

Official Transcript of Proceedings
NUCLEAR REGULATORY COMMISSION

Title: Advisory Committee on Reactor Safeguards
Future Plant Design Subcommittee

Docket Number: (n/a)

Location: Rockville, Maryland

Date: Tuesday, April 5, 2011

Work Order No.: NRC-817

Pages 1-303

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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SUBCOMMITTEE ON FUTURE PLANT DESIGNS

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TUESDAY, APRIL 5, 2011

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ROCKVILLE, MARYLAND

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The Subcommittee met at the Nuclear
Regulatory Commission, Two White Flint North, Room
T2B1, 11545 Rockville Pike, at 10:00 a.m., Dr. Dennis
Bley, Chairman, presiding.

SUBCOMMITTEE MEMBERS PRESENT:

DENNIS C. BLEY, Chair

SAID ABDEL-KHALIK

J. SAM ARMIJO

CHARLES H. BROWN

MICHAEL CORRADINI

HAROLD B. RAY

JOY REMPE

MICHAEL T. RYAN

1 CONSULTANTS TO THE SUBCOMMITTEE PRESENT:

2 THOMAS S. KRESS

3

4 NRC STAFF PRESENT:

5 MAITRI BANERJEE, Designated Federal Official

6 SUDHAMAY BASU

7 KATHY GIBSON

8 STEPHEN FLEGER

9 JOSEPH KELLY

10 MOURAD AISSA

11 HOSSEIN ESMAILI

12 STUART RUBIN

13 MAKUTESWARA SRINIVASAN

14 SHAH MALIK

15 AMY HULL

16 JOSE PIRES

17 JEFFREY WOOD

18 MARY DROUIN

19 SEAN PETERS

20 YAGUANG YANG

21 RUSS SYDNOR

22

23 ALSO PRESENT:

24 DAVE PETTI

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

10:02 a.m.

CHAIRMAN BLEY: The meeting will now come to order. I'm Dennis Bley, chairman of the Future Plant Design Subcommittee.

We have with us today ACRS members - I've got to recheck my list - Harold Ray, Sam Armijo, Joy Rempe. We expect very shortly to have Dr. Abdel-Khalik and Dr. Corradini join us. And there may be some others.

Tom Kress is here who is our consultant. Maitri Banerjee of the ACRS staff is the designated federal official for this meeting.

The purpose of today's meeting is to receive a briefing and discuss with the staff the NRC High-Temperature Gas-Cooled Reactor Research Plan that addresses work needed for the NRC to prepare to review the future NGNP Application.

The last time the subcommittee had a briefing on the Research Plan was on January 14 and 15, 2009. That was quite some time ago.

The Research Plan has been updated to address only the HTGRs and the discussion on sodium-cooled fast reactors has been eliminated.

Drs. Corradini and Rempe may have some

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1 potential organizational conflict. Hence, they will
2 not take part in any discussions specifically related
3 to their work.

4 The rules for participation in today's
5 meeting were announced in the Federal Register on
6 March 22nd, 2011, for an open-closed meeting.

7 I'm asking the NRC staff and the applicant
8 to identify the need for closing the meeting before we
9 enter into discussion regarding any proprietary
10 material, and to verify only people with the required
11 clearance and need to know are present.

12 We have a telephone bridge line for the
13 public and stakeholders to hear the deliberations.
14 This line will not carry any signal from this end
15 during the closed portion of the meeting.

16 Also, to minimize disturbance, the line
17 will be kept in the listen-in-only mode until the last
18 15 minutes of the meeting. At that time, we will
19 provide an opportunity for any member of the public
20 attending the meeting in person or through the bridge
21 line to make a statement or provide comments.

22 As a transcript of the meeting is being
23 kept, we request that participants in this meeting use
24 microphones located throughout the meeting room when
25 addressing the subcommittee.

1 Participants should first identify
2 themselves and speak with sufficient clarity and
3 volume that they can be readily heard.

4 We will now proceed with the meeting, and
5 I call upon Dr. Sud Basu of the Office of Nuclear
6 Regulatory Research to begin the staff presentations.

