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NUCLEAR REGULATORY COMMISSION

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In the Matter of: ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
SUBCOMMITTEE ON REACTOR RADIOLOGICAL EFFECTS

(MORNING SESSION)

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE ON REACTOR RADIOLOGICAL EFFECTS

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Room 762,
1717 H Street, Northwest,
Washington, D.C.

Tuesday, 10 March 1981.

The meeting of the Subcommittee on Reactor
Radiological Effects was convened, pursuant to notice at
8:30 a.m., with Dade Moeller, Chairman of the Sub committee,
presiding.

PRESENT FOR THE ACRS:

DADE MOELLER, Chairman
HAROLD ETHERINGTON, Member
STEPHEN LAWROSKI, Member
I. CATTON, Consultant
M. STEINDLER, Consultant
D. ORTH, Consultant
F. ALBAUGH, Consultant
M. KABAT, Consultant
JOHN C. MC KINLEY, Federal Employee

ALSO PRESENT:

Messrs. Kelber, Silberberg, Denning, Wichner,
Kress, Bell, Mynatt, Pasedag, Lee, Kuhlman, Gieseke,
Malinauskas, Campbell, Sallach, Elrick, and Sherry.

* * *

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

2 MR. MOELLER: Good morning. The meeting will now
3 come to order.

4 This is a meeting of the Advisory Committee on
5 Reactor Safeguards Subcommittee on Reactor Radiological
6 Effects. I am Dade Moeller. The other ACPS members here
7 today with us are, on my right, Stephen Lawroski and Harold
8 Etherington. We also have with us a team of consultants
9 consisting of Ivan Catton, Martin Steindler, Don Orth, and
10 Fred Albaugh, plus Milo Kabat.

11 The purpose of this meeting is to discuss and
12 continue review of the NRC reevaluation of the radiological
13 source terms to be used in accidents analyses. The meeting
14 is being conducted in accordance with the provision of the
15 Federal Advisory Committee Act and the Government in the
16 Sunshine Act. Mr. John C. McKinley is the designated
17 federal employee for the meeting.

18 The rules for participation in today's meeting
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14 is being conducted in accordance with the provision of the
15 Federal Advisory Committee Act and the Government in the
16 Sunshine Act. Mr. John C. McKinley is the designated
17 federal employee for the meeting.

18 The rules for participation in today's meeting
19 have been announced as part of the notice previously
20 published in the Federal Register on February 23, 1981. A
21 transcript of the meeting is being kept, and it is requested
22 that each speaker first identify himself or herself and
23 speak with sufficient clarity so they can be readily heard.

24 We have received no requests for oral statements
25 from members of the public, and we have received no written

1 statements from the public.

2 We are here, of course, to review in detail the
3 report entitled "Technical Bases for Estimating Fission
4 Product Behavior during LWR Accidents." Although several
5 members of the subcommittee have not had time, I am sure, to
6 read the report in detail, we will be covering it chapter by
7 chapter over the next two days. And for members of the
8 subcommittee and consultants, let me tell you briefly what I
9 hope we will be able to accomplish.

10 Today, primarily, we will be going through the
11 report, as I say, chapter by chapter, with members of the
12 NRC staff and their consultants who prepared the various
13 portions. Then tomorrow we will continue, and I am hoping
14 we can wrap up the formal interchange with the report
15 authors. And prior to conclusion of the subcommittee
16 meeting tomorrow, I want us to set down in writing some
17 thoughts in the way of preparing a draft report for the full
18 committee to consider for submission to the NRC
19 Commissioners.

20 The report reflects a tremendous amount of work.
21 It not only, of course, shows us what it knows, it shows us
22 much of what we don't know. But I think the staff does
23 certainly deserve commendation for the effort that has been
24 put into this and particularly for maintaining their
25 schedule. They promised us several months ago that it would

1 be available, the first draft, on the evening of March 6th,
2 last Friday. And indeed, it was available as indicated.

3 I think that, Mel, you deserve, I am sure, a lot
4 of the credit, plus your team supporting you.

5 Well, we will move on then to the interchange with
6 the staff and the first person on our agenda is the NBC
7 staff introduction by Charles Kulber.

8 MR. LAWROSKI: Could I ask a question?

9 MR. MOELLER: Yes, let's take a moment.

10 MR. SILBERBERG: We are missing two people.

11 MR. LOELLER: Does the subcommittee have any
12 comments or remarks?

13 MR. LAWROSKI: What ever happened to the judicious
14 service with which we occasionally got reports like this,
15 usually, the Federal Express or what have you. If this did
16 come out on the 6th, it would have been nice for some of
17 us. I would have had at least a week to look at it.

18 MR. ETHERINGTON: I am looking at it for the first
19 time.

20 MR. LAWROSKI: Last night, when I arrived at my
21 hotel room, was the first time that I saw it. And it is a
22 fairly thick report. I know on past occasions we did have
23 such a service. Is that a art of the budget cut?

24 MR. MC KINLEY: No.

25 MR. CATTON: Federal Express won't make it.

1 MR. LAWROSKI: Whatever kind of service it was,
2 because it was possible to get the stuff the next day.

3 MR. MC KINLEY: Yes.

4 MR. LAWROSKI: I must say, from what little time I
5 did have last night, I do agree with you, Ted, that it's a
6 tremendous effort.

7 MR. ETHERINGTON: I do, too.

8 MR. LAWROSKI: Also, from a quick glancing of it,
9 I was impressed by the amount done and what appears to me a
10 rather evenhanded treatment of the information on the part
11 of not only the NRC people but the contractor people that
12 they had assisting them in the preparation of this. It was
13 not a one-sided attempt in any way, from what I could
14 detect. I think this is to be commended.

15 MR. MOELLER: Are there other comments from either
16 subcommittee members or consultants?

17 (No response.)

18 MR. MOELLER: I think, then, why don't we just
19 simply take a short break until Charles is here?

20 MR. SILBERBERG: I appreciate that.

21 MR. MOELLER: Because I think we're ahead of
22 time. So let's just take a break.

23 (Brief recess.)

24 MR. MOELLER: The meeting will resume.

25 We will move forward then with an introductory

1 statement on behalf of the NRC staff by Charles Kelber.

2 MR. KELBER: Thank you, Mr. Chairman.

3 My name is Charles Kelber. I am assistant
4 director for advanced safety technology research in the
5 Office of Research. I shall make a very brief introduction
6 today of what I think is a very productive effort. I am
7 very pleased with the work that Mel Silberberg, Rich Sherry,
8 Walt Fasedag from NRR, and a number of others, plus a
9 significant number of our contractors did. I think it is a
10 very good report.

11 We met our deadline for the final draft report,
12 and we hope you have had an opportunity, although we
13 recognize it has been brief, to review at least the key
14 portions of it. This is a significant document addressing
15 an issue that has attained some prominence, but which has
16 always been a major issue in reactor safety. That is, the
17 nature of the radiological source term.

18 Today Mel Silberberg and Rich Sherry shall open
19 our presentation with a review of the points from the
20 introduction, summary, and conclusions of the report. Then
21 the contractors who were instrumental in preparing this
22 report will provide details of their report which form the
23 basis for the conclusions.

24 And I would recommend that you hold the detailed
25 questions of your review for the contractor presentation,

1 since that will enable you to deal directly with the people
2 who have done most of the technical work. We will
3 appreciate your comments and will be pleased to clarify and
4 amplify and further explain any points in the report that
5 may require it.

6 Anticipating that no significant errors either
7 omission or commission would be found in the source of the
8 peer review, we plan to forward the report, as revised, to
9 the Commission by the end of the month.

10 I would interject one point, one remark at this
11 point that reflects my personal judgment and feelings. I
12 believe this issue has become politicized out of all
13 proportion and that we are dealing as much with political
14 science as much as we are with natural science. This is a
15 technically sound report, I am convinced of that. I think
16 that there has been very sound thinking and work that has
17 gone into it, but I believe that the inception of the
18 problem by Malinauskas, Campbell, and Stratton was also
19 technically sound. But in between, there has been a great
20 deal of political noise and pressure brought to bear.

21 I hope that in any review you will help us focus
22 on the technical issues, scientific issues that have to be
23 resolved and help us keep this report a high-quality
24 technical document.

25 Our management backs us in this. Mel has

1 discussed the conclusions of the report and its substance
2 with the management of the Office of Research. And I
3 believe that he has the confidence and support of all of us
4 in making his presentation.

5 I am sorry that I can't remain with you today. I
6 have another meeting a little further downtown to go to. I
7 hope to be able to get back to you later on the series of
8 reviews.

9 So I would like to turn this meeting over now to
10 Mel Silberberg.

11 MR. MOELLER: One question, Dr. Kelper. To what
12 degree has the report already undergone review? Could you
13 give us some idea?

14 MR. KELPER: Mel can give you the details, but we
15 have significant reviews, collegial reviews between the
16 chapter editors, other key consultants, and our own staff.
17 We have not at this time received any of the independent
18 peer reviews. This is the first of them. The regular
19 research review group meeting is scheduled for next week,
20 and these two reviews, yours and the review group meetings,
21 are constant to the major independent peer review. And I
22 might say this report is getting as high a quality peer
23 review as any report I know, including, I would say,
24 WASH-1400.

25 MR. LAWROSKI: You said you are having a meeting

1 on it next week? Were the people sent this by mail, regular
2 mail?

3 MR. KELBER: Express mail. They should all have
4 it, including the overseas people should all have the
5 report. We have tried to establish appropriate means of
6 communication for issues like this.

7 MR. LAWROSKI: Could we have, or is there already
8 a list somewhere of the people you have asked?

9 MR. KELBER: Mel Silberberg will cover that.

10 MR. SILBERBERG: I will cover where they come
11 from.

12 DR. MOELLER: Any other questions or comments?

13 (No response.)

14 MR. MOELLER: Thank you.

15 MR. KELBER: Good luck.

16 MR. MOELLER: We will move on then to the overview
17 and summary of the conclusions by the report by Mel
18 Silberberg.

19 MR. SILBERBERG: Thank you, Mr. Chairman.

20 As Dr. Kelber has noted, Rich Sherry and myself
21 will divide up the introduction, summary, and conclusions,
22 and the summary of data base limitations. First -- and we
23 really aren't going to dwell on these points. I think what
24 we will be able to do is focus what we think are some of the
25 more important conclusions and some of the more important

1 points that we have found in the study.

2 I would like to introduce things by summarizing
3 some of the background, the key points that were related to
4 what initiated the study -- in other words, the issues,
5 technical questions that started the study -- and the basis
6 for proceeding and then what we found in relationship to
7 those issues and questions. And then as the rest of the
8 morning and afternoon evolves, we will be playing through
9 each one of these in the various chapters.

10 Now, again, let me suggest that it would be very
11 helpful, I think, to you and us if we leave the details for
12 the speakers from the contractors. They have, in effect,
13 done the lion's share of this work. They are the people who
14 have made the analyses and evaluations and calculations, and
15 they have made the conclusions.

16 All that we have attempted to do is faithfully
17 represent those conclusions up front. I believe we have
18 done that. So any conclusion that we will state will have a
19 basis later on. And if indeed you can't find that basis,
20 please note that, and we will certainly try to make it
21 visible if we haven't already done so.

22 Now, one thing you will note immediately is that
23 we have changed the title of the report.

24 (Slide.)

25 Largely, at the -- after our own review following

1 the meeting on the 6th with the subcommittee and the full
2 committee, the consensus was that among ACRS as well as
3 amongst ourselves that the title of the report needed to be
4 changed because it didn't represent -- the whole title
5 really didn't represent what it was about. This is the
6 objective again briefly stated, and that hasn't changed.
7 That has been the same from the beginning.

8 (Slide.)

9 A second area objective, of course, of the work
10 was to, in addition to providing information, the best
11 technical information available, to also put together an
12 understanding of what areas were there gaps and where were
13 we limited at this point in being able to provide the best
14 technical information. We were able to do that also as part
15 of the study, and I think that's an important part of the
16 study. And this was noted in your letter to the chairman.

17 (Slide.)

18 MR. LAWROSKI: In the title that you have for that
19 report, you said "release." I guess the new title, which is
20 not the same?

21 MR. SILBERBERG: Yes. The reason why --

22 MR. LAWROSKI: The release has many different
23 aspects to it and that's ...

24 MR. SILBERBERG: That was a problem we had. In
25 fact, we spent some time on deciding, believe it or not,

1 whether to make it "release" or "behavior." It wasn't
2 really clear. "Release" can mean a lot of different things
3 to different people, and we tried to --

4 MR. LAWROSKI: What did you want to have meant?

5 MR. SILBERBERG: We wanted to state that from the
6 time fission products are born, released from fuel during an
7 accident, find their way through the primary system, how the
8 chemical behavior might change, the physical behavior might
9 change; and then if they go into the containment, what is
10 their -- what are their characteristics in containment? And
11 then finally, knowing all that, what might be available for
12 a release from containment on containment failure or on the
13 leakage?

14 So we used the word "behavior" to kind of cover
15 the whole thing.

16 MR. LAWROSKI: I thought that you had "release" in
17 the title. I see it is "behavior" in the copy in front of
18 me. But I thought you said you had changed the title.

19 MR. SILBERBERG: What I meant was we changed it
20 from last months' title.

21 MR. LAWROSKI: Okay.

22 MR. SILBERBERG: Now, the scope of the report, we
23 do emphasize intentionally the transport behavior and
24 chemistry of radioiodine for three sort of, I think,
25 straightforward reasons that I have listed there. Iodine is

1 potentially a major contributor to public exposure. It has
2 been the focus of analysis procedures over the past number
3 of years. And, as you recall, the technical issues and
4 questions raised were, most of them, on iodine.

5 (Slide.)

6 And so we felt that it was necessary to address
7 iodine in particular. However, as I tried to explain last
8 time, without having the results of the information in front
9 of me -- and I think you will see today that the contractors
10 did an excellent job of really going into the natural
11 fission product removal mechanisms which have also been in
12 issue, including the aerosol generation, agglomeration, and
13 settling, as well as the effects of a condensing steam
14 environment on aerosols.

15 Now, in that sense, by treating the aerosols in
16 some detail to the limits of our ability within the state of
17 technology, we have, in effect, physically included all of
18 the other particular aerosols, as you might expect. As you
19 will see later where we backed off on the fission product
20 species, primarily because the information was lacking, was
21 in the chemistry, the chemistry of the individual species.
22 So fission products, whether it's at cesium iodide or any of
23 the other individual species, are treated as aerosols. And
24 I want to make that clear that they are covered.

25 Now the individual aerosols behave physically in

1 the mix, that's going to be addressed later on. That's
2 another point. Also, we did use quite a spectrum, a
3 reasonable spectrum of accidents, and it covered a wide
4 range of conditions and engineered safety feature failures
5 and degrees of core damage.

6 And we note also that we did not cover all
7 sequences or a super-large number. And that will be
8 explained later on, too.

9 (Slide.)

10 Now, let me go quickly to the four issues that we
11 think are the basis for what we have addressed in the
12 report, were the focus of the report. The first one deals
13 with chemical forms. Is cesium iodide, rather than
14 elemental iodine, as has been assumed in the past, the
15 predominant radioiodine form released from the fuel during
16 severe accidents?

17 The conclusion in the report is that the current
18 data base, with some qualification, supports the conclusion
19 that cesium iodide is the expected predominant iodine form
20 under postulated light water reactor accident conditions,
21 although the formation of some elemental iodine cannot be
22 precluded under certain conditions. And people will dwell
23 on that later as we go into chapters on chemistry.

24 So, in short, this would say we don't think you
25 can eliminate iodine at this point. I didn't say what

1 amount, but we don't think that iodine can be, in itself,
2 elemental iodine, can be removed from the books at this
3 point.

4 (Slide.)

5 Let me state -- I just realized, making my last
6 statement, I might have been treading on regulatory impact,
7 and that is the subject of another report which will address
8 this. So I want to caution myself on how far I want to use
9 my conclusions.

10 Issue number 2, since cesium iodide is less
11 volatile than elemental iodine and is much more soluble in
12 water, is release of iodine during postulated reactor
13 accidents currently being overestimated? What we found was
14 that the assumed form of iodine, either cesium iodide or
15 elemental iodine, does not have a major influence on the
16 estimated iodine release to the environment for the
17 risk-dominant accidents. And I don't want to go into this,
18 but this will come out later on. So we don't need to go
19 into it.

20 And these are particularly the ones where large
21 releases regardless of the form, generally early containment
22 failure, or near early containment failure. And there
23 hasn't been enough time, as I see it, for the cesium iodide
24 form that is released into the containment, not that which
25 is in the water, to, in effect, use its new form to its

1 advantage. And that's a simple way of putting it, but that
2 will be clarified.

3 Now, however, for less severe accidents, the
4 effect of iodine chemical on the predicted amount of iodine
5 released to the environment is more pronounced, and the less
6 severe accidents are obviously those where there is a
7 preponderance of water left in the system; for example, such
8 as TMI-2. So that is where the -- we think that is where
9 it's important, the chemical form is more important.

10 (Slide.)

11 MR. VOELLER: And although you don't really say
12 it, you mean in that last sentence that the effect is one of
13 reduction in the release?

14 MR. SILBERBERG: Yes. Yes. I believe so.

15 MR. VOELLER: You mean the effect is more
16 pronounced, you mean in a favorable way?

17 MR. SILBERBERG: In a favorable way. Yes. Thank
18 you for noting that.

19 MR. SHERRY: Well, I would just like to add one
20 thing. For the majority of the cases for the less severe
21 accidents, if you assume the chemical form of iodine is
22 cesium iodide then there will be more attenuation. However,
23 for certain specific phenomena, primarily in the containment
24 behavior of iodine, we have found that in certain cases the
25 elemental iodine, the molecular iodine removal rate would be

1 faster than cesium iodide in aerosol form. So it's not
2 completely straightforward that cesium iodide is always
3 better from the attenuation standpoint.

4 MR. MOELLER: Would you identify yourself for the
5 reporter?

6 MR. SHERRY: I am Richard Sherry, NRC Research.

7 MR. SILBERBERG: Thank you.

8 Item Number 3 had to do with the question of:
9 Have natural removal processes been adequately accounted for
10 in previous and past studies such as reactor safety
11 studies? That perhaps most severe postulated accidents have
12 been overpredicted because these items have not been --
13 these processes have not been taken into account.

14 The results of the study do not support the
15 contention above that the predicted consequences for the
16 severe accidents have been overpredicted by orders of
17 magnitudes in past studies. For example, the analysis in
18 this report indicates that the best estimate attenuation
19 factor for iodine is between about 2 and 10 for the
20 risk-dominant accidents; that is, from 10 to 50 percent of
21 the core inventory of iodine could be released to the
22 environment. And, again using the most advanced methods
23 that we have and as I will note later, really pushing the
24 state of the art on the study, the several orders of
25 magnitude just can't be supported. It just does not have a

1 good technical basis.

2 If there is information out there for something
3 that is missing that might bring that about and it is not
4 obvious to us at this point, then one will have to have the
5 data as well as a modeling that goes along with it that
6 allows one to include something that we really can't take
7 into account yet.

8 (Slide.)

9 MR. LAWROSKI: Is that question a fairly worded
10 one?

11 MR. SILBERBERG: Actually, they were generated in
12 two different ways. In one, they were generated. That
13 question evolves from the Levinson-Rohm paper as well as
14 from Dr. John C. Stahr's presentation on the 18th. One said
15 several orders of magnitude. Another said from 10^0 to 10^{-6} ,
16 I think. So we just said "several orders of magnitude."

