeah.

5 MR. POWERS: Let's say that about 40
6 percent of the iodine that's released as a gas, and
7 like 1 percent of the particulates.

8 MR. BOYACK: I'm going to take just one
9 more minute here and show you what we'll be embarking
10 upon tomorrow, and how we'll be doing it.

11 MR. LEAVER: Now we know why you didn't do
12 any of those guys, you used 1 percent for the other.

13 MR. BOYACK: In effect, what I propose for
14 tomorrow is the following. You'll see that I've taken
15 the top line here, noble gases, and I have the gap
16 release, the early in-vessel, ex-vessel, late in-
17 vessel, and these are from 1465. So as we started our
18 discussion, I guess we would do duration first, but
19 I'd pick one of the releases. Here on gap release
20 what there would be is a little bit of discussion.
21 Maybe we'd almost go down the little matrix question
22 first for each one of these, and then if we -- what I
23 propose to do is try to extract here are the key
24 points of the discussion, and just put those down, so
25 there might be on one of these, there might be three

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1 or four of these points.

2 When we sort of finish up the discussion in
3 that area, then I'd say okay, let's see if there's
4 sort of a general understanding or belief about what
5 that is. There may be cases where you just have
6 different opinions, and I would try to record those.
7 But that is the process by which I envision letting
8 you have the chance to go ahead and see the written
9 information that would be provided to you in draft
10 form.

11 After we have done the gap release -- now
12 there was some discussion it would be best to stay
13 with the noble -- the same release, in this case,
14 noble gases, and then after we've done the gap release
15 go to the next phase, and go through the phase, the
16 four phases, and so we would just move on. And that's
17 my proposal for how we do this tomorrow. And we have
18 -- right now we have about eight hours of discussion
19 time devoted to going through the PWR. And as you can
20 see, there's a fair number of values. Fortunately,
21 there's a few zeroes, and maybe they'll stay zeroes.

22 MR. KRESS: One hour for each one.

23 MR. BOYACK: One hour coming down you say
24 now.

25 MR. KRESS: Yeah.

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1 MR. BOYACK: Possibly. Well, some of these
2 may -- you can see there's a fair amount of similar
3 behaviors on some of those, like the noble metals, and
4 lanthanides. I don't know whether that will play out
5 similarly when we talk tomorrow or not. Maybe we'll
6 be able to just refer to some of the prior arguments
7 that we had done on other items, so that's where I
8 plan to go. And I think this will give us a chance to
9 move through and come out with an end result.

10 We'll leave the total table on the
11 viewgraph, and we'll offer it here and you'll be able
12 to see the text. Okay? Should we adjourn? Say yes
13 somebody.

14 MR. SCHAPEROW: Yes.

15 MR. BOYACK: Yes. Thank you.

16 (Whereupon, the proceedings concluded at
17 5:04 p.m.)

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