7 Sud.

8 MR. BASU: Thank you, Mr. Chairman, and
9 good morning ACRS members. We are waiting for - we
10 are waiting for Ms. Kathy Gibson - oh, there she is.

11 Kathy, would you like to say a few words
12 before I start?

13 CHAIRMAN BLEY: Thank you. Welcome.

14 MR. BASU: Kathy is the director of the
15 Division of Systems Analysis and we have the
16 cognizance of the HTGR R&D program for the Office of
17 Research.

18 CHAIRMAN BLEY: Okay. Kathy.

19 MS. GIBSON: Hi. I'm just going to take a
20 minute and introduce myself. I have replaced Jennifer
21 Eule who is now the Office of Research deputy
22 director.

23 And my name is Kathy Gibson. I was
24 Jennifer's deputy for two years. So, I'm not entirely
25 new to the work that we're doing here.

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1 And I just want to say we welcome the
2 opportunity to present our HTGR research plan. It's
3 been many years in the making. Fits and starts.
4 We're still interested to see where this program is
5 going to go for the long term, as I'm sure you are.

6 But the staff has put together a good
7 presentation. So, we're interested in your feedback.
8 Thank you.

9 CHAIRMAN BLEY: Thank you.

10 MR. BASU: Thank you, Kathy.

11 As Dr. Bley pointed out, we had the last
12 briefing before ACRS a little over two years ago. We
13 made a couple of attempts to come before you and brief
14 you on the status of the program. For one reason or
15 another, that did not happen.

16 We are glad to be here finally. And the
17 good thing is that we will be able to share with you
18 the progress made in the last couple of years.

19 So, I'm going to - let's see. How does
20 this go? I'm not doing something right.

21 CHAIRMAN BLEY: Help is on its way.

22 (Off-record discussion.)

23 MR. BASU: Okay. So, you know, I'm here
24 with a number of colleagues from the Office of
25 Research. And between us, we are going to cover all

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1 the topics that are in the R&D plan that you have a
2 copy now.

3 There is going to be altogether four new
4 presentations, including my overview presentation. In
5 the interest of time, I will request the Chair to time
6 each speaker so that we can give you the full coverage
7 and still be in time.

8 CHAIRMAN BLEY: And the Committee will try
9 to allow you to proceed.

10 MR. BASU: Thank you. So, the outline of
11 my presentation, which is an overview presentation
12 which is going to set the tone for the rest of the
13 presentations, is to talk about the objectives of this
14 briefing.

15 I'll say a few words on the role and scope
16 of NRC research for HTGR, high-temperature gas-cooled
17 reactor, assumptions we made in developing the plan,
18 as well as implementing the plan.

19 I'll spend a few minutes on implementation
20 status, and that's where I'm going to talk about the
21 problems over the last couple of years.

22 My presentation will still be fairly broad
23 in the overview mode, but the subsequent presentations
24 are going to cover individual topical area in far more
25 detail.

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1 And then I'll say a few words about going
2 forward from this point onward.

3 CHAIRMAN BLEY: Okay.

4 MR. BASU: So, the objectives of the
5 presentation I'll be briefing is to provide you an
6 update, as I mentioned before, on not only the
7 research plan, but also its implementation status.

8 We are going to solicit your feedback,
9 your input, comments, etcetera, as we always do for
10 any briefing.

11 We're also going to request a letter from
12 ACRS and that of course after we brief the full
13 Committee. And currently, my understanding is it's
14 scheduled sometime in May.

15 Okay. So, in terms of the role of NRC
16 HTGR research, we are focusing on development of
17 analytical tools and capabilities to perform
18 confirmatory safety analysis as we do for any other
19 reactor types.

20 So, this is not unique as such to HTGR,
21 but the idea is that we have to be ready to be able to
22 provide technical support for licensing review. And
23 also provide technical basis for any regulatory
24 decisions.

25 The role of the research is also to

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1 develop technical basis for identifying and resolving
2 safety issues. These are - these could be technical
3 issues and also policy issues, but providing the
4 technical basis for making any resolution of these
5 policy issues. And, also, technical basis for
6 developing regulations and guidance.