17 MR. ETHERINGTON: Can you quantify roughly the
18 risk-dominant accidents? Which is the dominant accident, or
19 which are they?

20 MR. SILBERBERG: Okay. Rich -- that is going to
21 be covered by Dr. Denny but --

22 MR. ETHERINGTON: I withdraw the question. Skip
23 it.

24 MR. SILBERBERG: Finally, in the letter to
25 Chairman Ahearne by Malinauskas, Stratton, and Campbell, a

1 very excellent point was made; namely, Question 4: Will the
2 engineered safety features, ESFs, designed for iodine
3 control be effective and optimal for the actual iodine
4 behavior rather than the behavior currently assumed? And
5 how will these engineered safety features perform under
6 postulated severe core damage and core meltdown accident
7 conditions?

8 And the report conclusion is that the
9 effectiveness and performance of the different ESFs varied
10 for different accident sequences. That is -- now, that may
11 be a little difficult to understand, and when I wrote it
12 yesterday I said to myself, "No one is going to understand
13 that."

14 But as we get into Chapter 8 and you will have an
15 opportunity to see what that means, but what it says is that
16 some engineered safety features did very well, others did
17 medium to low, and there was one, I think, that was very
18 poor. And that's what I mean by depending on the accident
19 sequence.

20 (Slide.)

21 Now, let me just note something about the people
22 who contributed to the report and go to the slides. First,
23 I would like to note a correction on Chapter 5, a correction
24 in your draft. In Chapter 5 there were two chapter
25 co-leaders, Dick Elder from Sandia and James Bell from Oak

1 Ridge National Laboratory, dividing up the vapor-phase
2 chemistry and the aqueous chemistry.

3 I want to note that. Secondly, it is not shown
4 here, but I would also like to note that the Oak Ridge
5 participation was organized and directed by Dr. Fred Eynatt,
6 who was indeed very helpful in pulling together the Oak
7 Ridge work.

8 I would also like to acknowledge several other
9 things. In spite of the severe pressure for time,
10 particularly down the homestretch, we never received even
11 one phone call from any of the team about not being able to
12 meet the schedule. I just want that to be noted for the
13 record.

14 We have also noted in the report certain scope of
15 the limitations, some of which were the results of time
16 constraints of the study. However, we won't -- and I am
17 sure that our contractors are not going to -- use schedule
18 to qualify what they have done. I think they are satisfied
19 that it was their best effort, and I think that everyone
20 recognizes the schedule constraints. So we won't use
21 schedule as an out.

22 The teamwork cooperation among the labs was
23 excellent. I don't believe we could have made the progress
24 we made without it. I believe that in most areas we
25 exceeded the initial goals we set for ourselves back in

1 December when the study was initiated. Some of the work
2 represents new efforts and extensions of available
3 information. Let me just list some of these so that you can
4 look for them as we proceed through the report.

5 One was a reevaluation of fission product release
6 fractions and rate data to yield a revised release model.
7 New assessment of the equilibrium chemical thermodynamics
8 for cesium-iodine-hydrogen-steam systems.

9 The first evaluation of the effect of condensing
10 steam environment on aerosol behavior for a specific
11 accident sequence; namely, TMLB prime and, to my knowledge,
12 and I know the calculations are still perhaps being made --
13 the first evaluation of aerosol behavior for a BWR. There
14 may be others that will pop up.

15 I just want to note that most of the new
16 evaluations of analyses were developed during the last two
17 weeks of the study. And at that time, I could sense a great
18 deal of enthusiasm out in the field that the contractors --
19 for the kinds of information they were getting and some of
20 the insights they were getting in how things were turning
21 out. And I really believe that we didn't run out of time as
22 much as we ran out of information. That's really what I
23 believe. I believe we went right up as far as we can tell,
24 right up to the stops of the state of the art and really
25 came up against -- we just can't go any further, really.

1 There are certainly improvements and
2 embellishments and different ways of presenting the data,
3 and maybe a few more calculations that we can make, and we
4 may indeed make in the next week or two to just round things
5 out. But I am not all that concerned about not having that
6 information at this point.

7 (Slide.)

8 Finally, just let me note something about our peer
9 review process, which I might tell you, took some time to
10 develop. We are even getting phone calls from around the
11 country from people who would like a copy because they would
12 like to comment and so forth. And as best we can, we are
13 sending people copies.

14 We have indicated to them that it is going to be
15 difficult for them at this point to be part of the formal
16 review process. We welcome any comments they have, but as
17 far as meeting on the 17th and 18th, there were going to be
18 time constraints on just having the people that I have
19 listed here, getting involved in the peer review.

20 Now, I have listed the peer reviewers by the
21 following categories, and I will try to name some of the
22 names in each one of those, and I may miss some.

23 But on the independent review side, we have people
24 like Leo Brewer from the University of California-Berkeley;
25 we have Dr. Lloyd Zumwalt, professor emeritus at North

1 Carolina State University. We've got David Garvin, Dr.
2 David Garvin from NBS, who heads up deputy director of a
3 section on chemical physics. We have -- although we list
4 him also as a DOE lab reviewer -- we have Richard Wallace
5 from Savannah River laboratories.

6 And we have others whom we can't really now claim
7 as independent, but nevertheless they are well known in the
8 field. And I feel that one can get as independent appraisal
9 from them as possible. Certainly, somebody like Bob
10 Hillyer, from HEDL, who has tremendous background in this
11 area whom we've used before on review groups. Carl Johnson
12 from Argonne National Laboratory. Donald Schweitzer from
13 Brookhaven National Laboratory. We've invited Dave Campbell
14 and Tony Malinauskas. And Bill Stratton has, if you will,
15 lab reviewers. Although I must say that in the stretch,
16 when things got exciting, Dave Campbell and Tony Malinauskas
17 pitched in and offered advice and contributions that were
18 indeed very, very helpful. And, again, another example, I
19 think, of good teamwork.

20 We have industry reviewers, Dr. Richard Vogel
21 representing EPRI; we have Dee Walker representing
22 Westinghouse and OES; and then we have representatives from
23 GE, B&W, and Combustion Engineering. We have Robert Ritzman
24 from SAI. We have invited Harry Korewitz from AI.

25 We have, in the way of foreign reviewers, right

1 now we have five out of six acceptances, very enthusiastic
2 cooperation from the foreign countries. We have Dave
3 Torgerson from AECL in Canada. Brian Ainscough from UKAEA
4 Spring Fair Lab. We have a Mr. Devillers from CEA, who is
5 responsible for the radiological work there. We have a Mr.
6 Ishikawa from JAERI in Japan. And Mr. Devell from Sweden.

7 We also will be represented by federal agencies. We
8 are still in touch with EEPA and trying to make contact
9 there. We have NBS, of course, and DOE will be represented
10 by themselves as well as one of their labs.

11 I have listed as others the following: There will
12 be an observer from Nuclear Safety Oversight Committee --
13 that should be -- NRDC has been invited. UCS is sending
14 Gordon Thompson and Bob Alvarez from Environmental Policy
15 Institute has been invited and will attend.

16 Basically, then, that concludes my presentation,
17 Mr. Chairman.

18 MR. MOELLER: The last synonym, or whatever you
19 call it, API, is that EPRI?

20 MR. SILBERBERG: Environmental Policy Institute.

21 MR. LAWROSKI: Have you asked the Academy of
22 Sciences, National Academy of Sciences yet?

23 MR. SILBERBERG: I thought about it, and I just
24 haven't really come to grips with it. I think I might do
25 that. I think that is a good suggestion.

1 MR. ALBAUGH: Where does this committee fit in
2 this list?

3 MR. SILBERBERG: They would be under "Federal
4 Agencies."

5 MR. MOELLER: Any questions for Mel?

6 MR. LAWROSKI: Anybody from Harwell? You
7 mentioned somebody from Springfield, but Harwell is the big
8 research --

9 MR. SILBERBERG: I understand that. What we did,
10 Dr. Lawroski, is we contacted our contact at UKAEA SRD, and
11 this is what was offered, and I am sure it's going to be
12 fine.

13 MR. MOELLER: The next presentation is by Battelle
14 Columbus then?

15 MR. SILBERBERG: No. I would like to introduce
16 Richard Sherry, who will do the second half.

17 MR. MOELLER: All right. I think when Richard
18 finishes, I hear the coffee perking, and we will take a
19 short break.

20 MR. SHERRY: My name is Richard Sherry. I am with
21 the NEC Office of Research. What I had planned to do today
22 is go over the summary.

23 MR. MOELLER: Make it as loud as you can, please.

24 MR. SHERRY: What I plan to do today is cover the
25 summary, the conclusions, and the data base limitations

1 which are presented in Chapter 1 of the report. I won't
2 spend much time on the summary, because the individual
3 chapter needs will cover this later on in the presentation.

4 (Slide.)

5 This is taken from the table of contents. It just
6 indicates what the various chapters contain. Chapter 2
7 describes basically the mechanisms with fission product
8 information within the fuel and a number of other subjects
9 dealing with the health effects of radioactive materials
10 barriers, releasing these materials, et cetera.

11 Chapter 3, where it presents a description of the
12 accident sequences which were used in the analysis of
13 fission product transfer, also, it goes into some detail in
14 the design of various type nuclear steam supply systems,
15 containments, et cetera.

16 Chapter 4, we really begin the discussion of
17 fission product release behavior. In Chapter 4 we have a
18 description of where fission products are located in the
19 fuel rods, how they migrate, how they are released under
20 accident situations, et cetera.

21 In Chapter 5, the chemistry of cesium iodide and a
22 few other fission products are discussed. There are two
23 main subsections in this chapter. One is section on vapor
24 phase chemistry, and another section, subsection, on the
25 behavior of iodine in aqueous solutions.

1 (Slide.)

2 In Chapter 6, the transport behavior of fission
3 products when they are released from the fuel and during
4 their transport through the reactor coolant system are
5 discussed. Basically, in this study, we used the TRAP-MELT
6 code to do this analysis.

7 In Chapter 7, the mechanisms of fission product
8 transport within the containment are discussed. The various
9 computer models that have been used in the study are
10 described, and then a number of calculations are performed
11 to determine the attention of various forms of fission
12 products, particularly vapors, et cetera.

13 And then in Chapter 8, the effectiveness of eight
14 different engineered safety features are addressed for a
15 range of accidents and for different chemical forms of
16 iodine.

17 (Slide.)

18 What I would like to do now is to go into the
19 discussion of the more important conclusions from the
20 chapters dealing with fission product release and transport
21 behavior. Those began with Chapter 4, which, as you recall,
22 the release from the fuel. During this study a review was
23 made of the experimental evidence for or against the
24 chemical form of iodine released from the fuel. This review
25 indicated that there was insufficient evidence to make a

1 determination one way or another whether cesium iodide was
2 the dominant form released or elemental iodine.

3 Also, in this study the equilibrium thermodynamic
4 calculations performed in the past were to determine the
5 chemical form of iodine under conditions equivalent or that
6 you would find in the fuel cladding gap was examined. These
7 calculations indicate the predominant form of iodine should
8 be cesium iodide; and the remaining cesium, which is not in
9 the form of cesium iodide, should be in the form of either a
10 compound with UO_2 , a cesium urinate; and also there should
11 be small amounts of cesium in elemental form in the gas
12 phase.

13 Another finding in this study was -- excuse me,
14 let me back up for a second -- based on three of what we
15 considered the best release from fuel experiments, a new set
16 of release rate estimates were made for the cesium products
17 based on these experiments. Using these new release rate
18 estimates, total releases for two accident sequences were
19 determined. These were then compared with the melt releases
20 presented in the reactor safety study. As for the reactor
21 safety study, we found that the release of iodine in cesium
22 during the in-vessel core meltdown phase was nearly
23 complete.

24 MR. HOELLER: Dr. Lawroski has a question.

25 MR. LAWROSKI: In part, it is with respect to your

1 Chapter 5. To what extent did people at least look into the
2 chemistry of tellurium, since it is a precursor to iodine
3 and, of course, its chemistry could have quite an effect on
4 that part of the iodine that would come as a result of decay
5 of tellurium after the accident?

6 MR. SHERRY: Okay. We briefly looked at in the --
7 as I will get to in the next chapter -- we looked at the
8 behavior of tellurium in a tellurium-oxygen-hydrogen gas
9 system. And I will get to that.

10 MR. LAWPOSKI: So it is in that?

11 MR. SHERRY: It is in there. Although I don't
12 believe we did any calculations of tellurium behavior where
13 we had uranium present like you would find in the gap
14 space.

15 MR. BELL: There is no tellurium in the gap
16 space.

17 MR. MOELLER: We can't hear you. Give us your
18 name, too, please.

19 MR. WICHNER: Bob Wichner from Oak Ridge. There
20 are no calculations performed in tellurium in the gap space,
21 but, in general, the question as posed does not -- there is
22 not sufficient background information to address that
23 question. And I will repose that question in my talk.

24 MR. MOELLER: Thank you.

25 MR. SHERRY: Using these release rate estimates in

1 our study, we found that we calculated that the releases of
2 tellurium actually vary, and strontium were significantly
3 higher for the in-vessel release period than we calculated
4 in the reactor safety study.

5 Also, using the release rate estimates, we
6 calculated the total aerosol masses released up until the
7 time of the failure of the lower core structure. For the
8 two cases analyzed we calculated 770 and 1450 kilograms
9 aerosols released in vessel.

10 Using a correlation developed by Sandia
11 Laboratories, we calculated the aerosol release during melt
12 concrete interactions for these two accident sequences, and
13 we calculated a maximum of 510 additional or 510 kilograms
14 of aerosol generated during reactor vessel failure.

15 (Slide.)

16 The major conclusions from the chapter on fission
17 product chemistry are listed here. We performed a -- or
18 Sandia and Oak Ridge performed calculations for the
19 iodine-cesium-hydrogen-oxygen system over a wide range of
20 conditions, temperatures, concentration of various species,
21 in both reducing and oxidizing conditions. And these
22 calculations indicate that in the iodine-cesium-steam
23 system, steam-hydrogen system, that the dominant species
24 would be elemental iodine, cesium iodide, and hydrogen
25 iodide.

1 It was found that the elemental iodine dominates
2 in oxidizing environments has been assumed, and in reducing
3 atmospheres and at lower temperatures the cesium iodide
4 dominates. These calculations also indicate that the major
5 cesium species in the gas phase in the primary system would
6 be cesium hydroxide, cesium oxide, and elemental cesium.

7 We also did the calculations for the -- to
8 investigate the predominant species of tellurium and the
9 tellurium-oxygen-hydrogen system, and it was found that
10 tellurium oxide would be the only significant tellurium
11 species that we found to be stable.

12 The conclusions from the investigations into the
13 behavior of iodine in the aqueous system indicate that at
14 equilibrium the iodine will exist predominantly as iodide or
15 iodate species, partition coefficient -- that is, the ratio
16 of concentration in a liquid phase to the gas phase -- for
17 aqueous iodine at equilibrium will be at least 100,000.

18 Conclusions about nonequilibrium iodine partition
19 coefficient, partition coefficients, and nonequilibrium
20 iodine chemistry are subjects of large uncertainty because
21 of the limitations in the data base.

22 However, some conclusions can be drawn about
23 nonequilibrium iodide partition coefficients. These would
24 indicate that a range of 100 -- that's 10 to the fifth --

25 (Laughter.)

1 MR. SHEPPY: -- not 100 and 5 -- would be
2 appropriate to these conditions, appropriate estimates for
3 nonequilibrium iodine partition coefficients.

4 The last two conclusions were based on the
5 assumption that I₂, or or elemental iodine, forms the
6 initial form of iodine. However, if the iodine is initially
7 released from the fuel as cesium iodide, then the partition
8 coefficients would be much larger.

9 A review of the available data on the formation of
10 organic iodide under accident conditions, a review of the
11 test information that is available was done. This material
12 was reviewed from a more realistic viewpoint. And based on
13 this review, it was concluded that the best estimate for the
14 fractional conversion of the elemental iodine for two
15 organic iodide should be less than one-tenth of a percent.

16 (Slide.)

17 MR. STEINDLER: How did you define that partition
18 coefficient? Complement of a gas?

19 MR. SHEPPY: Right. It is the concentration of
20 liquid over concentration of the gas. That includes all of
21 the iodine species except the organic iodine fraction.

22 MR. ETHERINGTON: But in the last item, it's
23 elemental iodine it's not all the iodine species, was it?

24 MR. SHEPPY: That was a fractional coefficient of
25 elemental iodine to methyl iodide.

1 MR. KABAT: Have you made an estimate the interval
2 or on how long it will take for elemental iodine to get in
3 at equilibrium to form the I₂ plus IO₃?

4 MR. SHERRY: Would Oak Ridge --

5 MR. BELL: Very little kinetic data for that
6 reaction. And, no, we are not prepared to make a half-life
7 calculation on that reaction.

8 MR. KABAT: Have you considered hydrolysis as the
9 process involved in dissolving elemental iodine involved
10 there? Because from these facts, it doesn't seem to be
11 clear.

12 MR. BELL: I am J. T. Bell, from ORNL. We do look
13 at the hydrolysis of I₂ species with water to produce HOI.

14 I am sorry. He asked me to say my name, and I am
15 not sure I caught all of your question.

16 MR. KABAT: There is no -- you haven't mentioned
17 HOI as one of the possible species at all? You just
18 conclude --

19 MR. BELL: Yes, we do, in Chapter 5, consider HOI
20 as possible species.

21 MR. KABAT: But not in the conclusions.

22 MR. SHERRY: That was the --

23 MR. BELL: They are really there in the
24 conclusions where the partition coefficients could be as low
25 as 100. That's the only way they could get to that low

1 number is if HOI is present. So, yes, they are included in
2 that sense.

3 MR. SHERRY: This conclusion is for the
4 predominant species at equilibrium.

5 MR. BELL: The one, two, three -- third conclusion
6 down is really based on only the reaction to form HOI.

7 MR. KABAT: Did you say there is coefficients for
8 I₂?

9 MR. BELL: HOI is also considered.

10 MR. KABAT: Thank you.

11 MR. MOELLER: Is that adequate, Dr. Kabat?

12 MR. KABAT: I guess we can discuss it in more
13 detail later on.

14 MR. MOELLER: Right. We can, when the chapter
15 comes.

16 MR. LAWROSKI: When you don't have partition
17 coefficients greater than ⁵10, the significance of such
18 numbers is not just sort of lost, though, when you consider
19 the effects of entrainment or aerosols. For example --

20 MR. SILBERBERG: Mechanical.

21 MR. LAWROSKI: -- many of us have been involved in
22 trying to concentrate radioactive wastes and finding it very
23 difficult to get factors of better than ⁴10, even when
24 rather significant efforts are made to cut down the
25 entrainment life.

1 I see a head shaking "Yes" back there. So we may
2 not be able to take very much advantage of the last
3 mentioned, you know, in the factors of partition greater for
4 cesium iodide than even the 10^5 , a few lines above, which
5 was the case for elemental iodine.

6 MR. SHERRY: I think the importance of the very
7 high partition --

8 MR. LAWROSKI: Because we are not dealing with a
9 quiescent system when you evaporate, say, at room
10 temperature saltwater, you don't get very much entrainment.
11 On the other hand, when you put it at boiling, you get a
12 different situation.

13 MR. SHERRY: I think the importance of the very
14 high partition coefficient is not from the standpoint of the
15 long-term ratio of the amount of iodine in the gas phase to
16 that in the sump, say, but the fact that with very high
17 partition coefficient, the liquid phase would not limit the
18 mass transport and, consequently, the steam flow carrying
19 radioactive materials would contact water in the primary
20 system would be limited by probably vapor phase transport
21 rather than the liquid phase. And that is quite important.

22 (Slide.)

23 Moving on to Chapter 6, using the trap code, the
24 calculations indicate that there was very little attenuation
25 of molecular iodine during transport through the primary

1 system for accident sequences where the primary system was
2 dry. However, calculations indicate if the flow path would
3 contact water, for example, in TMI-2, where the flow went
4 through the -- where the steam flow went through a partially
5 water-filled pressurizer during escape into the containment,
6 then through the very high attenuation factors of iodine
7 from within the primary system, mostly the IV transfer to
8 the liquid phase.

9 It was also found that the attenuation of cesium
10 iodide was high for accident sequences not involved in a
11 full core melt irregardless of whether there was water in
12 the primary system or whether the primary system was dry.

13 However, for accident sequences that led to full
14 core melt, there was less attenuation of cesium iodide.
15 This was primarily due to the formation of large quantities
16 of aerosols onto which the cesium iodide would deposit
17 rather than onto the walls. Once on the aerosols, it would
18 then be transported with the steam flow in the aerosols into
19 containment.

20 MR. CATTON: Is much attention given to the event
21 feed sequence?

22 MR. SHERRY: Event feed?

23 MR. CATTON: Yes.

24 MR. SHERRY: Yes, we --

25 MR. CATTON: Do these conclusions hold for Event

1 V?

2 MR. DENNING: Richard Denning from Battelle.

3 Actually, we looked at Event V more from the
4 containment aspects than from the primary system aspects,
5 although the pipe break accidents that we looked at in
6 Chapter 5 on primary system transport would be applicable to
7 event V, too. And the indications would be that there
8 wouldn't be much attenuation in the primary system.

9 MR. CATTON: Okay. Thank you.

10 MR. SHERBY: Okay. Using the results from Chapter
11 5 on the fission product chemistry in the gas phase in the
12 thermal hydraulic calculations that were done during the
13 study, several additional conclusions could be made about
14 the dominant form, the expected dominant form of iodine.
15 And because of the I concentrations of fission products and
16 the release conditions during the core region, even though
17 it is fairly high temperatures,, you would expect that
18 cesium iodide would be the dominant form near the core.

19 As the flow leaves the core area out into the
20 primary system and is diluted by additional steam flow and
21 is cooled, cesium iodide stability would be -- well, cesium
22 iodide would again be favored because of the lower
23 temperatures being in the lesser atmosphere.

24 (Slide.)

25 The conclusions regarding the behavior of fission

1 products during transport through the containment are that
2 the overall attenuation factors, the overall removal of
3 iodine in the containment was not dramatically different
4 whether the iodide would be in the form of particulate
5 cesium iodide associated with other aerosols, of course, or
6 whether it was in the form of elemental molecular iodide.

7 For the most severe accidents we looked at, that I
8 term the "risk-dominant accidents," those being accidents
9 where there is a core melt event, the containment engineered
10 safety features fail to operate, such as the containment
11 spray systems and eventually the containment fails, under
12 these types of accident conditions, the predicted
13 attenuation of iodine was on the order of 50 percent,
14 whether it was in the form of an aerosol or a molecular
15 iodine.

16 This calculation was made for the large dry
17 containments, such as Three Mile Island, comparable
18 attenuation factors for boiling water reactors. And ice
19 condensor containments were also addressed. We used the
20 NAAU code to evaluate the effect of steam condensation on
21 aerosols for the TXLB prime sequence, which will be
22 discussed later.

23 We found that the effect of steam -- we considered
24 steam condensation. There was an additional attenuation on
25 the order of 20 percent due to the condensation of steam on

1 the aerosols.

2 For a severe core damage accident which we
3 analyzed, which was characterized by having approximately 50
4 percent of the core melted, the late ECCS injection, no
5 containment failure, add the engineered safeguards in the
6 containment operable, we calculated attenuation factors of
7 greater than 100,000 for the containment for all the fission
8 product species we included in the analysis, which was for
9 essentially everything except the noble gases.

10 MR. ETHERINGTON: On the first item there, does I2
11 imply with associated organic iodide, or is that just
12 elemental iodide?

13 MR. SHERRY: That was just the vapor, the
14 elemental form.

15 MR. ETHERINGTON: It did not include organic
16 iodide?

17 MR. SHERRY: No. Not this one. Gases.

18 MR. CATTON: Shouldn't there be a fifth
19 conclusion? That is, that we don't know the
20 thermohydraulics really well enough to do a sound job on the
21 rest of the calculations?

22 MR. SILBERBERG: That's the sixth, I think. That
23 is the sixth and seventh.

24 MR. SHERRY: That's -- I have included that under
25 data base limitations. It doesn't show up as a conclusion.

1 But, yes, that is a valid conclusion.

2 MR. MOELLER: Mel.

3 MR. SILBERBERG: Let me just note I think that is
4 a valid conclusion, really for six -- better for six than
5 seven, I believe, for condensation. Thank you.

6 (Slide.)

7 MR. SHERRY: I would like to point out some major
8 limitations on the scope of this report. First of all, we
9 did not develop a new set of quantitative source terms for
10 release of radioactive materials from the plant such as was
11 presented in the reactor safety study. As Mel mentioned
12 previously, in some cases we took a close look at the
13 chemistry of the fission products other than cesium and
14 iodine, although these other species were treated as in the
15 bulk of the aerosols.

16 We only looked at a limited set of the postulated
17 accident sequences. Several potentially important
18 mechanisms were identified during the study which, because
19 of a lack of any data at all, we -- you know, these are not
20 evaluated for what the effect of hydrogen burn in
21 containment would be under the physical and chemical
22 products would be in the containment atmosphere or settling
23 onto surfaces within the containment.

24 MR. MOELLER: Your first limitation listed on that
25 chart, you are simply saying to us that you either give us

1 more confidence or less confidence in what we have been
2 doing in the past, but you don't really give us a set of new
3 source terms; is that it?

4 MR. SHERRY: Right. We take a look at the
5 individual mechanisms and point out what we feel are the
6 best models and do some calculations with these models to
7 provide some insights into what possible attenuation.

8 But because of the limited amount of time for the
9 study, we did not do a systematic calculation of where we
10 first calculated the new release rates from the fuel and
11 then to the primary system calculation and then the
12 containment calculation. And since we did not do this, we
13 don't -- we don't have -- we didn't have any way to generate
14 the new source terms systematically for each accident
15 sequence.

16 MR. DOELLER: M-h.

17 MR. SILBERBERG: I would just add that when we
18 first started this study, we knew that we were not going to
19 be able to come up with a new set of source terms, but we
20 would hope -- we had hoped -- that we would at least provide
21 enough information, enough evaluation analysis, to provide a
22 good point of departure in which to proceed in the future to
23 get those source terms.

24 And I might say I hadn't originally thought that
25 we would even get this close to that. And we did. So, as

1 such, at this point we are not going to recommend in that
2 context of reactor safety study saying these are the kinds
3 of release rates factors we want to use for release to
4 containment. One would want to go from the beginning to the
5 end again and add them all up and see what one gets.

6 MR. ETHERINGTON: On the last item on the previous
7 slide, was there any consideration of any qualitative
8 consideration of what a hydrogen deflagration might do?

9 MR. SHERRY: Yes.

10 MR. ETHERINGTON: Did you look at it and say,
11 "Well, we can't do anything or" --

12 MR. SHERRY: Well, we did take a brief look at
13 it. We asked Dr. Malinauskas at Oak Ridge to see what he
14 thought about it, and he indicated that he didn't feel that
15 it would be worth pursuing right now because --

16 MR. ETHERINGTON: Would you speak a little louder,
17 please?

18 MR. SHERRY: I am sorry. Initially, we had asked
19 Dr. Malinauskas at Oak Ridge what his thoughts were on this
20 subject, and he concluded that basically, with so little
21 information around to make any estimates, it would not be
22 worth the effort right now to pursue that.

23 MR. ETHERINGTON: His opinion was it was not
24 important? That is really what I was trying to drive at.

25 MR. SHERRY: I don't believe it was his opinion

1 that it was not important.

2 MR. ETHERINGTON: I see.

3 MR. KOELLER: He said we just don't know how to do
4 it?

5 MR. SHERRY: Right.

6 (Slide.)

7 Another limitation in the scope of this report is
8 that we did not evaluate the past reactor accidents or the
9 destructive tests with the models used for the analysis in
10 this report, for a number of reasons. Although we couldn't
11 examine the effect of these limitations rigorously on our
12 conclusions, we don't believe that because of these
13 limitations our conclusions are in error by large amounts.

14 MR. KOELLER: How much more do you have? I know
15 we are running a little behind.

16 MR. SHERRY: I have a number of slides on
17 limitations in the data base which can be taken at a later
18 time.

19 MR. SILBERBERG: At the end.

20 MR. SHERRY: So I can conclude my presentation
21 right now.

22 MR. KOELLER: All right, maybe we should do that.

23 MR. SILBERBERG: We can have that later.

24 MR. WINCHER: Bob Wincher from Oak Ridge. I would
25 like to question your definition of the term

1 "risk-dominating accident." It's a little bit different
2 from what I thought it would mean. You're using it, it
3 seems, synonymously with "severe accident," whereas I
4 thought a risk-dominating accident could be either severe or
5 a less severe accident as long as it's near the probability
6 consequence area.

7 It's a fairly important point, because you make
8 some conclusions regarding the risk-dominating accidents,
9 and I think perhaps what you really mean is "severe."

10 MR. SHERPY: Well, in the reactor safety study, if
11 I am correct, the risk-dominant accidents, irregardless of
12 what sequence they follow, would always have certain
13 characteristics. Among those were above-ground containment
14 failure or at least failure to isolate the containment or
15 something involved --

16 MR. LAWROSKI: Louder, please.

17 MR. SHERPY: I am sorry. As I was saying, the
18 risk-dominant accidents, irregardless of the sequence in the
19 reactor -- as analyzed in the reactor safety study -- always
20 had certain characteristics, such as above-ground
21 atmospheric release, containment failure above-ground, core
22 meltdown and, in most cases, failure of the containment
23 engineered safety features to operate.

24 That is what I meant when I said "risk-dominant,"
25 and I was not referring to any particular accident

1 sequence.

2 MR. WINCHER: If I might, the point I am driving
3 at is that some of the conclusions that were arrived at do
4 in fact effect the risk curve at the low-consequence end,
5 whereas the way in which the conclusion was stated, that did
6 not happen because of the difference in definition of the
7 term "risk-dominating accident." I am not sure I made my
8 point clear.

9 It is possible, from the conclusions as stated,
10 that the consequence of less serious accidents are indeed
11 reduced; therefore, in my review of what "risk-dominating
12 accident" means, I would say that the risk has in fact been
13 diminished of the low-consequence accident.

14 MR. BELL: Amen.

15 MR. MOELLER: You are saying also that if that we
16 are to give our attention to the more important contributors
17 to risk, we will look at the bigger-risk accidents?

18 MR. ALBAUGH: No, not necessarily.

19 MR. MOELLER: Any other comments or questions at
20 this point?

21 (No response.)

22 MR. MOELLER: I think we should all recognize, of
23 course, that when we cover the individual chapters, we will
24 have an opportunity to go into each of these items in more
25 detail.

1 Okay, let's take ten minutes.

2 (Brief recess.)

3 MR. VOELLER: The meeting will come to order.

4 We are in a very poor room, from the standpoint of
5 hearing what is being said. And we have a high level of
6 background noise. So we ask and plead with everyone to
7 identify yourself and to speak loudly.

8 Also, for the various laboratory people who are
9 here who have worked on various chapters of the report, I
10 would encourage you to raise your hand and contribute if you
11 have a comment, because we are here to learn and to do the
12 best job jointly that we can. So we very much encourage you
13 and invite your comments.

14 We will move on then to the Battelle Columbus
15 presentation. You are Mr. Denning?

16 MR. DENNING: That's right. I am Richard Denning
17 from Battelle Columbus. And I have worked on the accident
18 sequence identification with Mark Cunningham of the NEC.

19 The reason that we had to select specific accident
20 sequences here was to provide a context within which the
21 study would be performed. That is, the evaluation of the
22 accuracy of the data base, the evaluation of the analytical
23 methods depends upon which accident sequences one is looking
24 at. And so we had to define accident sequences which would
25 be used in the different chapters and in each of the results

1 type of chapters. Chapters 2 and 3, of course, are really
2 just background.

3 (Slide.)

4 Chapter 4 and the estimation of the release of
5 fission products and aerosols from the fuel, we had to
6 define some accident sequences there to help the Oak Ridge
7 people in doing this. There is no explicit consideration of
8 accident sequences in Chapter 5. However, there was
9 iteration between Chapter 5 and Chapter 6. When we looked
10 at the primary system transport behavior for different
11 accident sequences, we then told the people from Sandia what
12 regime they should be looking in with regards to H₂O ratios,
13 fission products, H₂O ratios to come up with the chemical
14 form.

15 So they selected their regime based upon the
16 analyses here, and then later, after we had done the primary
17 system transport analyses, we went back and looked to see
18 what we thought the chemical form of the fission products
19 would be, based upon those results.

20 And the particular accidents are selected for
21 Chapter 6, and in a second I will explain the background
22 behind why we chose the ones we chose for Chapter 7 on
23 containment transport, and then in Chapter 8 we really went
24 back and looked at the results from these other chapters.

25 (Slide.)

1 The criteria for selecting the accident sequences
2 were, first of all, we wanted to cover a broad spectrum of
3 accident sequences. We realized, though, it couldn't be
4 comprehensive. But we wanted to try to cover as broad a
5 spectrum as we could. We wanted to look at real accident
6 sequences. And our intent in the analysis was to analyze
7 these realistically.

8 And there were not intentional conservatisms put
9 into the analysis. We wanted to include a range of possible
10 conditions in the reactor coolant system and in the
11 containment. We wanted to examine the influences of the
12 containment design and engineered safety features.

13 Now, there are a number of different areas within
14 the plant where there are accumulations of fission products
15 that can be released to the environment. We decided to look
16 specifically at damage to fuel in the operating reactor
17 because of the inventory of fission products there. There
18 are like 5000 curies of fission products in the waste gas
19 storage tanks, about 5000 curies of fission products in the
20 reactor coolant system dissolved there. There are about 2
21 times 10 to the seventh curies in the spent fuel storage
22 pool.

23 These are ductile numbers, but they are greater
24 than 10 to the ninth curies fission products within the fuel
25 of the operator reactor. So this is where there is a

1 potential for a major release, and so this is where we
2 focused in our study, not to say that the accidents involved
3 in the others aren't important, but this is what we decided
4 to look at in this particular study.

5 (Slide.)

6 We divided the accidents up into two categories:
7 ones which involved minor or no fuel damage; and then ones
8 that involved severe core damage. The minor or no fuel
9 damage sequences are the types of sequences that are
10 typically analyzed in safety analysis reports or, if one is
11 familiar with the AWS classification of accidents, their
12 categories 1 through 4 defined there, these would be the
13 condition 4 type of accidents. Realistic accident sequences
14 in which one might get cladding damage, that is the type of
15 thing that is involved there.

16 MR. LAWROSKI: You use the number of 10 to the
17 ninth as the inventory of fission products.

18 MR. DENNING: Yes.

19 MR. LAWROSKI: Yet I see numbers that are at least
20 a factor of 10 higher than that quoted for a thousand
21 megawatt electrical.

22 MR. DENNING: The value for a thousand-megawatt
23 electrical reactor -- rather, 1200 megawatt electrical
24 reactor that Sandia analyzed with origin was 1.4×10^9 . I
25 think that's a good number for the curies in an operating

1 reactor.

2 MR. WINCHER: At what time?

3 MR. DENNING: This was after three years of
4 operation, I believe. This was immediately. Zero time. I
5 am not sure where your 10 to the tenth would have come
6 from.

7 MR. LAWROSKI: Well, because I recall a paper by
8 Dr. Weinberg in which he states an inventory of 15 billion
9 curies.

10 MR. DENNING: 15 billion? I think that 1.5
11 billion is really the better number. I think there is an
12 error of a factor of 10 there. However, I don't think I
13 would like to challenge Dr. Weinberg.

14 (Laughter.)

15 MR. DENNING: Then the other category was the
16 severe core damage accidents. The problem we have run into
17 here is semantics. People use "severe core damage,"
18 "degraded core," then the "core meltdown." Some people use
19 them for different purposes. I use here "degraded core,"
20 things that are more severe than clad damage, but not going
21 to complete core meltdown. But that is not universally
22 used.

23 In this report, when we refer to "degraded core
24 sequences," there are things that are more severe than
25 cladding damage but don't go to complete core meltdown.

1 Now, for these severe core damage accidents, there
2 are characteristics of them that are pretty much all the
3 same; that is, there has to be a heat coolant imbalance.
4 Either the heat generation rate has to rise and exceed the
5 capability of the coolant to take away the heat such as in a
6 reactivity accident, or you have to degrade the heat
7 transfer capability of the coolant such as by losing the
8 coolant. And it is really the second type that is primarily
9 what we have looked at in this study.

10 This seems to be the more likely type
11 (indicating), although the characteristics aren't
12 appreciably from between these two different types of
13 accidents. But this is more loss of coolant type of
14 condition there leading to degraded core conditions.

15 (Slide.)

16 MR. STEINDLER: Are you planning to address at
17 some later time the difference in the characteristics
18 between the first and the second of those two last items
19 that you indicated?

20 MR. DENNING: Yes. Let me go back and make sure I
21 understand. I am going to go through now and tell you which
22 accident sequences we analyzed here, here, and here
23 (indicating). And I will tell you what those accident
24 sequences looked like.

25 Put then when Jim Gieseke gets up this afternoon

1 he will explain what the fission product transfer was.

2 MR. STEINDLER: That's not what I had in mind.

3 Under your last heading there, the severe core damage
4 sequence involves one of two situations. Now, down one
5 further --

6 MR. DENNING: Here? Yes.

7 MR. STEINDLER: It's the first one that
8 constitutes the largest amount of accumulated data on the
9 reactor accidents that have led to people becoming
10 interested in this whole problem in the first place. And if
11 there is a difference in fission product behavior with
12 release characteristics, et cetera, then looking at the
13 models that are prepared on the basis of the second item and
14 comparing them to the data, what we have is a difficult
15 item. It's the difference between the two I am looking
16 for.

17 MR. DENNING: Let me see if I understand. You are
18 saying that reactivity excursion accidents are the ones we
19 have the most experience from?

20 MR. STEINDLER: A part of the experience. That's
21 right.

22 MR. DENNING: It certainly is a part of the
23 experience. Now, there are a number of reasons why we
24 didn't select reactivity excursion accidents specifically to
25 look at. One of them is that typically they happen in

1 water-bounded environments, so that the releases are going
2 going to be into -- eventually wind up into water. And I
3 think in that sense these accidents are going to look
4 eventually a lot like an accident that we analyzed right here
5 (indicating).

6 As far as what -- it also turned out that
7 reactivity excursion accidents didn't look like they are
8 risk-dominant. That may be unfair, because I think we
9 overplay this question of risk-dominant. But in WASH-1400
10 it didn't look like the rod ejection accident, the control
11 rod dropout accident, are really that likely, particularly
12 in comparison to the expected consequences.

13 So I am afraid that we may not answer all the
14 questions that you might ask in this regard and I think at
15 the moment, then, all I can say is that you might save your
16 comments until afterwards and perhaps make some suggestions
17 in that regard.