7 The third role is unique to HTGR, which is
8 development of staff technical expertise and review
9 capabilities.

10 As you all know, that the Agency has been
11 involved in the Light Water Reactor business, you
12 know, for all the time at least that I'm with the
13 Agency, and even before that.

14 We have had some brief past experience
15 with the HTGR activities. Review, sort of,
16 activities. The resources, and I'm talking about
17 human resources in this case, who were at the time at
18 NRC, there are very few and far between to find them.

19 So, one objective on role of the research
20 is to develop staff technical expertise and review
21 capabilities. And that's kind of unique to this.

22 MEMBER RAY: In this historical context,
23 could you just touch on Fort St. Vrain, or will you,
24 in terms of the NRC's involvement in it, if at all, or
25 how it was involved?

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1 MR. BASU: Well, first of all, it's long
2 before my time at NRC. And at that time -

3 MEMBER RAY: Before my time also.

4 (Laughter.)

5 MR. BASU: If I am not misspeaking, some of
6 the activities were carried out under the banner of
7 AEC in those days. And then later on the NRC was
8 created.

9 So, and of course we - I believe Fort St.
10 Vrain was licensed under a different set of rules.

11 MEMBER RAY: Well, that's what I'm asking.
12 If you're not prepared to speak to it, that's okay.
13 I just would like to - you're talking historically.
14 And, certainly, Fort St. Vrain existed and operated.

15 MR. BASU: Right.

16 MEMBER RAY: I'm just trying to make a
17 connection there.

18 MR. BASU: Could we get back to you on
19 that?

20 MEMBER RAY: Sure.

21 MR. BASU: Thank you.

22 So, and of course I have to acknowledge
23 that there are some staff from the Office of New
24 Reactors, which is our sort of regulatory counterpart,
25 if you will. The program office. So, if anyone from

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1 Office of New Reactors would care to address this at
2 some later point, feel free, please.

3 The scope of HTGR research I have kind of
4 listed here. Again, the major focus is on the
5 development of confirmatory safety analysis tools.

6 We have codes, computer codes, evaluation
7 models, models of physical phenomena, data, data for
8 assessment, validation given for model development and
9 improvement.

10 A number of major technical areas where we
11 are focused in, these are listed here. Thermal-
12 fluids, nuclear analysis, accident analysis.

13 And I'm going to introduce the staff
14 members at this point who are going to speak to these
15 topical areas.

16 The thermal-fluids, nuclear analysis and
17 accident analysis are going to be covered by a team
18 led by Joe Kelly, sitting in the back, who is going to
19 talk about the evaluation model development. Also,
20 code development. In particular, the PARCS/AGREE
21 code. That's the coupled neutronics/thermal
22 hydraulics code. And, also, supporting experimental
23 programs that we have.

24 He will be followed by Dr. Mourad Aissa
25 who is going to talk about the nuclear analysis

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1 development.

2 And then followed by Dr. Hossein Esmaili
3 who is going to talk about the MELCOR development and
4 assessment work.

5 We also are heavily focused in fuel and
6 fission product transport, release and transport
7 program.

8 And Stu Rubin, who is the senior level
9 advisor for the Office of Research in our division, is
10 going to give presentations on the fuel.

11 That will be followed by two
12 presentations. One on graphite to be given by Dr.
13 Srinivasan - Makuteswara Srinivasan. I hope I
14 pronounced it correctly.

15 And then on the high-temperature metallic
16 materials, that will be given by Dr. Shah Malik. And
17 also a portion of that will be given by Dr. Amy Hull.

18 We are going to talk to you about
19 structural integrity of systems and components, the
20 structural analysis area. That presentation is going
21 to be given by Dr. Jose Pires from the Division of
22 Engineering in the Office of Research.

23 The work has been done by a number of
24 staff members and their contact organizations. And
25 the staff members are present here to answer any

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1 questions you have.

2 I will come back and talk to you about the
3 process heat utilization. I understand that is the
4 very last item in the agenda.

5 So, depending on how we proceed, you will
6 probably hear very little or a lot from me at the
7 time.

8 There are other technical areas that we're
9 going to give presentations on. Mainly, probabilistic
10 risk analysis. This presentation will be given by
11 Jeff Wood from the Division of Risk Analysis in the
12 Office of Research. Also, assisted by Mary Drouin.