18 MR. STEINDLER: Just a final comment. Looking at
19 the experience of those accidents that are cited in one of
20 the reports that Gary circulated to us, which I can't cite
21 to you, it's a sequence of experiences which indicate that
22 noble gas release as well as iodine release and so on. I
23 gather then that we need to look at the consequences of
24 those accidents with great caution because they are in fact
25 different from the heat transfer capability. They're the

1 ones I am focusing on.

2 MR. DENNING: I think the most important thing
3 there is that there aren't many accidents that have happened
4 in PWRs or BWRs of this type. Okay. I think that is the
5 big difference as opposed to the difference between do they
6 look like this type or that type (indicating).

7 I think the biggest thing is were they really in
8 similar geometries for similar behavior to what one might
9 expect in a real operating reactor.

10 (Slide.)

11 Now, we only considered one of the minor or no
12 fuel type damage sequences. This was a large-pipe-break
13 accident with the emergency core cooling system operating as
14 expected. In this particular accident sequence, you would
15 expect some cladding failure, some release of gas
16 inventory. And we only looked at this particular accident
17 sequence with regard to this primary system accident
18 behavior; we were looking to see how much retention of
19 radioactivity will we expect in the primary system. And the
20 results will be discussed later.

21 One would expect in this particular accident
22 sequence a very small release from the containment.

23 (Slide.)

24 The degraded core sequences are really very
25 difficult to characterize, because they involve partial BSC

1 performance. In general, the reason you get into a degraded
2 core condition is because there has been either the failure
3 of an engineered safety feature or the delayed performance
4 of an engineered safety feature. And the the thing that
5 arrests it short of full core meltdown is that the
6 engineered safety feature must have at least worked to some
7 degree.

8 So we are faced here with quite a broad range of
9 possible releases to the containment, and they range from
10 things that are characteristics of these minor fuel damage
11 accidents all the way up to accidents that are typical of
12 the full core meltdown accidents.

13 We looked at two particular conditions, because it
14 seemed to us that there were two conditions of major
15 interest. One of those is release into water-bounded
16 primary systems, such as as happened at TMI. At TMI, the
17 core was uncovered, but there was always water in the
18 pressurizer. For the iodine to get into the containment
19 atmosphere it had to go through water. So this was the
20 condition that we wanted to look at.

21 On the other hand, there are also sequences such
22 as pipe break accidents where there could be a dry pathway
23 to the containment, and one might expect a larger transport
24 of radioactive material to the containment under those
25 conditions.

1 So the two sequences we looked at were a TMI-like
2 accident, and that is what this stuck-open relief valve with
3 partial ECCS operation is. It's not supposed to be a mockup
4 of TMI, and there are some assumptions in the analysis that
5 are different from TMI. It's supposed to be characteristic
6 of a spectrum of accidents of this type.

7 We looked at fissionproduct transport through
8 water to the containment atmosphere in this case. And we
9 also wanted to look at transport through systems like the
10 letdown system. And we did it within the context of this
11 accident sequence here.

12 Then the other type was a large-pipe-break
13 accident with delayed ECCS injection. In this particular
14 case, the ECC system, the active ECC system, was delayed 16
15 minutes. When it came on, the core was 50 percent
16 core-molten or 50 percent of the core had been melted, and
17 then it rapidly, or presumably, recovered the core, and
18 arrested core melting at that point.

19 There was a dry pathway to containment during the
20 period of core uncovering when the damage was occurring to the
21 core. Note the similarity here to the TID assemblies. 50
22 percent release of iodine in the TID assumptions. Now, this
23 is not a design basis accident; this is supposedly a
24 realistic type of accident that looks something like the TID
25 assumptions!

1 So if you want to see what would something look
2 like, the TID assumptions look like, within the context of a
3 realistic accident sequence, then this is somewhat like
4 that.

5 (Slide.)

6 Now I am going to be talking about core meltdown
7 sequences that we analyzed. We started off by looking at
8 release from the fuel. This was input required for Chapter
9 4, and we looked at two specific cases. A rapid fuel heatup
10 case, where the core would melt down very quickly, and then
11 a delayed core meltdown case where core meltdown was delayed
12 30 hours.

13 I won't go into the specifics of this particular
14 accident sequence, but meltdown doesn't really occur until
15 30 hours after shutdown. So it happens over a more
16 protracted time period.

17 So we used these two sequences here (indicating)
18 to give us the spray.

19 MR. CATTON: The first one, rapid fuel heatup,
20 that is still slow relative to the chemical kinetics?

21 MR. DENNING: I think this is true, because this
22 is like 20 minutes to melt down the core.

23 MR. SILBERBERG: Right.
24
25

1 (Slide.)

2 Then we moved on to transport in the primary
3 system.

4 Now, Appendix A has a generic categorization of
5 accident sequences. The intent there is to try to cover a
6 broad spectrum of possible conditions so that we could show
7 that the specific ones that we chose were characteristic of
8 the entire spectrum.

9 In there we looked at the behavior in the reactor
10 coolant system and in the reactor cavity. I won't go into
11 this categorization that we went through there. But the
12 principal variations that we saw between the sequences were
13 in the flow path to the containment, which is different for
14 different sequences, the thermohydraulic conditions in the
15 flow path, the pressure during core meltdown recognized that
16 in some sequences the pressure in the primary system can be
17 post-atmospheric, such as a core meltdown that was initiated
18 by a large pipe break, or it can be a full system pressure
19 like 15 bars in some transient accident sequences.

20 And what we wanted to look at were these
21 conditions and also the hydrogen-to-oxygen ratios. We have
22 both potential for oxidizing or release in the atmosphere
23 and the fission product-to-H₂O ratios.

24 (Slide.)

25 In general, we saw two stages of core meltdown

1 here. And the first stage, which is before pressure vessel
2 melt-through, there are two primary release pathways. The
3 core is heating up here (indicating) and releasing the
4 radioactivity and relating many of the transient accident
5 sequences, the pathways at the top of the core to the hot
6 leg and the pressurizer to the reactor coolant drain tank
7 and into the containment atmosphere.

8 If you have a pipe-break accident, then you go
9 from the top of the core to the location of the pipe break.
10 Now, that location can be quite a bit different for, like,
11 example, like it can be in the hot leg; that's a pretty
12 direct pathway. It could be in the cold leg and require
13 transport through the steam generator, which could give you
14 quite a difference as far as deposition within the primary
15 system before release to the environment.

16 The maximum temperatures that we saw for core melt
17 during this stage were up to 1500 degrees C, leaving the
18 system in a hot leg break. The range of temperatures
19 throughout this system could be from something like 2000
20 degrees centigrade in the upper plenum down to 250 degrees
21 centigrade far down the pathway system.

22 (Slide.)

23 Then after you have pressure vessel melt-through
24 and the core is attacking the concrete, you can have flow up
25 to the containment atmosphere.

1 There are also some other potential flow paths,
2 such as through the keyway back up to the containment
3 atmosphere.

4 I guess I forgot to mention that I wanted to, in
5 that earlier phase of the accident that I went into before,
6 it really is pretty unlikely that you are going to have air
7 ingress into the reactor vessel. You are almost certainly
8 going to have a reducing environment. One can dream up
9 conditions where you can have air ingress, but they look
10 like they have very remote possibilities.

11 In this case, took, it looks like at least in this
12 portion of the transport pathway, that you are going to have
13 reducing conditions. The conditions are going to be
14 dominated by the products of decomposition of the concrete,
15 hydrogen, carbon monoxide, carbon dioxide.

16 Temperatures in here (indicating) are going to
17 range from 1200 degrees centigrade to as high as possibly
18 2200 degrees centigrade. There are some conditions where
19 you might have sprays operating in water flowing down into
20 the cavity, and then things would be pretty cool in the
21 cavity.

22 There is some possibility for a flow pathway
23 coming down the keyway and up around the vessel, and we
24 don't know whether that would actually be realized in an
25 accident where oxygen could be brought down in here

1 (indicating). I think it is unlikely, but it is something
2 that we will have to look at further in the future.

3 (Slide.)

4 The specific sequences that we looked at were for
5 the pressurized water reactor, a large-pipe-break accident
6 with failure of the ECC system, and here we looked at both
7 hot leg and cold leg breaks. And then for transient
8 accident, we looked at loss of heat removal capability, the
9 TMI-2 prime accident. This is according to WASH-1400, one of
10 the more important accident sequences.

11 MR. CATTON: Can you tell me again why you didn't
12 look at the V sequence?

13 MR. DENNING: As far as the primary transport is
14 concerned, you will see that on containment we did. I
15 thought that as far as looking at the primary system
16 deposition, that the V sequence would look somewhat like
17 cold leg break. It doesn't look exactly like that, but it
18 looks somewhat like it. And I would expect similar orders
19 of magnitude certainly of deposition to occur at the V
20 sequence.

21 And then, in the boiling water reactor, we looked
22 again at the large-pipe-break accident with failure of the
23 ECC system. And the transient we looked at here was failure
24 to scram.

25 (Slide.)

1 Next, we looked at the transport in the
2 containment building.

3 (Slide.)

4 This shows a large high-pressure containment
5 design. I have shown in red the envelope of the containment
6 (indicating) so we can see that boundary. And then the
7 important systems here, and the large high-pressure system
8 are the spray systems and the filter systems. And I have to
9 take credit for that artwork.

10 (Laughter.)

11 (Slide.)

12 The particular accident sequences we looked at
13 then were ones with the sprays operating or nonoperating.
14 There are some cases, there are some designs where there is
15 filtered recirculation. This is not typical, but we did
16 look at a case here (indicating).

17 So the case without the sprays operating was TMLB
18 prime, transient with loss of containment heat removal
19 capability. And this is the sequence in which one would
20 expect early containment failure, early atmospheric
21 containment failure. In fact, possibly right near the end
22 of the core meltdown period.

23 We also looked at another version of this TMLB
24 prime in which we did not allow the containment to fail at
25 this early time, and we then followed the transient for some

1 time later, so there was no above-ground containment failure
2 in this other sequence that we looked at.

3 This was particularly useful in comparing the
4 different aerosol transport codes, and you will see that
5 most of those comparisons are for this case (indicating)
6 rather than for this one. With the early containment
7 failure, you don't get a chance to see what differences are
8 going to set up in the aerosol behavior of the different
9 codes.

10 Okay, then we also looked at a small-pipe-break
11 accident with ECC failure, sprays operational; there is no
12 filter in this particular design.

13 And then finally, we looked at a case of
14 small-pipe-break accident with ECC failure with the filter
15 operating. And in the particular design we looked at here
16 (indicating), the pressure never gets up to the point where
17 you would automatically trigger the spray system. So we
18 really have a case here where we just look at the filter.

19 (Slide.)

20 MR. YOELLER: Was there below-ground failure
21 between the sequence where you say there is no above-ground
22 containment failure?

23 MR. DENNING: There actually was not. And in the
24 only sequence where that is important is with the TMLB
25 prime. There was actually no containment failure in that at

1 all.

2 Now, in most of the sequences where the pressures
3 in most core meltdown sequences where the pressure is
4 reduced within the system, it doesn't really make much
5 difference whether you melt through the base mat or not
6 because you're not going to puff out into the ground. In
7 TMLB prime, presumably if you melted through that concrete,
8 you would have some elevated internal pressure, you would
9 have the puff through. We did look at that in this
10 particular comparison.

11 MR. ALBAUGH: Question.

12 MR. DENNING: Yes.

13 MR. ALBAUGH: Not being a veteran of the TENA
14 syndrome, could you refresh me or tell me how long after
15 shutdown you have enough fission product heat left to melt
16 through the base mat?

17 MR. DENNING: To melt through the base mat?

18 MR. ALBAUGH: Yes. Considering all the heat
19 transfer considerations.

20 MR. DENNING: I can't absolutely answer that for
21 you. It's a very open question as to whether you would
22 really melt through. Typically, these base mats are like 12
23 feet thick in the United States.

24 The computer codes that are currently in existence
25 are based upon quenching type of analyses. They cannot

1 really accurately predict what happens in the long term as
2 you are attacking the base mat in the long term. So even
3 for these cases where you have rather rapid meltdown, there
4 still is some question as to whether you would really
5 penetrate the concrete or not.

6 Certainly, it is less likely if you were to delay
7 core meltdown for several hours than if you were to have an
8 immediate core meltdown. But it really is an unanswered
9 question.

10 MR. ALBAUGH: You assumed it for one of your cases
11 here, didn't you?

12 MR. DENNING: Well, actually, we didn't assume it
13 in any of our cases. It wouldn't have made any difference
14 to the atmospheric releases for most of the sequences we
15 looked at. But the specific sequence that you raise, the
16 TMLB prime, it would have made a difference if we had looked
17 at that -- not a very major difference, but it would have
18 made a difference. Let me take that back. It would have
19 made a difference. I can't say that it wouldn't have been a
20 major difference, because it could have been a significant
21 difference to the results.

22 (Slide.)

23 Okay, then, the next is the ice condensor.

24 (Slide.)

25 And then within the ice condensor we have two very

1 important features. I have shown the outer boundaries of
2 the containment and then I have also shown the boundary that
3 separates the upper containment volume for the lower
4 containment volume. Even when you don't have electricity,
5 you have a core meltdown here and things have to go through
6 the ice.

7 Okay. And then up above here (indicating), we
8 also have a spray system which is in there really to vent
9 steam bypasses here, but it also would have some
10 effectiveness in removing radioactive materials.

11 (Slide.)

12 We looked at three cases here. First of all,
13 large-pipe-break accident with failure of ECC system, the
14 ice in place and the sprays functional. We looked at a case
15 with loss of AC power, because the ice condensor has a
16 fairly interesting capability here of a passive
17 condensation. And we looked at the ice functional but with
18 no sprays because there would be no sprays if we lost all AC
19 power.

20 Incidentally, the capability of the ice to remove
21 radioactive materials has been evaluated experimentally by
22 Westinghouse for elemental iodine, but we didn't really have
23 anything here particulate iodide. I don't know if Jim plans
24 to talk about that later.

25 And then there is another accident sequence which

1 is a fairly interesting one for the ice condensor.

2 (Slide.)

3 That is one. It's a common mode failure where the
4 accident happens, a small pipe break, and water gets
5 sprayed, of course, up here (indicating). It would collect
6 up here (indicating) and not run down to the sump. If one
7 were to forget to leave open some valves that go down to the
8 sump from this upper deck area (indicating) and in this
9 particular accident sequence it is assumed that either the
10 pathway gets blocked or people forget to take those things
11 out of there, that block that flow path.

12 So you have a pipe-break accident, everything is
13 happening normally. Spray water is happening up here, the
14 ice is melting, and eventually it all melts away. They run
15 out of water for the sprays because everything is up here
16 (indicating). Then you go into core meltdown. You don't
17 have any ice left, and you don't have any water for sprays.
18 So that is another accident sequence that we looked at
19 there, where neither the ice nor the sprays are functional.

20 MR. MOELLER: In terms of the ice condensers, we
21 noted in reading the report, and we heard a few minutes
22 earlier this morning, that the potential impact of hydrogen
23 burn was not taken into consideration. Now, I gather that
24 was because you lacked the data. But do you further
25 consider that its impact is so insignificant that you can

1 ignore it?

2 MR. DENNING: When we said this morning that the
3 hydrogen deflagration wasn't taken into account, we were
4 referring specifically to the potential for conversion of
5 cesium iodide to elemental iodine through oxidation, through
6 an event like a deflagration. The potential for that,
7 insofar as the potential for a deflagration event to lead to
8 containment failure or to lead to an earlier containment
9 failure, we do indeed take that into account.

10 And, in fact, in the AD case that I mentioned
11 earlier -- let's see, where am I here -- in this case right
12 here (indicating), the containment failure mode is really
13 the result of burning of the hydrogen in the upper
14 compartment. So in that sense, leading to containment
15 failure was taken into account.

16 MR. YOELLER: Now, will someone tell us what their
17 estimate is of the potential impact of the hydrogen burn
18 upon the conversion of cesium iodide into elemental?

19 MR. DENNING: That's what Dr. Malinauskas was
20 saying is a difficult problem that he doesn't feel -- didn't
21 feel could be addressed in this study, I guess.

22 Is that proper?

23 MR. SILPESBERG: Let me just note that I believe
24 Dr. Etherington's comment is still a reasonable one, that
25 perhaps one should at least think about it and see what one

1 might expect. But we might go back and do that.

2 MR. MOELLER: Rich.

3 MR. SHERBY: If the hydrogen burn causes
4 containment failure at the time of the hydrogen burn, then
5 the transformation from one species to another probably
6 doesn't make a whole lot of difference in the atmosphere.

7 However, if it does not immediately lead to
8 containment failure, it may change the deposition mechanisms
9 which could affect later release.

10 MR. MOELLER: Okay. Thank you.

11 (Slide.)

12 MR. DENNING: Now you will see there are a couple
13 of places in here where I have specifically put in for Dr.
14 Catton, and this one is the interfacing systems LOCA
15 bypassing containment, event V.

16 (Slide.)

17 Let me just review for you again what that is. On
18 this side (indicating) we have the containment. We have
19 high-pressure systems that are connected to the low-pressure
20 systems through check valves. If these check valves should
21 go fail while you are at operational pressures, then you
22 could have the high pressure imposed upon these low-pressure
23 systems that can't stand it and a failure that you would
24 then have a flow going back through -- these are connected
25 to the reactor vessel -- through these high-pressure lines

1 into the low-pressure lines through the break into the
2 auxiliary building.

3 The auxiliary building, this is (indicating) is
4 equivalent to about a six-inch break, so it's a pretty large
5 pipe break or potentially large pipe break. It depends upon
6 the mode of failure over here, which is very uncertain.

7 However, this building does not have a high design
8 capability, so it would fail within seconds, up to a minute.
9 Then you would have passage from the fluid from the primary
10 system then out to the environment. So this is the flow
11 path that we're talking about.

12 It bypasses the containment mechanisms, so it was
13 a case that we analyzed. Now, we didn't analyze the primary
14 system deposition, which Dr. Catton has mentioned before
15 could be very important here. I think that you can infer
16 some things about the primary system deposition one might
17 expect here from the analyses for the pipe-break accidents.
18 But we did look at the potential for deposition within this
19 volume here, once it gets released into this volume before
20 it leaks out into the environment.

21 (Slide.)

22 Okay, next we have the boiling water reactors, and
23 I will quickly run through what those designs look like,
24 because I know you are familiar with them.

25 (Slide.)

1 I have shown in red the containment boundary.
2 This building here (indicating) is the containment building
3 or secondary containment building. But this is really the
4 containment envelope (indicating). Of course, the important
5 feature in all of these is the suppression pool.

6 (Slide.)

7 That was the Mark I. A feature that I should
8 point out in the Mark I is that in WASH-1400 the predicted
9 failure location for overpressurization of the BWR Mark I
10 containment was in this region here (indicating) in the
11 suppression pool region. If it did fail in that region,
12 there are a couple of possible flow paths for radioactive
13 materials to take on their way to this building.

14 Now, remember, there is a building around here
15 (indicating), but it has very low design pressure. In all
16 cases, in all core meltdown cases, we predicted that the BWR
17 containment would fail by overpressurization eventually.
18 When it does, this building (indicating) will also fail.

19 Now, in this particular design, there is a standby
20 gas treatment system that would operate if this system
21 (indicating) were intact, and they in fact have some
22 effect. Even though it's not intact, we did not take any
23 credit for that, recognizing that there were panels in this
24 building that would blow out.

25 One release pathway is to go into this little area

1 here (indicating) and out what we call the annulus. There
2 is some credit taken for deposition in this annulus, and you
3 will see we have analyzed the case in which the flow path is
4 this way (indicating).

5 Another possibility is for this wall here, which
6 goes directly to the environment to fail, in which case
7 there is a direct release pathway (indicating).

8 (Slide.)

9 We did not actually do any sequences for the Mark
10 II containment, but this is what it looks like. Of course,
11 the important feature is, again, the suppression pool.

12 (Slide.)

13 And then the Mark III, with the suppression pool.
14 And then there is also a spray system up here (indicating)
15 in the Mark III containment design. Once again I have shown
16 the boundary of this inner region, the drywell here, and
17 this outer containment volume, which is the vapor space to
18 the suppression pool of the Mark III containment design.

19 (Slide.)

20 The key systems again are suppression pools and
21 sprays in some designs. We looked at a large-pipe-break
22 accident with failure of emergency core cooling system in
23 the Mark I, and this is a case where the suppression pool is
24 subcooled, and you would expect it to be very effective in
25 removing radioactive materials from the flow of fission

1 product material.

2 We also looked at a transient with failure to
3 scram in the Mark I. In this case, the pool is boiling
4 during the core melting period, and the particular sequence
5 we looked at here was one where the containment failure mode
6 was such that the flow went up through the annulus. We
7 looked at a transient with failure of heat removal.

8 Incidentally, these two sequences were found to be
9 (indicating) risk-dominant sequences for the PWR in the
10 reactor safety study. But in this case, we looked at the
11 flow bypassing that annular region going directly to the
12 environment, and then we also looked at a transient with
13 loss of all makeup water in the Mark III design, TQUV, in
14 the cooled, subcooled.

15 See that we don't know, really, this is a
16 difficult problem to handle (indicating), the boiling pool,
17 particularly with regard to fission product removal. You
18 will see that when we analyze this from a fission product
19 removal standpoint, we've done that parametrically. It
20 isn't clear just how much retention there would be there.

21 You should also recognize that in these cases,
22 containment failure can occur before or during a core melt
23 period, which introduces another question about it's not
24 just a question of is the water boiling but also is it even
25 there? Because the containment failure is predicted to

1 occur within that region of the pool.

2 (Slide.)

3 And now, in the other -- as we move on to the
4 other chapters, people will describe the code that we use
5 for fission product transport behavior. I wanted to mention
6 here the methods that are used for the thermohydraulic
7 analyses, because, as Dr. Catton has pointed out, there are
8 some significant uncertainties in thermohydraulics. They
9 can have a major effect on fission product transport
10 behavior.

11 Now, throughout here, we have used the March
12 computer code to analyze the thermohydraulic behavior. As
13 far as the thermohydraulic conditions within the primary
14 system, the March code does not predict those. It predicts
15 gross behavior of the primary system, but it doesn't show,
16 as you go from the upper plenum to the hot leg to the steam
17 generator, what the steam temperatures and conditions are as
18 you move through the primary system. There is no code
19 currently available that does that during this period.

20 So we did some hand calculations to supplement the
21 March computer code, and they are subject to large
22 uncertainties. They can have a significant effect on the
23 amount of deposition that one predicts within the primary.
24 There is some sensitivity analyses to try to give you a
25 handle as to how big that effect might be. There is a

1 definite weakness or inability to analyze these things.

2 Also, you should recognize that with regard to
3 containment, that the timing and mode of containment failure
4 have a particular effect on the consequences of an
5 accident. If the containment remains intact or it remains
6 intact for a specific period of time, you're going to have a
7 pretty minor accident in comparison to the alternative. If
8 you have an early atmospheric failure of the containment,
9 that's the kind of condition in which you have the very
10 large release fraction and which you will see as a result of
11 some of these accident sequences.

12 So, in conclusion, I want to say that there are
13 uncertainties in the thermohydraulics as well as in the
14 models for predicting fission product transfer. And these
15 uncertainties affect one's ability to predict fission
16 product behavior.

17 That concludes my presentation.

18 MR. CATTON: What would you say is the biggest
19 uncertainty? Knowledge of the source strength or the
20 transport mechanism?

21 MR. DENNING: I am not sure what you meant by the
22 "source strength."

23 MR. CATTON: The fission products that you are
24 moving from one place to another, I sort of have a
25 simplistic view of source transport environment. Transport

1 is controlled by thermohydraulics, and I am wondering where
2 is the weakest link.

3 MR. DENNING: It is not in the source with regards
4 to particularly what one looks at iodine and cesium. For
5 core meltdown sequence, there is quite a bit of assurance
6 that a very large fraction of that is going to be released
7 from the fuel. Okay? So then you have uncertainties as far
8 as the deposition in the primary system, uncertainty with
9 regard to deposition in the containment for things like TMLB
10 prime, I think the biggest uncertainty is will you have a
11 containment failure that occurs right after core meltdown?

12 MR. CATTON: But really, without a code to handle
13 the primary system, without a means of calculating the
14 behavior in the containment very well, we really don't --
15 can't do anything but bound.

16 MR. DENNING: No, I definitely wouldn't say that.
17 You will see the results of uncertainty studies that have
18 been done here which I think pretty well show us what the
19 spread of possible consequences are. We've done an
20 uncertainty analysis, for example, on TMLB prime with
21 MARCH-CORRAL. And we have also done an uncertainty analysis
22 with the TRAP code.

23 Now I think you can get a pretty good idea there
24 of what the possible ranges are with realistic assumptions
25 about how broadly those conditions might vary. And the

1 range is fairly broad. So there is a lot of room for
2 improvement or for error.

3 MR. CATTON: I thought that's what I implied.

4 MR. DENNING: Okay, well, I think what you had
5 said was all you could do is bound. And I thought you were
6 implying upper bound. Whereas, if you're saying a range of
7 uncertainties, I agree with you.

8 MR. MOELLER: Any other questions for Mr. Denning?

9 MR. ETHERINGTON: I found the drawings that you
10 showed on the screen of the RWS much better than they are
11 shown in the report. Why do you use these?

12 MR. DENNING: That is an excellent question. I
13 think that the drawings could definitely be improved, and
14 maybe we can spend some investment into that.

15 MR. ETHERINGTON: Yes, you could clean them up.

16 MR. DENNING: Yes. Actually, the drawings that
17 would actually be in the real report, those were, of course,
18 Xeroxes of figures. The figures would come out more
19 clearly. However, you can't see the type of things that I
20 tried to show here.

21 MR. ETHERINGTON: Yes, that's what I meant.

22 One other question. Have you tried to assign any
23 probabilities to your various sequences?

24 MR. DENNING: Well, it wasn't our intent to do
25 that for this study. That is very plant-design-specific, as

1 you can imagine.

2 MR. ETHERINGTON: When you talk of risk, you have
3 to do something --

4 MR. DENNING: We did try to include what we
5 thought were risk-dominant sequences, primarily using our
6 judgment based upon the reactor safety study and the Reactor
7 Safety Study Methodology Applications Program, which is a
8 study that is just nearing completion, a joint
9 Battelle-Sandia study.

10 However, I think that you have to recognize that
11 that does depend very much on the particular plant design.

12 MR. ETHERINGTON: Well, at least, if somebody
13 subsequently decides to assign probabilities, then they
14 can't use this report to establish relative risk.

15 MR. DENNING: I think they can use it to help
16 predict what the release magnitudes are, yes.

17 MR. MOELLER: Any other questions for Mr.
18 Denning?

19 (No response.)

20 MR. MOELLER: Thank you very much. That was well
21 done. We will move on to the next presentation, which is
22 fission products releases from the fuel, and this will be by
23 the Oak Ridge group and Mr. Wichner.

24 (Slide.)

25 MR. WICHNER: Just to introduce the authors, I am

1 Bob Wichner, from R&L.

2 MR. MOELLER: We are going to have trouble hearing
3 you, Bob.

4 (Laughter.)

5 MR. WICHNER: This talk is divided. In the first
6 half, I will be giving the first half, and Tom Kress will be
7 providing the second half of the talk. And Dick Lorenz is
8 another significant chapter author who is not here. And I
9 might mention that we did have contributions from Argonne
10 and AEGG, which are present in the report.

11 (Slide.)

12 The objective of Chapter 4 in the overall scheme
13 of things is given in this slide. Principally, what we
14 would like to do is to look at the evidence and see if we
15 can determine the chemical form of iodine in the fuel or
16 evolved from the fuel; secondly, determine what the rate of
17 evolution is -- and here we are a little bit more general.
18 The rate of evolution of fission products from overheated
19 fuel is somewhat of a side issue. We were asked to look at
20 the effect of interacting the cladding with the UC_2 as it
21 might affect the rate of release from the fuel. And
22 finally, to put this together with an accident sequence to
23 determine the whole core release.

24 This item 3 will be handled as the second part of
25 the talk by Tom Kress. I will be addressing principally

1 item 1 and 2.

2 (Slide.)

3 I will briefly go into where the fission products
4 -- how they arrive in the fuel, very briefly. I will just
5 briefly indicate what is indicated on this slide, without
6 going into too much detail. For example, the first column
7 indicates the mass number; the second column indicates the
8 amount of atoms per hundred fissions that arrived that are
9 borne, had that mass number. For this case, they will be
10 2.93 for mass number 131.

11 The bracket indicates the element at birth. In
12 this case, for the example, antimony and tellurium are the
13 birth elements in mass 121 and subsequently with date of
14 decay, it goes to your right.

15 So the point I would like to make with this slide
16 -- which you can study perhaps later -- is that indeed
17 tellurium is a significant precursor for all iodine as well
18 as all xenon species.

19 The second -- in addition to simply being a
20 precursor and possibly affecting the subsequent location of
21 the iodine as it is borne, it is also present as a stable
22 species, so that even beyond that, if there is a chemical
23 effect of tellurium, there is sufficient amounts of
24 tellurium to effect the subsequent behavior. However, this
25 is an unknown area, and no positive statements could be made

1 about it.

2 The second thing I would like to point out is that
3 the amount of cesium produced is significantly greater not
4 just solely by radioactivity, but by mass. The amount of
5 cesium being generated by fission directly indicates stable
6 cesium species are almost stable cesium species. You get
7 cesium as well by building it in from a xenon by neutron
8 activation.

9 So the amount you can take xenon-133 and it could
10 absorb neutron, emit a beta, and cesium-134 and these cesium
11 species add significantly to the amount of cesium you
12 generate directly by fission. So when you add it all up,
13 roughly you have about 10 times as much cesium as iodine on
14 all the bases.

15 MR. MOELLER: A couple of questions.

16 Go ahead, Dr. Lawroski.

17 MR. LAWROSKI: I just want to make sure I
18 understand your second column. The total of that second
19 column would be 200 percent; is that correct?

20 MR. WICKNER: Yes.

21 MR. MOELLER: I was intrigued when I read the
22 original report, which this is taken from. I-129 has a
23 half-life of about what, 10 million years? And you say
24 that's approximately infinity?

25 MR. WICKNER: Yes.

1 MR. MOELLER: Is that an Oak Ridge's judgment?

2 (Laughter.)

3 MR. WICHNER: I didn't mean anything
4 sophisticated. If you're adding up masses or molar amounts,
5 you would for that purpose lump 129 with the thing that
6 stays around for very long periods of time. I didn't mean
7 that to imply any radioactive hazard from that.

8 MR. MOELLER: Okay, that's adequate. I think you
9 ought to give a footnote or something and explain what you
10 meant.

11 Down there, with the two reactions that are
12 producing the cesium-134 and -136, again the way you have
13 written these you imply it's an end beta reaction.

14 I am getting into details, but what you actually
15 do, isn't it in 133 to go to 134 xenon, which decays by
16 beta?

17 MR. WICHNER: Yes. Right.

18 MR. MOELLER: Most end reactions are in gammas and
19 probably it is an end gamma reaction that drives the 133 to
20 134.

21 MR. WICHNER: Right. Your point is well taken.
22 This terminology is not correct as to what happens.

23 MR. MOELLER: Okay. Thank you.

24 Go ahead.

25 MR. LAWROSKI: Using too much shorthand there.

1 MR. WICHNER: Yes.

2 MR. KABAT: I am sorry, may we see that table
3 again?

4 (Slide.)

5 MR. KABAT: The yield of iodine-121 from decay of
6 thorium-131, which has only 25 minutes' half-life, it means
7 that the number, if they are in equilibrium in the fuel, in
8 the decay equilibrium, it means that there would be about at
9 least 100 times lower amount of tellurium atoms. It means
10 from the accident that would be only one-hundredth of
11 thorium atoms countering this iodine-131; so it means that a
12 subsequent production of iodine-131 from thorium would be
13 relatively insignificant. MR. WICHNER: Yes.

14 MR. KABAT: That would add only less than 1
15 percent off the iodine-131 from thorium decay. And that was
16 actually a subject we discussed on a few occasions here, how
17 much iodine would be actually produced from tellurium
18 released from the fuel during the accident itself. So I
19 think it wouldn't truly be so significant.

20 MR. SHERRY: In fact, that exactly is addressed in
21 Chapter 4.

22 MR. KABAT: The 132, 133, and 134 are short-lived
23 iodines and would be produced in larger quantities, but it
24 is relatively shortlived isotope which wouldn't produce any
25 environmental hazard.

1 MR. MOELLER: Did you get the answer you needed?

2 MR. KABAT: I would say it was rather a comment
3 than an explanation.

4 MR. MOELLER: Okay.

5 (Slide.)

6 MR. WICHNER: Let me point out some basic physical
7 properties of some of the materials that we're dealing
8 with. Let me emphasize that the melting point and the
9 boiling point columns. Cesium, it is thought, would exist
10 primarily as a cesium uranate and the melting point at 940
11 degrees, which like cesium iodide indicates that some of the
12 inner portions of the fuel will be molten and it would be
13 solid at the outer portions of the fuel. And in fact, also
14 that cesium uranate is not one of those compounds that has a
15 distinct boiling point.

16 What you do is you drive off the cesium from the
17 uranate and simply increase the vapor pressure of cesium
18 above the uranate so you don't have a clear boiling point,
19 whereas the elements are much more volatile with the lower
20 melting points for the elements and also lower boiling
21 points for the elements.

22 So we're dealing with materials that could exist
23 either as a crystalline solid or as a liquid on the
24 interior.

25 MR. ETHERINGTON: Does the formation of cesium

1 uranate imply oxidation of some of UO₂ and the reduction of
2 another part of the UO₂? Where does the extra oxygen come
3 from?

4 MR. WICHNER: It combines with UO₂, cesium
5 combining with UO₂.

6 MR. ETHERINGTON: Yes, but then that wouldn't give
7 you the CS₂, that would just give you UO₂ unless you pick up
8 the oxygen from somewhere else.

9 MR. WICHNER: Cesium uranate would tend to form
10 with a slight excess of oxygen. You don't normally have
11 UO₂. You have UO₂ with a slight excess of oxygen.

12 MR. ETHERINGTON: I see. There is sufficient
13 excess to give you that?

14 MR. WICHNER: Right. So the slight excess would
15 tend to --

16 MR. ETHERINGTON: Is this known to exist or just
17 believed?

18 MR. WICHNER: That's a good question. I am
19 assured that it exists. However, it has not been observed,
20 and I will get to that point.

21 MR. ETHERINGTON: In general, with all of the
22 fission products coming out as elements and many of them,
23 like calcium and strontium, the tendency would be to reduce
24 UO₂ rather than to provide the extra oxygen.

25 MR. WICHNER: Well, the point you raise about

1 whether this actually exists, I am not certain it has ever
2 been observed. However, thermodynamically, it is strongly
3 implied.

4 MR. KABAT: Would this excess of oxygen be
5 available for reaction with some of the fission products?

6 MR. WICHNER: The proper way to phrase the
7 question is that the fuel has a certain oxygen pressure
8 associated with it which depends upon the amount of oxygen
9 in excess of the stoichiometrically required amount. And
10 that oxygen pressure has an effect on stochastically
11 required amount. And that oxygen pressure has an effect on
12 a large number of possible reactions.

13 (Slide.)

14 Now, as far as identifying the iodine chemical
15 form, there are a number of approaches that you would want
16 to take or that you could take.

17 You could observe the phase composition directly,
as has been done by Clay Camp and KFK; or one can look at
19 concentration profiles from discharged fuel and try to infer
20 from the manner in which the profiles match what sort of
21 chemical species you have.

22 MR. MOELLER: Dr. Steindler has a question.

23 MR. STEINDLER: Before you go too far, I assume
24 you are going to eventually get to your thermodynamic
25 calculations.

1 MR. WICHNER: Yes.

2 MR. STEINDLER: My question is: Did you use that
3 value of minus 1511 kilojoules per mole for the pre-energy
4 formation of cesium uranate?

5 MR. WICHNER: No, I just put that column in as
6 sort of --

7 MR. STEINDLER: Where did that value come from?

8 MR. WICHNER: It came from a paper by Besman and
9 Lindemer on this subject.

10 MR. STEINDLER: Would you estimate that it is
11 reliable?

12 MR. WICHNER: Yes. That is not an unusual
13 compound. That should have a reliable value for the free
14 energy formations.

15 MR. STEINDLER: It seems awfully high for material
16 that you can't find in the solid phase. In fact, you can't
17 find it.

18 MR. WICHNER: Yes. It could be dispersed. That
19 could possibly be a reason it's not found.

20 MR. BELL: Excuse me, Bob.

21 Bell, from Oak Ridge.

22 When you say it's not found, you mean that it's
23 not been observed experimentally, or it's not been observed
24 in the fuel?

25 MR. WICHNER: Not been observed in discharged

1 fuel.

2 MR. BELL: But in controlled experiments, it can
3 be made?

4 MR. WICHNER: Yes. And the high value is a bit
5 misleading. It has something to do with the number of atoms
6 per molecule as well.

7 MR. STEINDLER: Well, even if you divided by two
8 and you normalize everything to per mole of cesium, it is
9 still pretty high.

10 MR. WICHNER: Well, the general implication of
11 that large negative value is that it is the preeminent
12 stable specie of cesium in UO₂.

13 MR. STEINDLER: That is exactly my problem. I
14 don't think it is a preeminent stable specie of cesium.
15 There is a cesium-U₄ compound that apparently is more
16 stable, and that's why I am trying to focus in on why you
17 are addressing that particular species.

18 MR. WICHNER: I believe on that point there is a
19 disagreement between that and the thermodynamic studies that
20 I have used to form the -- that part of this chapter.

21 MR. STEINDLER: My real question is how important
22 is that disagreement to your conclusions?

23 MR. WICHNER: It may be significant, because,
24 well, for one thing, I don't put a great deal of weight on
25 the thermodynamic results. I present them, but I feel that

1 perhaps one ought to qualify those results. I present
2 them.

3 However, if one were to use the thermodynamic
4 results with a great deal of force, then I would believe
5 that that would -- that that comment of yours would be
6 significant, because the thermodynamic calculations presume
7 that the environment that the iodine sees in the fuel is one
8 in which the partial pressure of cesium is basically the
9 partial pressure over cesium uranate. So it would have a
10 big effect in that case.

11 MR. SILBERBERG: You mean effect on release
12 fraction of cesium?

13 MR. WICHNER: No. Effect on the chemical form of
14 iodine as calculated by chemical thermodynamics.

15 MR. SILBERBERG: I see. Thank you.

16 MR. KABAT: Have you calculated the free path of
17 the iodine in cesium atoms in the uranium nitrates which
18 would, of course, be quite limited and that might eventually
19 affect the reaction rate or the equilibrium? If the free
20 path is long enough, it might still be diffusion-controlled
21 reaction but it would surely affect kinetics of reaction
22 between cesium and iodine?