13 There will be a presentation on the human
14 factors given by Mr. Stephen Fleger from the Division
15 of Risk Analysis again.

16 And the final presentation on the
17 instrumentation and control technology to be given by
18 Dr. Yaguang Yang. Assisted by Russ Sydnor from the
19 Division of Engineering.

20 CHAIRMAN BLEY: Sud, if I remember our
21 discussions correctly, the reason these are so short
22 is because these are just going about through the
23 planning stages now. You haven't done much work in -

24 MR. BASU: Some are. Some we barely
25 started work. And, yes, you are going to hear about

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1 some work that was initiated, but more on the planning
2 stage.

3 CHAIRMAN BLEY: Okay.

4 MR. BASU: That's correct.

5 There are some other areas that I am not
6 going to cover, we are not going to cover in this
7 briefing. And they are also not covered in the R&D
8 plan. These are important areas.

9 We didn't cover them in the plan for
10 various reasons, and I'm going to list them. I don't
11 have a slide.

12 The fuel cycle is not covered in the R&D
13 plan with the exception of some neutronics aspect of
14 the back-end of the fuel cycle, spin fuel, et cetera,
15 that Mourad is going to talk briefly about.

16 We have not addressed security and
17 safeguards in an integrative manner in the R&D plan.
18 We have not addressed siting in the R&D plan, and I'm
19 not going to cover any of that.

20 And I'll tell you the reason why
21 historically they were not covered. Now, remember in
22 the Energy Policy Act, the NGNP was defined as a
23 prototype plan to be constructed at Idaho in the DOE
24 property.

25 DOE was going to assume the ownership of

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1 fuel, and of course the siting was that DOE protect
2 the siting. And DOE was also going to take the
3 ownership of the security aspect.

4 So, all this is combined for NGNP. And I
5 should probably mention for the benefit of the
6 audience here, NGNP, Next-Generation Nuclear Plant, is
7 a high-temperature gas-cooled reactor plant. That's
8 how it is defined in the licensing strategy that we
9 submitted to Congress back in 2008.

10 So, these were not part of the licensing
11 strategy, development. And as a result, these did not
12 become part of the R&D plan.

13 These are important aspects. We have to
14 revisit them as the time progresses. And at some
15 point, we will probably have to revise our R&D plan
16 with the appropriate R&D activities.

17 MEMBER RAY: Dennis, looking all the way
18 ahead to the letter, which of course is after the full
19 committee meeting, I think these carve-outs here will
20 be something we'll want to take note of because things
21 have moved on to the point where they are more
22 important now than they were when this plan was
23 developed, and that will need to be acknowledged.

24 CHAIRMAN BLEY: Thanks, Harold.

25 MR. BASU: Yes, I think you are absolutely

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1 right. The climate has changed. It is changing. So,
2 we'll have to revisit these issues at some point.

3 I'm not going to talk about policy issues
4 in this briefing. These - it is the parlay of the
5 Office of New Reactors, and they have actually come
6 before you to talk about at least one White Paper, one
7 policy issue in the past.

8 And I understand there's a plan for them
9 to come and brief you. So, I'm going to skip those
10 and the associated White Paper review process.

11 We made a number of assumptions going
12 forward developing the R&D plan, as well as
13 implementing the plan, and these are listed here.

14 The first one is that out scope is, in
15 large part, generic. And by that, I mean applicable
16 to the HTGR technologies that are in the market
17 currently. Namely, the pebble-bed technology, as well
18 as the prismatic technology.

19 So, we try very consciously to design our
20 research program to address as much as possible both
21 technologies.

22 Again, at some point when the point
23 selection is made, we probably have to revisit the
24 research program and put our focus on the right
25 technology. But for now, it's mostly generic in

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1 nature.

2 We heavily rely on the data from DOE-
3 sponsored programs in a number of areas like fuel,
4 graphite, high-temperature materials and so on and so
5 forth.

6 And you're going to hear in the subsequent
7 presentations, some of these subject areas. And
8 particularly in the fuel area, we'll touch upon DOE
9 programs in some detail.

10 We of course are going to rely on
11 applicant-furnished data for plant-specific licensing
12 review. And this is no different from any other
13 licensing activity.

14 We do rely on the applicant-furnished data
15 to make their safety case. We take the data and we
16 conform through our confirmatory safety analysis
17 activities.

18 MEMBER ARMIJO: Dr. Basu, do you have an
19 idea of who the applicant will be for this first
20 prototype?

21 Will it be a DOE as an entity or will it
22 be some commercial entity, private or what?

23 MR. BASU: My short answer is, no, I do not
24 have an idea at this point.

25 MEMBER ARMIJO: All right. You just don't

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1 know.

2 MR. BASU: I don't know.

3 MEMBER ARMIJO: Okay.

4 MR. BASU: We are going to rely on the
5 availability of complementary data from international
6 HTGR R&D programs. There are a number of programs.
7 HTTR program, High-Temperature Engineering Test
8 Reactor program in Japan. HTR-10, the High-
9 Temperature Reactor program in China. There was a
10 program in South Africa, PBMR. That's kind of
11 cancelled at this point.

12 But there's also a program in Europe,
13 Europe, EUROPAIRS program, which is a fall under
14 RAPHAEL program.

15 So, we will benefit from data that's been
16 generated, that will be generated on this program.
17 And so, we'll rely on the availability of the data
18 from these programs.

19 And then of course we'll rely on the
20 national and international codes and standards
21 activities. Primarily, of course, national. But in
22 some specific cases, we'll sort of make use of the
23 international codes and standards data.

24 The final bullet I have is - and I'm going
25 to just leave it at that, is adequate resource

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1 allocation.

2 In the Licensing Strategy Report, we
3 stipulated that we are going to be ready by 2013,
4 primarily, you know, mostly ready by 2013 with our
5 tools to be able to entertain a License Application at
6 that time.

7 Again, the landscape is changing. We
8 obviously don't know whether we are going to receive
9 an application. 2013, it's probably relatively a safe
10 assumption to say it's going to slide beyond 2013.

11 But, again, the R&D plan was predicated on
12 our being ready, in large part, by 2013. And so, any
13 resource implication thereby so that we can be ready.

14 And now that the professor walks in, we
15 all have to rise, right?

16 (Laughter.)

17 MEMBER CORRADINI: I thought I could sneak
18 in quietly.

19 MR. BASU: Okay. So, I think you expressed
20 an interest to know what are the new developments
21 since the last briefing.

22 Well, cosmetically there is one new thing.
23 You saw last time a probably 270 plus pages of the
24 Adverse Reactor Research Program document. We pared
25 it down to about fifty pages or so.

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1 We obviously have excluded a few things
2 from there, and I'll just quickly run by those few
3 things.

4 One is that we had a small section on the
5 LMR in that ARRP, which is not included in this NGNP
6 R&D plan that you have. It is strictly HTGR R&D plan.

7 The ARRP also had the - if you could
8 picture the universe of research that would be
9 conducted not only by NRC, but by applicants, by DOE,
10 in this particular case, DOE Lab, the international
11 community, what we did, we extracted and focused on
12 the NRC research that we are going to conduct, and we
13 are conducting of course, again, relying on data that
14 will come from all the other programs. So, that's the
15 cosmetic change that you have probably noticed
16 already.

17 There are a few other things that I will
18 just sort of go quickly through. There's some
19 development that affect our R&D program.

20 As you know, there is a trend to go into
21 a lower reactor outlet temperature for the HTGR
22 design. And with that lower reactor outlet
23 temperature comes the consideration of the choice of
24 materials.

25 Now, if we go to temperature like 700,

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1 750, we have materials that have been qualified, code
2 qualified to that temperature, which we can then make
3 use of in large part. There may be some residual
4 research that will be needed.

5 So, our focus currently is on the lower
6 reactor outlet temperature meaning that we will
7 validate our tools with the existing data as a large
8 part.

9 The tools themselves are not going to be
10 different for - hopefully not different for even
11 higher-temperature applications, but we will not have
12 the means to validate these tools in any short term.
13 So, that's a change.