23 MR. WICHNER: I have a very limited knowledge in
24 that area. My impression is, however, that at temperatures
25 below 1400 these large atoms are essentially immobile --

1 MR. KABAT: Yes, that's what I mean.

2 MR. WICHNER: -- in the matrix. And it would be
3 extremely difficult to predict the frequency of collisions
4 between these atoms to allow some generalization on the
5 subsequent chemical form. And this is, in particular, my
6 reason for not overly emphasizing the chemical-thermodynamic
7 results, one of the reasons.

8 MR. KABAT: Yes.

9 MR. WICHNER: However, I do present them.

10 (Slide.)

11 The conclusions regarding -- these are actually
12 partial conclusions.

13 First, there are no iodine-bearing phase has been
14 identified in the fuel. But of the 20-odd phases that have
15 been observed by Clay Camp at KFK, he has observed none
16 containing iodine. I think what that means, is that either
17 iodine is not -- is either in a separate phase finally
18 dispersed or in the UO₂ grain. So the direct observation
19 does not lead to a clear result of specifying the chemical
20 form of serving concentration.

21 Yes, sir?

22 MR. STEINDLER: I think that's a fairly critical
23 conclusion.

24 MR. WICHNER: Yes.

25 MR. STEINDLER: I am wondering why you decide that

1 because you haven't been able to see cesium iodide in
2 sufficient size agglomerates, that you can identify cesium
3 iodide crystal that you worry about whether iodine is there
4 as a cesium iodide.

5 MR. WICHNER: Well, let me put it the other way.
6 What I am doing is looking at what evidence is there to
7 determine whether or not one can come to a conclusion from
8 that evidence.

9 Now, the evidence is a description of phases that
10 have been identified, and none of those phases have been
11 listed as containing iodine. Now, that is the fact in the
12 literature. Now, what conclusion one forms from that, that
13 is just my impression.

14 MR. STEINDLER: I am not in a position to quarrel
15 with your facts, I think. But I am wondering how you got to
16 the conclusion.

17 MR. WICHNER: Well, the conclusion is really my
18 opinion.

19 MR. STEINDLER: I see. Okay. You will perhaps
20 admit that there is a possibility of cesium iodide being
21 there in such a phase that you can't see it as a crystalline
22 material?

23 MR. WICHNER: Yes, certainly. Sure. However,
24 cesium, the second half of the item 1, cesium iodide
25 crystals have been found on cladding case by Argonne

1 researchers, in one case by Cooper Jahdi, working for EPRI.
2 And usually, these are observed on fuel pins that have
3 higher pins, higher heat rate in them than usual, and these
4 crystals have been observed.

5 The second item, I found nothing really
6 distinctive in concentration profiles to give any clear
7 evidence as to what the chemical specie is. This was sort
8 of a long shot. Sometimes you can see a unique feature in a
9 concentration profile to allow identification of a chemical
10 specie, but that does not occur in this case, as far as I
11 can tell.

12 Third, there are a number of thermomigration
13 experiments that have reported. These are experiments where
14 you have powder and temperature gradient, and you add cesium
15 and iodine in various forms, and you see where it comes down
16 in the temperature gradient. There have been experiments by
17 Pease and Wiedenbaum, and they disagree as to whether or not
18 cesium iodide form. Wiedenbaum says yes, Pease says no.

19 However, they do agree that when you add a small
20 amount of oxygen to the system, that you tend to form
21 whatever you had before you tend to form a molecular iodine
22 subsequently.

23 Now, all I am going to say about chem-thermo is
24 listed in item 4. Within the limitations of the study that
25 was made by Pesman and Lindner, their conclusions are that

1 the stable forms and the fuel are cesium iodide, cesium
2 uranate up to 950 centigrade, which is the limit of their
3 study. They found that adding steam to this system did not
4 change things too much. However, oxygen, they found, did
5 destabilize cesium iodide. Basically, what it did was lock
6 up cesium in a more stable uranate, making it unavailable
7 for cesium iodide.

8 MR. STEINDLER: Are you suggesting by that
9 conclusion that cesium is present in really only two kinds
10 of material; namely, cesium iodide and cesium uranate?

11 MR. WICHNER: I think the more careful statement
12 would be to say within the realm of chemical-thermodynamics
13 and within the temperature range of this study, yes.

14 However, the realm of chemical-thermodynamics is a
15 limited realm. Sometimes there are rules that you have to
16 use in chem-thermo that don't really apply to your situation
17 that you have. And this is the reason why I am not
18 overemphasizing thermodynamics in this regard.

19 MR. STEINDLER: Well, can I drive you out away
20 from that nice, neat limitation?

21 MR. WICHNER: Yes.

22 MR. STEINDLER: If you would just address the fuel
23 in general and not the study and what you know of the rest
24 of the literature, would you still say that cesium is only
25 found in two compounds? If I pulled fuel out of the reactor

1 and let it cool for a few days at room temperature and gave
2 it to you and you looked at it, where would you expect to
3 find cesium?

4 MR. WICHNER: In some cases, you would find cesium
5 that has migrated down to cooler portions and exists there
6 as metallic cesium. In some cases you would find cesium,
7 some cesium, in around the gap between the pellet and the
8 clad.

9 MR. STEINDLER: As metallic cesium?

10 MR. WICHNER: As a form that during operation was
11 in the gas phase. I mean vague. And occasionally you would
12 find cesium as a compound with zirconium on the surface of
13 the pellet. But this has been observed only in extremely
14 high-heat-rated fuel. Similarly, you would find some
15 cesium-bearing compounds on the cladding and cesium iodide
16 has been found on the cladding. Again, I believe, only for
17 heat ratings above the design heat ratings.

18 MR. STEINDLER: The rationale for the question,
19 obviously, is I am looking to see what information you have
20 been able to accumulate on where cesium to get tied up in
21 compounds more stable than cesium iodide --

22 MR. WICHNER: That point is a very good point.
23 And I did look, and I don't believe there is much background
24 to allow an answer to that question. It is a complicated
25 question, because of the very difficult mobility of these

1 heavy atoms in UO_2 and what opportunities they have for
2 chemical combination. I don't believe that question can be
3 answered.

4 MR. STEINDLER: One comment, or two comments. The
5 cesium uranate that you're looking at is -- the one that's
6 on the slide -- is probably not the most stable form of the
7 cesium-uranium-oxygen system. Two, there has been no
8 comment made -- I was a little bit surprised that there has
9 been no comment made on cesium molybdates, which vaporize
10 congruently and represent part of the vapor transport at
11 high temperature. Congruent vaporization is not a good
12 enough reason to call something stable, but at least it adds
13 the question as to whether or not a cesium molybdate may be
14 another sink for cesium that would take it out of the cesium
15 iodide domain.

16 MR. WICHNER: Cesium molybdates were examined by
17 the study by Pesmer and Lindner and they determined that
18 cesium uranate was more stable than a molybdate. Again, I
19 have to qualify, for a given oxygen pressure, their
20 conclusion is that cesium uranate is the most stable species
21 for this oxygen pressure that is appropriate for a UO_2 with
22 a slight excess of oxygen.

23 Now, it's true that other cesium uranates become
24 more stable, but at higher oxygen pressures.

25 MR. KABAT: Have you included the effect of

1 hydrogen high energy of different kind of radiation on
2 actually the thermochemical analysis?

3 MP. WICHNER: No. That is another point, another
4 reason why I do not like to emphasize the chemical
5 thermodynamics. This point cannot be accounted for in
6 chemical thermodynamics.

7 MR. KABAT: Would you expect that it could have a
8 very significant effect?

9 MR. WICHNER: It's only my suspicion, but I think
10 metal halides can be affected by intense radiation. So it
11 could shift some of the equilibrium.

12 Maybe some of the more chemically oriented people
13 could comment on that.

14 Well, I don't know. I don't want to put anybody
15 on the spot.

16 MR. BELL: I would expect the gradient radiation--

17 MR. LAWROSKI: We can't hear you, sir.

18 MR. BELL: I would expect the greatest radiation
19 damage in the fuel would be on some oxygen-containing
20 species creating an oxygen radical type reaction,
21 essentially the redox contention.

22 MR. LAWROSKI: It is what?

23 MR. KABAT: Significantly affect the chemistry of
24 iodine and cesium inside the fuel.

25 (Slide.)

1 MR. WICHNER: I will have to go a bit into release
2 rate mechanisms, and this is a very touchy point, as some of
3 your questions have already indicated. And it is also a
4 matter of some opinion, one investigator to the next. This
5 opinion presented here is predominantly the one presented by
6 Lorenz. I have to go through this a bit to be able to
7 understand some of the variations in the data that are going
8 to be observed.

9 Initially, what you have, you have the cladding
10 burst and you have a release of gaseous materials from open
11 voids in the plenum. Confounded with that release is a
12 release of some embedded noble gas which -- well, again, I
13 am presenting a model as developed by Lorenz -- in a
14 temperature range approximately that. Then you would get
15 cladding burst.

16 You can also release noble gases that are
17 shallowly embedded on various surfaces. And it's a subtle
18 difference, but some experiments might have different
19 amounts of this release relative to the others, and it does
20 cause a bit of confusion occasionally in looking at some of
21 the release data.

22 Following cladding failure and release of the
23 shallowly embedded noble gas, you then have a process of
24 diffusion to the failure point at about 1400 centigrade.
25 You have something called "grain boundary release" beginning

1 to occur, which involve several processes and seems to occur
2 about 1350 to 1400 centigrade.

3 And the processes involve bubble, linkage, grain
4 boundary growth and separation, all of which you tend to
5 have sort of a rapid evolution at this point, and high
6 burn-up fuel. I don't know what it would be in low burn-up
7 fuel. It might occur at a different temperature.

8 And then, subsequently, you can diffuse material
9 actually from the grain interior to the grain surface.
10 Actually, diffusion occurs altering this process. However,
11 it would become the dominant method of release only at
12 higher temperatures.

13 (Slide.)

14 So you have these release mechanisms.

15 MR. ETHERINGTON: Let me ask a question to clear
16 up something for me, please. In a solid lattice-like UO_2 ,
17 where both cesium and iodine, does it know that it's cesium
18 iodide to the extent that it becomes a separate phase?

19 MR. WICHNER: I don't think that question can be
20 answered. There are several things that possibly could
21 happen, and I don't know if anyone can say definitely that
22 one thing happens. You have a general notion of noble
23 gases.

24 MR. ETHERINGTON: Yes.

25 MR. WICHNER: It could be towards the grain

1 boundary.

2 MR. ETHERINGTON: When it migrates to the grain
3 boundary, you have a void in which a compound can form.

4 MR. WICHNER: Yes.

5 MR. ETHERINGTON: But within the lattice, would
6 there be anything to say what it is?

7 MR. WICHNER: No.

8 MR. ETHERINGTON: All right. Thank you.

9 MR. WICHNER: One can look at --

10 MR. BELL: Excuse me.

11 MR. WICHNER: I am looking -- Yes, sir?

12 MR. BELL: Excuse me, sir?

13 MR. MOELLER: Harold, they have further
14 comments.

15 MR. ETHERINGTON: Excuse me.

16 MR. BELL: With respect to your question of
17 species in the lattice, I don't think you'd expect migration
18 of anything other than atoms --

19 MR. ETHERINGTON: That's right.

20 MR. BELL: -- inside the atom.

21 MR. ETHERINGTON: That was my thought. But when
22 you get to the grain boundaries, you'd have a different
23 condition.

24 MR. BELL: Yes, you could.

25 MR. WICHNER: That's an extremely important point,

1 because a significant fraction in the life of any fission
2 product exists in that form as atoms migrating in. UO₂ and
3 how they migrate, what opportunity they have for chemical
4 combination within that grain is, I believe, not answerable
5 at this point.

6 MR. ETHERINGTON: The metallurgists have empirical
7 rules. I think it's somebody -- Rotheri, isn't it -- rules
8 of potential solubility based on atomic size, atomic radius
9 and valents and a few other things? Is there any similar
10 theory in a compound like UO₂?

11 MR. WICHNER: That takes me out of my area of
12 specialty.

13 MR. ETHERINGTON: Humeri is the name, or something
14 like that.

15 MR. WICHNER: It was the same purpose of
16 identifying the iodine species. One can look at release
17 rates. In particular, one notes that iodine and noble gases
18 come off uniformly at equal rates. Well, that is a strong
19 indication that you have a highly volatile form of iodine in
20 the fuel. On the other hand, if iodine and noble gases come
21 off at significantly lower rates, that would be an
22 indication that the iodine is locked into some more stable
23 species than molecular iodine.

24 So, with that point in mind, I have to note that
25 the early data, in basically Parker and Davies, actually

1 indicate a more rapid evolution of iodine in noble gases.
2 And this bias is still built in the ANS 5.4 code, which is a
3 little bit surprising to recommend for the release rate
4 correlation. They recommend diffusion coefficient for
5 iodine seven times that of xenon, and it's based on these
6 early observations of Parker and Davies.

7 Again, let me speculate why is this so. I think
8 the reason it is so is that both Parker and Davies did not
9 use fuel elements and their experiments did not fully
10 account for all the release mechanisms that are possible.
11 And I think that they actually did not see some of the noble
12 gases that they had lost prior to the experiment, because
13 they didn't contain it with cladding and they lost the
14 shallowly embedded noble gases.

15 That is my speculation. But that is still present
16 in existing technique, that bias.

17 MR. LAWROSKI: But they should have been observed
18 differently, depending on the size of the chunks of fuel
19 they were working with.

20 MR. WICHNER: They didn't do that many
21 experiments. And Davies did observe such, because he used
22 pellets and powders, both.

23 MR. MOELLER: Dr. Steindler.

24 MR. STEINDLER: Are you saying that the Parker and
25 Davies' experiments are not well enough written up to be

1 able to evaluate the validity of the speculation that you
2 came through with?

3 MR. WICHNER: They make no such speculation. I
4 emphasize that is my speculation. And I don't want to say
5 that.

6 MR. MOELLER: Repeat your question.

7 MR. STEINDLER: My question is: Do you believe
8 that the papers written by Parker and Davies contain
9 insufficient information to either validate or comment on
10 the importance of that speculation?

11 MR. WICHNER: I wouldn't put it that way. Parker
12 and Davies both present their observations, and now you are
13 free to analyze them and interpret them.

14 MR. STEINDLER: Let me try it once more. A lot of
15 people write a lot of papers in which they present
16 information, but the question usually is: Is it presented
17 well enough to be either complete, or traceable, so you can
18 identify fairly clearly the answer to the questions that you
19 ask ten years later. There is an awful lot of junk in the
20 literature, sir.

21 (Laughter.)

22 MR. WICHNER: Yes. Yes, indeed.

23 MR. STEINDLER: That may be part of it. I guess
24 what I am really getting after is: In the work that was
25 behind putting this volume together, was there any

1 significant attempt to critically evaluate the quality of
2 the information that you have been able to dig out of the
3 literature?

4 MR. WICHNER: I am actually going to come to that
5 point in a moment. But the short answer is: not
6 completely. The full evaluation of each experiment could
7 not be done in the scope of time. But if I can get a plug
8 in for another NRC-funded program that is a milestone in the
9 severe accident sequences analysis program for later in the
10 year.

11 MR. MOELLER: Don Orth has a comment.

12 MR. ORTH: Yes. I don't remember that particular
13 paper right now. But I have gone through evaluating some of
14 the papers. One of the key points when you are trying to
15 support the speculation you get is not just the rates which
16 came out but the total amounts. And in some cases, you find
17 the rates indeed say this sort of thing, but they can't
18 account for about 90 percent of the material that was really
19 supposed to be there. So --

20 MR. WICHNER: I agree. I don't know about Davies,
21 but I agree that the mass balances on Parker's experiments
22 did not work out very well. That much I know.

23 Well, later experiments by Lorenz -- and here I
24 wish -- I miswrote this -- I wish you would correct this on
25 your copy. I don't mean "grain boundary release." I mean

1 "embedded gas release." So please cross this out. I just
2 wrote the wrong words down.

3 Cross out "grain boundary" and write "embedded gas
4 release." That's mechanism 2 rather than 3 or 4. I just
5 wrote it down incorrectly.

6 Later experiments by Lorenz don't bear this bias
7 of more rapid iodine release relative to xenon release.
8 However, the situation is not clear, because you have
9 several mechanisms being involved, and all you can say is
10 that you get approximately the same amount of iodine and
11 xenon released at low temperatures as far as Lorenz'
12 experiments go

13 At higher temperatures, at 1400 and above, or at
14 about 1400, Lorenz' experiments show equal parts of iodine,
15 cesium, and noble gas release.

16 The other thing I would like to get into relates
17 to a feature of Lorenz' experiments where he had something
18 actually identifying the species. Up till now we've been
19 looking at -- seeing if we can infer something from a
20 relative release rate. But there is a species
21 identification attached to Lorenz' experiments. And that is
22 on the next slide.

23 (Slide.)

24 A couple of significant points here. Lorenz had
25 several types of experiments, and I have abstracted these

1 results from Table 4.3, which is in the report, and I really
2 urge you to look at the full report, because there is not
3 any fully adequate way of abstracting it. I have tried just
4 to get it on the slide.

5 What I mean to show here is that in his
6 experiments, where he employs helium to carry off the
7 evolved noble gases, he -- oh, the three species that he can
8 crudely identify -- and maybe "crude" is not the proper word
9 -- but in its analytical train he has, he can observe a
10 location of a deposit and infer that that deposit is cesium
11 iodide or he can look at a charcoal figure and infer that
12 that deposit is a molecular iodine, and he can look at some
13 filters and infer that that is a particulate form of
14 transfer. So that this much an oversimplification, I want
15 to tell you, because it is not clear particulates can cause
16 it every place. So it takes a little bit of unfolding.

17 MR. LAWROSKI: It is really too good of a
18 100-percent material balance.

19 MR. WICHNER: Now, Lorenz did have a careful
20 material balance. That's one thing he did have --

21 MR. LAWROSKI: That would indicate --

22 MR. WICHNER: -- which was absent in Parker's
23 experiments, but Lorenz did have a good mterial balance.

24 Well, the point I would like to make is that in
25 his experiments where he employs helium that he calls a "cap

1 purge test," now, the range of temperatures less than
2 1100-1200 degrees centigrade, the dominant species does
3 indeed seem to be cesium iodide. In other tests, in steam
4 there was a range of species that are identified.

5 The range I have given here, the low point, the 4
6 percent cesium iodide and the high point -- I believe I
7 picked the high one; I am not sure. It's 86 percent cesium
8 iodide. So that when he ran his experiments with steam, he
9 got a range of percent of cesium iodide, a range on the
10 location where the molecular iodide would come down, also a
11 range of particulates.

12 MR. LAWROSKI: Excuse me. I guess it's a
13 different way of expressing material balance from what I am
14 accustomed to. What that is is of the stuff that he
15 measured, that's 100 percent, but that doesn't say that he
16 was accounting for all of the 100 percent of the iodine.
17 It's just that you can do material. That's not --

18 MR. WICHNER: Yes. That's right. Although he did
19 make comparisons with predicted amounts actually in the
20 fuel. But these are not those numbers; these are simply
21 percentages of what was observed.

22 So this would go up to 100. However, the
23 statement is still true.

24 MR. LAWROSKI: Yes.

25 MR. WICHNER: In comparing these total amounts

1 with what was in the fuel, he did get good comparisons.

2 MR. ETHERINGTON: It seems to me important to know
3 how much of the equilibrium iodine-131 is in the voids and
4 presumably found a stable partner and how much is still in
5 the lattice. Do we know what that ratio would be?