14 You also probably heard about
15 reconsideration of steam cycle for power conversion.
16 It started out with steam cycle. At some point, it
17 then migrated to direct cycle-bred, and now it's
18 coming back to steam cycle.

19 With that, there's this issue of moisture
20 ingress that is coming into the picture. That is sort
21 of becoming a more important consideration. Something
22 that we recognized in the past, but we left out from
23 further consideration, because we thought it was going
24 to be a direct thermal cycle. So, you're going to see
25 some future activities in that direction.

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1 And the final one I said, broadening scope
2 of process heat utilization. Initially under the
3 Energy Policy Act, the focus was on hydrogen co-
4 generation, in large part, hydrogen co-generation for
5 which to be more efficient, you need a higher reactor
6 outlet temperature.

7 Now, with the landscape changing to lower
8 temperature, you can actually use the process here for
9 many, many more applications in just as efficient
10 manner as you would for hydrogen co-generation at a
11 much higher outlet temperature.

12 So, there is some broadening of scope
13 which has, again, some implications on materials R&D,
14 as well as the degradation of components in the
15 process heat part of the equation.

16 There are some other developments with
17 potential R&D, design or regulatory impact. I'm not
18 going to go through in any detail with these.

19 Co-location at industrial sites, again,
20 that's the changing landscape. Multi-module design,
21 that comes with the commercialization of the plant
22 and, you know, sort of economics is driving that.

23 The two items that I have, the last two
24 items, consideration of fuel form. By that I mean the
25 kernel in the TRISO particle fuel.

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1 You have the TRISO uranium oxycarbide or
2 the uranium dioxide. The fuel that had been used in
3 the past primarily in the AVR and THTR and in the
4 European reactors are uranium dioxide fuel.

5 So, we have experience in that fuel, but
6 the AGR program at Idaho has focused on uranium
7 oxycarbide fuel and fuel development. You're going to
8 hear more about that.

9 Depending on where we end up with, the
10 choice between uranium oxycarbide or with uranium
11 dioxide, there may be some issue that we are going to
12 look into it at some point.

13 And, finally, consideration of technology
14 alternatives, I told you about the PBR versus PMR. We
15 are not there yet in terms of the point design, point
16 selection of the design. And when that comes, then
17 we'll have to revisit our R&D program accordingly.

18 This is the only cartoon I'm going to show
19 you only to make the point that I already made which
20 is that so far we are trying to stay technology-
21 neutral, if you will, generic as much as possible.
22 But at some point, we'll have to revisit our plan and
23 program.

24 So, with that I'm going to move on to the
25 implementation status. I don't want to go through

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1 each and every line here in detail. There's some
2 points that I want to make.

3 Thermal-fluids, nuclear analysis, accident
4 analysis, that is our major focus area. That's where
5 we are going to develop - we are developing the tools,
6 confirmatory safety analysis tools.

7 And in that vein, there are two areas that
8 we are concentrating on. One is the analytical
9 development of the codes, both system level and more
10 detail - more mechanistic, if you will, code, and also
11 the assessment database.

12 We are also involved in a number of
13 supporting experimental programs. These experimental
14 programs are in collaboration with DOE under the DOE-
15 NRC Interagency Agreement.

16 And that, by the way, is going well. Both
17 parties are benefitting from that agreement. We have
18 some experimental programs in place that are funded
19 under that agreement. We are also benefitting from
20 very close collaboration with the DOE main laboratory,
21 the Idaho National Laboratory.

22 MEMBER ARMIJO: For those particular
23 programs, is it co-funded by NRC and DOE, or is it
24 funded primarily by DOE and NRC monitoring the work?

25 MR. BASU: Well, let me talk about the

1 program very briefly. We started that program under
2 NRC funding, and now it is funded under the DOE-NRC
3 Interagency Agreement program. So it's, you can say,
4 fully funded under that agreement, but we started that
5 program under the NRC funding.

6 There's a program that we are currently
7 discussing negotiating and trying to put in place as
8 the OECD-HTTR Loss of Forced Circulation. This is in
9 Japan. And NRC will be, if everything goes well, NRC
10 will be a participant in that program very shortly.

11 Then there are a number of programs in the
12 university, and these programs are complementing the
13 DOE programs at universities under the Nuclear Energy
14 University Program initiative.