6 MR. WICHNER: That ratio, that was measured for
7 two pair of fuel elements. And for PWR fuel element, the
8 amount of iodine in the void that was readily available for
9 departure on fracture of the void was on the order of 1
10 percent, 1 percent of the total inventory in the fuel.

11 MR. ETHERINGTON: You mean 99 percent was still in
12 the lattice?

13 MR. WICHNER: Yes, for the PWR experimental pair.
14 I have to emphasize that, because for a similar pair of
15 tests using a BWR fuel element, that number was 14 percent.

16 MR. ETHERINGTON: So the assumption that the
17 iodine pairs out with for cesium iodide will then depend on
18 the relative rates of diffusion out of the lattice as well
19 as the relative amounts of cesium and iodine in the
20 lattice. Is that somewhat indeterminate?

21 MR. WICHNER: I am sorry, I missed the gist of
22 your question. I don't know at what point in the pellet
23 void cladding geometry you generate stable chemical species
24 and at what point you keep these elements apart just simply
25 because of --

1 MR. ETHERINGTON: The point was that in a meltdown
2 presumably everything that is in the void disappears
3 quickly, and that is to say cesium iodide. Now, in the
4 lattice we still have cesium and iodine, which are diffusing
5 out at different rates, and it isn't so clear that we can
6 assume that we will have cesium iodide unless we have some
7 numbers. Have I made that clear there?

8 MR. WICHNER: No, not really. Let me just say
9 this. The cesium iodide and other -- and the noble gases --
10 are predicted to be almost completely gone significantly
11 before melt occurs.

12 MR. ETHERINGTON: Then the distribution at
13 shutdown is very rapidly upset then by increasing
14 temperature?

15 MR. WICHNER: Yes.

16 MR. MOELLER: Don Orth.

17 MR. ORTH: Was all of that done on samples of the
18 same fuel, different samples of the same fuel?

19 MR. WICHNER: All of that was done on different
20 samples of two fuel rods, one fuel rod from the Peachbottom
21 boiling water reactor, and one fuel rod from the H. P.
22 Robinson PWR.

23 MR. ORTH: But is there any way we can tell from
24 that table which were from which, or do you have any kind of
25 a radiation data?

1 MR. WICHNER: Not on this table, but on the table
2 in the report, I believe it is identified.

3 MR. MOELLER: Rich Sherry.

4 MR. SHERRY: Bob, you may want to point out the
5 difference between the experimental apparatus for the helium
6 setup and the steam setup which may account for some of the
7 difference in chemical form.

8 MR. WICHNER: Yes.

9 MR. SHERRY: I think that's important.

10 MR. KABAT: There is also an interesting
11 coincidence also. In the case of the report which are
12 indicating that for a larger amount of total amount of
13 iodide we are getting a higher yield of cesium iodide; here
14 we are in the low quantity, we are getting high, too.

15 MR. WICHNER: Yes.

16 MR. KABAT: And also they are actually shorter
17 periods. We are getting a higher amount of cesium on cesium
18 iodide; it means that cesium iodide might even be in the
19 voids and elemental iodine from diffusing subsequently from
20 the uranium oxide. That might be. That would also be
21 actually a point worth -- what we discussed before about the
22 free path of cesium and atoms inside the lattice. It means
23 that the iodine would be reacting so much in the voids.

24 There are quite a few cases like that in the table
25 and the report. And it might be worth analyzing it from

1 this point of view.

2 MR. WICHNER: I was getting to the point of
3 setting down some postulates that could explain this
4 behavior. I noted what you have said. However, I did not
5 use that as an explanation.

6 MR. ETHERINGTON: Jim, I would like to try another
7 tack on my previous question. Assuming that immediately we
8 get overheating, everything in the void disappears, we still
9 have cesium and iodine in the lattice. If that iodine in
10 the lattice was a large proportion of the total shutdown, do
11 we know there is enough cesium in the lattice to take care
12 of it?

13 MR. WICHNER: To take care of what?

14 MR. ETHERINGTON: Do we know there is enough
15 cesium in the lattice to satisfy the iodine in the lattice?

16 MR. WICHNER: Yes, I think that's clear. There
17 are about 10 times as much.

18 MR. ETHERINGTON: No, no. That's the total. But
19 we don't know how much of that is in the voids and how much
20 is still in the lattice.

21 MR. SHERRY: I think the observations that were
22 made on the higher-temperature tests, which were as much as
23 20 percent of the cesium and iodine were released during the
24 test, indicated that there were -- or most of the release
25 was coming from the grain structure itself. And the

1 observations were that the total fraction of cesium and
2 iodine being released were approximately the same, about 20
3 percent.

4 And based on the overabundance of cesium, you
5 would expect that about 10 times as much cesium coming off
6 the UO₂, coming from the UO₂ grains.

7 MR. ETHERINGTON: You said that awfully fast and
8 also I didn't hear it very well.

9 MR. SHERRY: In the higher-temperature tests, the
10 test was compared to 216 degrees C. There was a total
11 release of approximately 20 percent of the available
12 inventory of both the iodine and cesium. Okay? And they
13 came off about the same rates. And since there is
14 approximately 10 times as much cesium as iodine, okay, and
15 they're coming off about the same rate, there should at all
16 times be an abundance of cesium for a combination of iodine
17 if they are combined prior to release.

18 MR. ETHERINGTON: Let me probe a little further.
19 At shutdown, essentially all of the iodine is in the
20 lattice. Now, if one-tenth of the cesium is in the lattice,
21 then we've got enough cesium there. Do we know that there
22 is one-tenth of the cesium in the lattice at shutdown?

23 MR. SHERRY: Well, the gap inventories of cesium
24 and iodine during normal operation should be approximately
25 the same.

1 MR. ETHERINGTON: In the gap.

2 MR. SHERRY: In the gap, yes.

3 MR. ETHERINGTON: Now with the ratio in the
4 lattice --

5 MR. SHERRY: Approximately the same as in the
6 gap. To the first order --

7 MR. ETHERINGTON: You're saying they diffuse at
8 the same rate?

9 MR. SHERRY: Yes.

10 MR. ETHERINGTON: That's very surprising, because
11 cesium has an atomic radius enormously greater than the
12 radius of iodine.

13 MR. SHERRY: The two top tests were tests to
14 measure the gap inventory of cesium and iodine, and these
15 indicated that the --

16 MR. ETHERINGTON: I see.

17 MR. SHERRY: -- fraction of the available
18 inventory that got to the gap was about the same for cesium
19 and iodine.

20 MR. ETHERINGTON: Okay. If you have firm numbers
21 there.

22 MR. WICHNER: In looking at this table --

23 MR. MOELLER: Well, now, had you done what Dr.
24 Kabat asked about on the type of analysis that he
25 suggested?

1 MR. WICHNER: By that you mean?

2 MR. MOELLER: Looking at the total quantity and
3 looking at the time factors and so forth.

4 MR. WICHNER: No. I presume you mean looking at
5 the behavior of migrating species within a UO₂ crystal. No,
6 I haven't done that. And furthermore, I am not quite sure
7 how that could be done. That's quite a difficult job.

8 MR. KABAT: I believe that in the voids actually
9 because it's gaseous phases, the iodine and cesium would be
10 in the form of gas, gaseous forms. So that probably the
11 reaction probably would be much better because of the free
12 path.

13 MR. WICHNER: Yes.

14 MR. KABAT: So that eventually that would affect
15 the ratio of cesium iodide to elemental iodine in voids,
16 while in the crystallic structure of UO₂, it wouldn't have so
17 much chance.

18 And the other thing, also, the half-life of
19 iodine-131 is relatively short compared to the dynamics or
20 kinetics of that action between cesium iodide. So it means
21 it really wouldn't have -- it's diffusion-controlled in this
22 case. And at today's half-life, that would give us actually
23 less chance to get a inter-reaction than, say, the stable
24 iodine atoms.

25 So this way, actually, probably the ratio of

1 elemental iodine to cesium iodide would be different in the
2 matrix, UO2 matrix, than in the voids. And this would
3 eventually indicate that it might be the case.

4 MR. LAWROSKI: How reproduceable are those, do you
5 know? I am looking at the steam at 900, I guess. Those
6 three are at 900. They're on two different kinds of fuels,
7 I guess, because of the amount of iodine reducing -- the
8 last pair is a common sample, and then the other one is
9 not. If it isn't, then I have some questions about the
10 reproduceability.

11 MR. WICHNER: These are very difficult
12 experiments, and one-shot experiments.

13 MR. LAWROSKI: I agree with that, yes.

14 MR. WICHNER: And testing for reproduceability is
15 frequently not a luxury that is afforded people.

16 MR. LAWROSKI: Because if it was indeed the same
17 sample of fuel, those three you looked at, then you get a
18 crazy pattern there that leaves you with a great deal of
19 uncertainty as to what's going on.

20 MR. WICHNER: These may involve phases in the test
21 series where the temperatures approached and allowed the
22 plateau and then subsequently elevated and left the plateau,
23 and that tends to emphasize -- explain why some of these
24 large differences. Some of these might refer to a plateau
25 in a series of tests and not necessarily to inventory of the

1 fuel rod.

2 But I just wanted to get to some postulated
3 reasons for this behavior, and there was one such given a
4 moment ago.

5 (Slide.)

6 One possible reason for this behavior, if we look
7 at the last two experiments, the last pair, we see under
8 nominally similar conditions, similar amounts of iodine.
9 When we run the experiment briefly, we get proportionally
10 more cesium iodide than if we run the experiment for a long
11 period of time.

12 Okay. So you can form a postulate that the cesium
13 iodide has some finite reaction time with the environment,
14 say, steam or impurities in the steam, so that the long-term
15 experiments tend to degrade the cesium iodide to form the
16 molecular form. Okay, that's a postulate.

17 The other postulate is that the steam in this
18 experiment was not chemically pure, it did contain -- they
19 used demineralized water, but they didn't purify it
20 otherwise. And if there is a reaction with an impurity, it
21 would tend to have an effect whenever you have a smaller
22 amount of iodine involved.

23 So I do observe this thing that was mentioned a
24 minute ago that you have cases where not vastly different
25 conditions, but when you have small quantities of iodine,

1 you tend to manufacture larger observations of molecular
2 iodine from that point of view.

3 And the third possibility is that in this
4 experimental system, which consisted of quartz, it is
5 possible to get some interaction with the quartz, and you
6 have, between the steam experiments and the helium
7 experiments, a different type of geometry that allows more
8 of a contact with quartz. So that is also a possibility
9 with the reaction with cesium iodide with quartz would tend
10 to lock the cesium in the quartz and allow the iodine to
11 dissolve.

12 MR. STEINDLER: You're not saying that experiments
13 at 1600 degrees centigrade were done in quartz, are you?

14 MR. WICHNER: No, the boundary tube was quartz,
15 however, and the carrier gas convected past the quartz.

16 MR. STEINDLER: Do you know anything at all about
17 the impurity content of the steam?

18 MR. WICHNER: It would be ppm level air. That
19 would be the impurity content. There was no special pains
20 taken to de-aerate, that's all.

21 MR. STEINDLER: Is that right? I guess my
22 conclusion on that basis is most of those experiments won't
23 mean much.

24 MR. WICHNER: No. I think that will -- that might
25 prove to be true, but the indications are that higher oxygen

1 levels in what you would normally get from dissolved air and
2 water would be required to alter chemical species. But that
3 remains a not completely resolved question.

4 MR. MOELLER: Don Orth.

5 MR. ORTH: Well, I mean with all of the caveats
6 that keep coming in on this, is it -- would it be fair to
7 say that these particular data as reproduced in Table 4.3
8 and your table and your book here really aren't very good in
9 terms of trying to make any of these interpretations?

10 MR. WICHNER: Well, I wouldn't put it that way.
11 They're a step forward, and whenever you take a step
12 forward, you recognize things that if you were that smart in
13 the beginning you would have done differently.

14 MR. ORTH: Right. And from the standpoint,
15 though, it's fine. There is a lot of interesting points.
16 You can postulate the reasons as you did for why two series
17 of tests you got those two results.

18 MR. WICHNER: Right.

19 MR. ORTH: However, those data are only useful if
20 then you can go on and design some experiments and confirm
21 that those explanations really are any good.

22 MR. WICHNER: Right.

23 MR. ORTH: So my reaction on reading this the
24 first time -- because now I am beginning to remember the
25 original reports, because I think I read some of those --

1 were that they were very interesting from the standpoint of
2 planning tests. But you still couldn't draw any conclusions
3 from them.

4 MR. WICKNER: Well, I would agree with that. If
5 one were aware of these possible phenomena that are
6 illustrated in the results at the outset you would have
7 designed the experiment differently.

8 MR. ORTH: Correct. So they are valuable for that
9 purpose. But I guess what I am really wondering about then,
10 does this table and a few of the others like it really have
11 any input into what our general conclusions are as you have
12 put them in this chapter? Because if they do, they call
13 those "conclusions."

14 MR. WICKNER: Well, you've got me on the spot a
15 little bit.

16 MR. MYNATT: Fred Mynatt, from Oak Ridge.

17 Almost all of this discussion is focused on the
18 steam part of this table, and when you get to the point of
19 questioning the experimental technique, that's appropriate,
20 because the best experiments were the helium and steam purge
21 experiments.

22 And if you turn the question around and say for
23 those experiments which have the best experimental
24 technique, if the form is atomic or molecular iodine, how
25 could that have been observed in the analytical train? And

1 that is the firmest piece of evidence, I think, in the
2 experiment.

3 MR. ORTH: Right. But we are also interested in
4 the overall conclusions on accidents that involve, in many
5 cases, having a large amount of steam there. It's hard to
6 have a water reactor and have no water whatsoever present.

7 MR. MYNATT: Yes. It's important to take the
8 questions one at a time. I certainly don't reduce the
9 emphasis on that question. I just did it one at a time.

10 MR. ORTH: I don't question the data here. As I
11 point out, it's interesting data from the standpoint of
12 designing experiments. You can draw a lot of conclusions
13 that are very worthwhile as far as designing the next
14 experiment. I just worry about using it right now to draw
15 conclusions on pathways and migration rates.

16 MR. STEINDLER: There is one other hooker,
17 though. You've got to be very careful when you make that
18 statement. That's a selected table, and he carefully
19 pointed out you ought to go to the text.

20 If you go to the text, you find it is two kinds of
21 experiments. It's helium experiments and gap purge
22 experiments. The other ones are not. And unless you do a
23 lot more talking or reading, you can't compare necessarily
24 the results from a gap p urge experiment from what they call
25 a burst release test and the interpretation of a comparison

1 of what you have on the slide, I think, is a little
2 hazardous.

3 MR. MOELLER: Harold Etherington.

4 MR. ETHERINGTON: Yes. I would like to understand
5 those last two lines. As I understand it, in the final
6 tests the extra 60 minutes of heating only released an extra
7 three milligrams of iodine; is that right?

8 MR. WICHNER: I am not familiar with the exact
9 chronology of each individual test. I don't know. I would
10 have to look at the chronology of the tests to be able to
11 answer any question that is that specific to the test
12 sequence.

13 MR. ETHERINGTON: Well, then, I will ask a
14 hypothetical question. If this is true, then it doesn't
15 seem reasonable that an extra three milligrams can so
16 radically change the cesium iodide and iodine distribution.
17 So I will just drop it there, as long as we don't want to
18 discuss it.

19 MR. KABAT: Was this iodine released from one
20 element?

21 MR. WICHNER: It was released from two from
22 segments from two discharges.

23 MR. KABAT: So that the five grams actually in two
24 experiments, an order of one gram from the other
25 experiment? That's quite a large amount of iodine. That

1 would represent probably almost a total release of iodine
2 from the fuel.

3 MR. WICHNER: The experiments, as they ended up at
4 the upper temperature levels of 1200 or so above, most of
5 the iodine would end up in the vault, yes.

6 MR. KABAT: That shows really a very rapid rise.
7 A few hundred minutes, a rapid release of all the iodine
8 from the fuel into the steam.

9 MR. WICHNER: Yes. Right. I have some release
10 rate coefficients, but I am not sure how much time you want
11 to give me.

12 MR. MOELLER: I was going to ask you where you
13 stand. Mr. Kress still has to appear; is that correct? I
14 know we have delayed you with questions. But let's do move
15 along.

16 MR. MYNATT: Fred Mynatt again.

17 Let me restate the conclusions that I think boil
18 down from this discussion. That is, for the gap purge
19 experiments. The helium test, the observed form is not
20 molecular iodine. Strongly suggestion from analytical and
21 cesium iodide, but that's not a definitive measurement for
22 the steam test.

23 The conclusion, I think, that comes from this
24 discussion is -- our observations -- is that the
25 experimental technique has to be much more carefully done in

1 order to get real conclusions, so you can see we're not
2 really getting all that much from this table. But on the
3 other hand, it is very important that in one very clean case
4 it is not molecular iodine.

5 MR. MOELLER: How much more do you have?

6 MR. ETHERINGTON: Could I just ask one more
7 question quickly? Was the last table included in the
8 report?

9 MR. WICHNER: Yes.

10 MR. ETHERINGTON: Looking at Lorenz' more recent
11 publication, his numbers are on micrograms. You might want
12 to check to see whether that milligrams is correct on the
13 table.

14 MR. WICHNER: I am pretty sure it's milligrams,
15 but I will check that.

16 MR. ETHERINGTON: Some of this goes down to five
17 grams. That's a lot of iodine.

18 MR. WICHNER: Well, all right. Thank you. Okay.
19 Thank you.

20 MR. MOELLER: If you can finish your part up in
21 ten minutes or so, go ahead, Bob.

22 MR. WICHNER: Okay.

23 (Slide.)

24 I think I have covered, I think, the most
25 important area, and very briefly I would just like to look

1 now at relative release rates, sort of leading into Tom
2 Kress' part of the talk. I just would like to say that we
3 have examined a host of -- well, not a host -- but many
4 release rate experiments. And I think these are all that
5 pertain to materials other than noble gases. Each has
6 different characteristics, and I have to mention that
7 somewhat to indicate some of the subsequent uncertainty.
8 Each represents some sort of a compromise, and the
9 experimental conditions affect the results in different
10 ways. And the results, on the surface, is confusing. And
11 even below the surface it's confusing.

12 But in Lorenz' experiments, he actually used
13 discharged fuel, and the environment was helium and steam.
14 Parker used chunks of low-burning fuel and helium. He also
15 had some melt experiments. We used the causal experiments.
16 These used fuel simulants, which have a set of uncertainties
17 introduced therefore, and their experiments are
18 predominantly in air, which alters the chemical species.
19 And now there is generating some steam experiments.

20 We have the power burst facility tests and
21 reactor. Davies used low-burner material, powders, and
22 compacts and helium and so on, where you have in each
23 experiment either a burn-up effect, a chemical form effect,
24 a cladding, existing or nonexistent. And in-reactor tests
25 involve problems of their own.

1 But what we did to obtain relative release rates,
2 we emphasized for this study the first four studies.

3 (Slide.)

4 And while the result is confusing at first, there
5 does seem to be some sort of a pattern. These results are
6 expressed as release rate coefficient, fraction release of
7 remaining uncontrolled for a minute, and this curve for the
8 noble gases and the volatiles indicate some trend that we
9 examined, the individual experiments, qualitatively tried to
10 note their biases, and from that scatter attempted to define
11 an interim release rate coefficient for iodine, xenon,
12 krypton, and cesium, based on these individual tests, which
13 are a function of temperature.

14 (Slide.)

15 And from these uncertainties that we have come up
16 with this, which I would just like to present as our what I
17 would call an "interim" set of release rate coefficients
18 from fuel based on a partial examination of the body of
19 data. You might correct "zinc" there at the bottom. That
20 "Z" should be "ZR."