15 In the fuel performance and fission
16 products area, our work activities are primarily
17 analytical in nature. We work with very closely
18 monitoring the DOE program at Idaho National Lab, the
19 AGR program that you're going to hear more about it in
20 the subsequent presentations.

21 In the graphite high-temperature
22 materials, likewise our programs are primarily
23 analytical.

24 We have listed initiative as more
25 experimental program on graphite at the Oak Ridge

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1 National Laboratory looking at the stored energy
2 aspect of graphite. And, again, you're going to hear
3 more detail about that later.

4 In the structural analysis program, we are
5 concentrating - again, this is all analytical. We are
6 concentrating on the assessment of concrete behavior
7 at high temperature and under irradiation environment.

8 We're also looking at the seismic and
9 soil-structure interaction, and seismic loading
10 consideration. I'll leave it at that.

11 Digital I&C and human factors there, we
12 are looking at the instrumentation and control area.
13 Our work at the moment is more like literature
14 survey/review of what is there, what is out there,
15 what we can benefit from in order for us to be
16 prepared for any sort of new design that's coming in
17 for -

18 CHAIRMAN BLEY: Is there anything we're
19 seeing there that's different from what we're seeing
20 in the new Light Water Reactor designs that are coming
21 through?

22 MR. BASU: I think I'm going to defer that
23 to -

24 CHAIRMAN BLEY: This afternoon. Okay.

25 MR. BASU: -- this afternoon.

1 CHAIRMAN BLEY: Fine.

2 MR. BASU: I would tend to say not much,
3 but I may be totally off base on that.

4 In the human factors area, again, the
5 focus is to update the guidance documents based on of
6 course the information that we are going to gather.

7 In the probabilistic risk assessment area,
8 we have conducted a planning study to identify the PRA
9 needs and scope. And so based on that, we are going
10 to initiate some future work on this.

11 So, going forward we'll continue to focus
12 on the R&D that is, as I said, generic as much as
13 possible. But at some point, there will be a
14 bifurcation and we'll focus on the right technology.

15 We'll continue tracking the DOE NGNP
16 program and modify our R&D recent activities based on
17 the technology selection, technology development.

18 We will continue coordination with DOE to
19 resolve key technical issues and also underlying
20 policy issues. Also to close the R&D gaps.

21 And we plan to come before you hopefully
22 this time in a more frequent interval than had been in
23 the past. We'll just wait for your, you know, design
24 indication and we'll come back.

25 CHAIRMAN BLEY: Thank you, Sud.

1 On the digital instrumentation and the
2 human factors, I just want to mention I know you folks
3 all talk to each other, I'm sure, all the time. But
4 later this week, the human factors folks from Research
5 are going to present to us work that was done with
6 some focus on the possible negative impacts of some of
7 the new instrumentation on human performance in the
8 plants.

9 I hope that's getting factored into the
10 work you folks are doing as well.

11 MR. BASU: Let me see if I can get Steve's
12 attention.

13 Steve, would you address that particular
14 item in your presentation this afternoon?

15 MR. FLEGER: Yes, that work you're
16 referring to, I believe, is the degraded I&C.

17 CHAIRMAN BLEY: Yes.

18 MR. FLEGER: The interface issues. I'll
19 just briefly mention that this afternoon.

20 CHAIRMAN BLEY: Okay.

21 MR. FLEGER: But this Friday there will be
22 a lot more detail on that.

23 CHAIRMAN BLEY: Okay. I just wanted to
24 make sure that that program was feeding your program.

25 MR. FLEGER: Yes, sir. Yes, it is.

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1 CHAIRMAN BLEY: Okay. Thank you.

2 MR. BASU: Thank you. I think that's all
3 I have for the overview.

4 Any question, comment?

5 CHAIRMAN BLEY: Anything from the Committee
6 before we get to the details?

7 MEMBER RAY: Well, again, having served on
8 a HTGR Codes and Standards Committee in the past, that
9 was one of the things listed up here, I just at some
10 time would like - I mean, we take for granted that
11 nobody is going to redo things that were done before.
12 And that's an assumption that I think doesn't need to
13 be tested, even.