21 This set of curves applies. It does not apply to
22 the release part to the burst release and to the shallowly
23 embedded release, but to the subsequent release.

24 Well, I think I will end my talk at this point.

25 MR. MOELLER: Are there any other questions?

1 (No response.)

2 MR. MOELLER: Okay, let me ask how long Tom Kress'
3 presentation will be?

4 MR. KRESS: I had planned about a 20-minute talk.

5 MR. MOELLER: All right, I think we will go ahead
6 with it now and break for lunch after you finish.

7 (Slide.)

8 MR. KRESS: Tom Kress, Oak Ridge Laboratory.

9 The part I worked on and will discuss is the
10 calculation of release rates of fission products and other
11 materials. That includes fuel, clad, structure. As the
12 core heats up and passes through melt and is sustained at
13 some melt temperature.

14 In addition, if I have time I will talk about the
15 release from concrete and molten fuel, interacts with as it
16 falls through the vessels.

17 (Slide.)

18 The release calculations in this study are
19 somewhat different from the original reactor safety study.
20 And so that you can notice that those differences and more
21 or less highlight them a little bit, I have one slide which
22 I would like to present.

23 (Slide.)

24 This reviews briefly what was done at the reactor
25 safety study. In that study, if you look at some small

1 coherent mass of fuel that is heating up to melt, then it
2 was assumed that there was no release from that part of the
3 fuel. I am not talking about gap releases. This is
4 subsequent to that. There would be no release from that
5 part of the fuel until it was fully molten. And at that
6 time you would instantaneously release some fraction of its
7 inventory.

8 If you combined that then with the rate at which
9 the different parts of the core become molten, putting the
10 two together and multiplying this release fraction times the
11 fraction molten, you get a timed rate of release of the
12 total mass of the inventory.

13 I wanted to emphasize that this high rate of
14 release is strictly governed by the rate of the core
15 melting, and the total quantities is strictly governed by
16 this release fraction, which was established based on some
17 early experiments and based partially on volatilities of the
18 various fission products.

19 The experiments that Bob Wichner discussed --

20 (Slide.)

21 -- were observations that you don't have to wait
22 for the fuel to get completely molten before you release
23 materials. We have releases on both sides of the melting
24 point as it's being heated up and after it melts. And the
25 observations are that the release, the mass release,

1 decreases more or less exponentially if you hold the fuel at
2 a fixed temperature and not let it heat up.

3 This temperature can be below or above the melt.
4 This increases exponentially. But it will continue in time,
5 and it may even approach the total inventory if you held it
6 at that temperature long enough.

7 This suggests a release equation in this form
8 (indicating). The release rate is proportional to the
9 inventory that is there times some coefficient. And this
10 was the definition of this release rate coefficient that Bob
11 presented as his best estimate values from the set of
12 experiments that he looked at.

13 This is the approach that I used in estimating
14 these releases.

15 (Slide.)

16 Taking these, once again showing Bob Wichner's
17 table, I am showing there is continuous release as the core
18 heats up and passes through melt and even beyond melt as it
19 continues to heat up.

20 (Slide.)

21 We do recognize, however, that different parts of
22 the core heat up at different rates and melt at different
23 times during the accident sequence. So the question is how
24 do we use these strictly empirically established release
25 rate coefficients on a whole-core basis to account for this

1 fact that the core heats up differently and melts
2 selectively at different parts?

3 What I would like to have done was having a
4 thermohydraulics analysis that calculated the temperature
5 distributions in space and time within the core, couple that
6 with this release rate type equation with these coefficients
7 and how this code acted together to produce release rates at
8 a function of time for each of the isotopes.

9 Unfortunately, we didn't have this luxury in this
10 study, because the codes, the thermal dynamic codes are not
11 confined to such release rate equations. So I was forced to
12 try to do this by hand calculation. I computerized it, but
13 it was more or less a mechanized hand calculation.

14 (Slide.)

15 And to apply the equations, we used two sequences,
16 the AB sequence and the S2 sequence. And I think I will
17 just show you the S2C sequence, in the interest of being
18 brief.

19 We do need thermohydraulic calculations. We do
20 need the rate at which the core heats up and becomes
21 molten. This is the results of a March computer code
22 calculation. I am not going to dwell on it. This is the
23 time from the start of the accident, the delayed sequence in
24 which the melting only starts well within the accident.

25 ! But the point I want to make on this slide is this

1 gives the fraction of the core that is within a given
2 temperature increment. And the temperature increments are
3 shown up here plus or minus 100 degrees.

4 The point that I want to make here is that this,
5 in general, does give you percentages of the core that are
6 in particular temperature environments as a function of
7 time. However, we don't know from this kind of output
8 whether this particular part of the core passed directly and
9 became this part later on.

10 So it is not really specific for given locations
11 of the core. And in order to make calculations, we were
12 looking at release -- that is, a function of the current
13 inventory -- I really need these temperature histories that
14 would look at a specific chunk of fuel and follow its
15 complete history.

16 So what I did, in essence, was synthesize this
17 kind of result --

18 (Slide.)

19 -- by an analytical function that looks like
20 this. I replotted the data on that table. This line
21 (indicating) is a fraction of the core as a function of
22 time. That is, above a thousand degrees centigrade. For
23 the really significant release starts. The second line is a
24 fraction of that core above 2200 degrees centigrade, which
25 was the upper limit on the table.

1 The thing I wanted you to notice on these two
2 (indicating) is that when a given percentage of the core,
3 like going from two-tenths to three-tenths after it reaches
4 a thousand degrees, the amount of time for that percentage
5 to then arrive at 2200 degrees is not much different during
6 the whole course of the accident.

7 And, in essence, then, what I did was say once it
8 reaches to a thousand degrees, I will assume a heat-up of
9 about 80 degrees C per minute, which is the difference
10 between these two divided by this time and assume that that
11 heat-up rate is linear.

12 I can also combine that with, if we look at this
13 part of the curve and linearize that by this rate, this
14 tells me how fast parts of the core arrive at the thousand
15 degrees before they begin to heat up. By combining this
16 curve with this linear heat-up (indicating), I get a set of
17 numbers that look a lot like it in that table. It is an
18 approximation to the S2C accident sequence in terms of the
19 time-temperature history of the core.

20 (Slide.)

21 Given that type of time-temperature history, then,
22 I want to apply this new type of release rate equation. And
23 I did it as follows: To aid the analytical process, I took
24 this best-estimate release rate coefficients, if you recall
25 those, the empirical data taken from the experiments, and I

1 approximated them analytically. If you recall, it was a
2 semi-log plot release rate, a release rate coefficient
3 versus temperature.

4 You get that sort of equation for a straight
5 line. So I approximated them by two different straight line
6 over two different time intervals, although that is not made
7 clear.

8 So this then would give one a release rate
9 coefficient which would be specific for a given isotope,
10 where the A and the B define the isotope release rate. So
11 it's an analytic representation of these release rate
12 coefficients.

13 The temperature transient, as I said, I linearized
14 the heat-up 1000 degrees on up to as far as I wanted to go.
15 So this would be the 80 degrees per minute (indicating), and
16 this would be the thousand degrees here (indicating) in that
17 linearized approximation.

18 I still haven't said how I used the rate at which
19 I arrived at the thousand degrees, but I will talk about
20 that in a moment.

21 If you put this in through the temperature and use
22 release rate equation -- but this, by the way, should have a
23 minus in front of it, which was left off, and this double
24 equation should be a minus also.

25 If you put that into this equation, it becomes

1 this form, and you can integrate that and put it in the form
2 to get the total amount released as a fraction of the
3 original inventory. You get an equation of this form, where
4 the constant, the coefficients reflect both the empirical
5 data, data for release coefficient. It reflects the initial
6 starting temperature, and it reflects the heat-up rate.

7 So this was basically the equation I used to
8 calculate the release of the various fission products,
9 except this assumes that the heat-up rate is applied
10 uniformly for a given portion of the fuel. So you have to
11 incrementize the fuel and look at specific finite element
12 control volumes, and that is where the rate at which the
13 fuel rises reaches a thousand degrees is used.

14 If you recall, that straight line gave you 2
15 percent per minute arrival of the core above a thousand
16 degrees. What that means is that every five minutes an
17 additional 10 percent of the core has reached a thousand
18 degrees.

19 If I used the 10 percent of my core as a finite
20 element in my equation, then using that previous equation
21 for the release rate on an incremental basis when my
22 increments were 10 percent -- that's not a decimal point;
23 that's 10 percent -- then the equation really looks like
24 this.

25 (Slide.)

1 The one-tenth takes care of the -- well, now, this
2 is a whole-core inventory, so I divided the one-tenth. I
3 add up all of the incremental releases for each increment of
4 the core, its delayed and its release, by five minutes
5 because of this five-minute interval, and I still have the
6 same coefficients with the thousand degrees and 80 degrees C
7 per minute.

8 So this is really the equation I used to calculate
9 the release based on the empirical established release rate
10 coefficient.

11 I had to computerize it, part of it, of course.
12 Applying that equation with the best-estimate coefficients
13 for the two sequences, you get a set of curves that look
14 like this --

15 (Slide.)

16 -- for the different isotopes. This is a fraction
17 of the total core inventory now released as a function of
18 time for the S2C sequence. And this time is measured really
19 from the point on the table which was the point at which the
20 first core element had reached a thousand degrees
21 centigrade. So it's not the time when we started the
22 accident. But basically, what we get out of this kind of
23 calculation is the time history of the release of the
24 various parts of the isotopes based on strictly empirical
25 data of small-scale release.

1 I left the WUEA curve off of here. It falls in
2 between the (inaudible).

3 If then we look at -- this accident is projected
4 that the core support barrel would fail at about seven
5 minutes, so that at that time the release would be quenched
6 by the core falling in the water below. So if you look at
7 the values for the release at that time, you would get and
8 add up all of the materials so that one can establish a
9 total amount of release for each of the sequence --

10 (Slide.)

11 -- you get numbers like for the AB sequence and
12 the time of grid plate failure you get on the order of 770
13 to 1000 kilograms. I wouldn't attach my significance to
14 these figures here. The S2C sequence, you get perhaps 1500
15 kilograms at the time of grid plate failure.

16 If we compare the individual release of the
17 different isotopes --

18 (Slide.)

19 -- for the, in this case, the AB sequence, which
20 was more comparable to the things suggested in the RSS --

21 MR. MOELLER: Excuse me. On the previous slide,
22 you showed the grid plate value predicted by the March code
23 at 20 minutes? Oh, and then the S2C is the 70 minutes. I
24 missed the 70. Go ahead. I am sorry.

25 MR. KRESS: Comparing the release of individual

1 isotopes for the AB sequence at 20 minutes, which is at the
2 time of grid plate failure, you get virtually complete
3 release of iodine and cesium. Surprisingly, we get
4 virtually complete release of the tellurium; however, it may
5 be a tenth in the reactor safety study.

6 The rest of the figures are comparable
7 magnitudes. They are somewhat higher. Barium and strontium
8 release and hydrogen release. But they're the same order of
9 magnitude.

10 There is a considerable quantity of structure
11 cladding fuel that is important in the release because it
12 adds to the total airborne, the aerosols which affect the
13 subsequent transport in the containment.

14 So these released quantities for the fractions are
15 small, but the total inventories are large. So that they
16 are very significant in the total release.

17 MR. MOELLER: Harold, I don't know if it helps you
18 at all, but at least that chart shows the iodine and cesium
19 coming off at roughly --

20 MR. ETHERINGTON: It doesn't really tell me,
21 really, what I want to know.

22 MR. MOELLER: It's the detail you want?

23 MR. ETHERINGTON: How much was really in the
24 lattice was what I wanted to know, and how much was a gross
25 amount. It doesn't help me. But it's okay.

1 MR. SHERRY: I just want to point out where some
2 of the products in the second group, the tellurium --

3 MR. MOELLER: We can't hear you.

4 MR. SHERRY: I'm sorry. I just wanted to point
5 out that for the second group of elements, although we
6 predict a much larger release during the in-vessel phase in
7 the reactor vessel safety study essentially all of the
8 tellurium was released at the subsequent stages of the
9 accident in the interaction with concrete. That isn't to
10 say the reactor safety study grossly underestimated the
11 consequences, at least for that group.

12 MR. KRESS: I think the major conclusion is this
13 calculation is based on newer data for release rate
14 coefficients, and it allows the process to occur
15 continuously rather than with the melt. Still, it more or
16 less -- we didn't know that at the start, but it's an
17 important conclusion.

18 MR. STEINDLER: Could I ask a question? I think I
19 got lost in the turn, if you will bear with me. You've got
20 both iodine and cesium in this last table that you showed
21 essentially complete released in 20 minutes.

22 (Slide.)

23 It's about 10 times as much cesium as there is
24 iodine. So the release mechanism can't be by cesium iodide
25 because it leaves you a bunch of cesium left over. We've

1 heard so far the focus on cesium uranate through steam
2 composition gives you some cesium and another cesium uranate
3 that works its way up to the line until you get cesium
4 uranate, if you have enough time, that's fairly stable, to
5 cesium for uraniums.

6 The vapor pressure of that material was trivial, I
7 think, even at 2000 degrees, if I have that right, or at
8 least trivial by that mechanism.

9 What is the way by which all of that cesium gets
10 away from the refractory oxide compounds that are left after
11 the iodine is gone?

12 MR. KRESS: I don't feel -- would anybody like to
13 comment on that?

14 MR. STEINDLER: Am I asking the wrong question?

15 MR. WICHNER: That's a good question. I am not
16 sure the answer to that has been thought out, frankly.

17 MR. STEINDLER: But yet you give a total -- you
18 know, you give a coefficient for cesium release that dumps
19 it all out.

20 MR. WICHNER: Yes, believe that's what we say,
21 yes. But the step-by-step mechanism whereby that happens
22 has not been completely worked out.

23 MR. STEINDLER: Well, then, can you tell me a
24 little bit about -- we didn't cover it in detail, but tell
25 me how tellurium moves? As the volatile oxide? And, if so,

1 how do you account for sodium as the oxide decomposes?

2 MR. WICHNER: Well, I wish you would address those
3 questions to us a little bit later. Some of those questions
4 can't be answered at this point. The mechanism for mobility
5 at this stage has not been worked out.

6 As far as cesium leaving those, as you heat the
7 uranate, you evolve the cesium. If you have a cesium
8 iodide, you vaporize the cesium iodide; if you have the
9 cesium in the elemental form, you will naturally at first
10 evolve the cesium metal as the vaporization.

11 All of these things -- at the same time, you're
12 diffusing cesium in the grain out towards the surface of the
13 grain, and while this is happening, you're changing the
14 chemical environment, perhaps altering the chemical species
15 that would be in equilibrium. And I haven't mentioned the
16 possibility of interaction in the zirconium with the iodine
17 material.

18 So, as you heat up a host of chemical and physical
19 processes occur -- and I don't mean to avoid your question,
20 but I think it's fair to say that what those processes are
21 have not been worked out.

22 MR. KRESS: From my viewpoint -- and the
23 calculations could be thought of as almost nonmechanistic,
24 strictly empirical, based on small-scale experiments, to get
25 these release rate coefficients. What the mechanism is for

1 release of deuterium, cesium, iodine, I don't know. And
2 that may be entirely wrong. It's based on small-scale
3 experiments with all the uncertainties.

4 MR. ETHERINGTON: If it helps any, the tellurium
5 boiling point is only 100 degrees higher than cesium iodide,
6 but that doesn't completely answer anything.

7 MR. STEINDLER: I was willing to buy the tellurium
8 just on the basis of simple inorganic chemistry. I have a
9 little more trouble with silver, the metallic boiling point
10 is awfully high and the oxide decomposes

11 MR. WICHNER: However, the tests show a very rapid
12 evolution of silver in a steam atmosphere, and it is very
13 surprising.

14 (Slide.)

15 MR. KRESS: Well, to summarize that part of the
16 calculation, it is significantly different from WASH-1400.
17 This calculation is different from WASH-1400. It is based
18 on empirical data for the release rate coefficients, and in
19 general these are best estimates based on present
20 state-of-the-art data. But the important conclusion is that
21 the values used in WASH-1400 for this particular sequence
22 are not much different. We more or less support those
23 values. Based on some of the comments that were made, there
24 are large uncertainties in these results. The release rate
25 coefficients.

!

1 (Slide.)

2 We did have another portion; that is, to estimate
3 the total quantities of materials that might be made
4 airborne, the secondary containment as a result of hot fuel
5 falling on the concrete and interacting. And we did make an
6 estimate of the material that gets released. It is strictly
7 abstracted from and based completely on the Sandia results
8 for the Zion Indian Point, if you are familiar with that.
9 It's almost verbatim, word for word. And the basis for that
10 is that's the only -- that's the real quantitative evidence
11 right now, correlations for release of aerosols from
12 concrete as a fuel interacts with that.

13 (Slide.)

14 Just some comments about the data. They observed
15 that the release rates were proportional to the rates at
16 which gases got evolved from the concrete that's barged up
17 through the mouth. They observed it to be a sharp function
18 of the melt temperature initial function as it falls on the
19 concrete. They observed it not to be strongly dependent on
20 the concrete type, but I am not sure what that means now
21 because I don't know how many concrete types were tested.

22 The important part is this aerosol is composed
23 mostly of nonfuel material. It comes out of the concrete
24 itself.

25 (Slide.)

1 The calculations I summarize on one slide, and I
2 won't dwell on it.

3 The release rate, as I mentioned, is a function of
4 the gas velocity. It is also a function of the surface area
5 and the concentration in that gas itself. But this
6 concentration was based on the empirical equation that
7 related the temperature of the melt and the superheat
8 velocity of the gas, which is determined once again by heat
9 transfer calculation, giving the gas released from the
10 concrete as a function of the heat transfer rate. That's
11 basically the correlation we used.

12 They had to use the computer code to get the heat
13 transfer rates, and the one they used was called WECHSI to
14 determine the Q. And these quantities are known
15 quantities. And they're particular to given concretes. And
16 that gives the gas velocity to go to here (indicating),
17 combined with the temperature to get the concentration in
18 gas, and then it goes on up to this relationship to get the
19 release. The results for the AB sequence --

20 MR. MOELLER: Dr. Lawroski had a question.

21 MR. LAWROSKI: What is it you thought was meant by
22 the different concrete types?

23 MR. KRESS: They tested some different concrete
24 types which would have different constituencies in them.

25 MR. LAWROSKI: One of them was the so-called --

1 MR. ETHERINGTON: Different aggregates, is that
2 the difference?

3 MR. SALLACH: My name is Bob Sallach, from Sandia.
4 The two concretes were tested, a basalt-based
5 aggregates and limestone-based aggregates, those were the
6 two.

7 MR. SHERRY: Limestone aggregate produces more
8 gas.

9 MR. KRESS: The final slide --
10 (Slide.)

11 -- shows the total release of aerosols as a
12 function of time for the AB sequence in the Zion reactor.
13 In this case, what you notice is the releases interacted
14 very early. These are ours, in this case. There is a
15 rather rapid release early, and it reaches, depending at the
16 value, of about 800 in this case, which added to the 1500
17 kilograms -- well, in fact, it was about 1000 kilograms for
18 the AB sequence, which would give you about 1500 total.

19 That concludes my presentation.

20 MR. MOELLER: Thank you, Mr. Kress.

21 Questions or additional questions on this?

22 (No response).

23 MR. MOELLER: I assume you will be here all
24 afternoon and then tomorrow, too?

25 MR. KRESS: Yes.

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