14 But it just seems like there is a starting
15 point there. So, you're not starting from complete
16 scratch as you carry this forward in that there was a
17 plant built and operated. Moisture intrusion, for
18 example, was a big deal. And I just would like some
19 mention of how the work that you're talking about
20 doing now builds on what was done at that time and how
21 the licensing basis, for example, at Fort St. Vrain
22 would be relevant.

23 MR. BASU: Very good point. We are going
24 to make most use of the legacy information and data in
25 drafting the -

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1 MEMBER RAY: I would take that for granted,
2 sure.

3 MR. BASU: Any other -

4 CHAIRMAN BLEY: We can go on to the next
5 topic.

6 MR. BASU: Thank you, again. So, I'm going
7 to hand it over to Joe Kelly who is - there he is.

8 (Off-record discussion.)

9 MR. KELLY: Okay. So, my name is Joe
10 Kelly, and I'll be talking about the NRC development
11 of its evaluation model for the NGNP.

12 And, actually, I have ninety minutes, but
13 five presentations. So, I will be giving a,
14 hopefully, brief overview of the evaluation model
15 itself.

16 I'll be followed by Mourad Aissa talking
17 about the SCALE development that's our nuclear
18 analysis tool. Then by Hossein Esmaili talking about
19 MELCOR development for NGNP. And that's in the
20 accident analysis area.

21 Then I'll come back and talk about core
22 analysis. That's the PARCS/AGREE codes, and then the
23 NRC-supporting experimental programs.

24 So, the objective of this work is to give
25 us a confirmatory safety analysis capability,

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1 basically, an evaluation model, as to both supports
2 the NGNP licensing review, as well as provide a
3 technical basis for regulatory decisions.

4 So, what's the scope of this? What is it
5 that we have to do? What are we trying to compute?

6 What we want to do is be able to evaluate
7 the radiological consequences. And that's basically
8 just to dose to the public and the workers.

9 To do that, we have to be able to
10 calculate the fission product release from the
11 containment and its subsequent dispersal in the
12 atmosphere.

13 So, consequently, we need expertise in
14 five different areas; nuclear analysis, thermo-fluids,
15 fuel performance, fission product transport and
16 consequence analysis.

17 And so, all of that's going to be part of
18 the evaluation model that I'm going to talk about
19 today.

20 As Sud said, up to now it's generic in
21 scope. So, we have to apply it to both the pebble-bed
22 and the prismatic. And those are the abbreviations
23 I'll be using for pebble-bed and prismatic.

24 And, traditionally, an evaluation model
25 for a gas reactor has three separate evaluation models

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1 that we'll be rolling into one.

2 The first part is normal operations. What
3 your pre-break conditions are. And those are
4 important because we need to know the magnitude and
5 distribution of the fission products within the helium
6 pressure boundary before an event occurs.

7 The second part is the initial fission
8 product release or the blow-down release. And then
9 finally the delayed fission product release which
10 occurs during a heat-up event.

11 This could take more than the ninety
12 minutes that I have if I were to explain every box on
13 this schematic.

14 So, this is a schematic of the evaluation
15 model. And since I don't have time to go through
16 every box, I'm going to start at the end.

17 So, if you look at the large box in the
18 bottom right labeled "LBE" or Licensing Basis Event,
19 Transient Analysis, this is really where, you know,
20 our accident analysis occurs.

21 And then specifically the box in the red
22 on the left, a system accident analysis which is done
23 by the MELCOR code, that gives us our source term
24 release.

25 That's handed off to the MACCS code for

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1 the consequence analysis. And the eventual product is
2 the environmental release and dose. Most of our
3 transient safety analysis go through that path.

4 On the other side of that box you'll see
5 the PARCS and AGREE codes listed. Those are basically
6 for any type of reactivity insertion event that
7 requires a 3D kinetics code to be able to resolve it.

8 The rest of this, the other three main
9 boxes, all had to do with normal operation. And
10 that's a little bit of a disconnect from what we do
11 with Light Water Reactor where, you know, primary
12 focus is loss of coolant, you know, whether it's large
13 break, small break, whatever.

14 Here, a lot of the focus is normal
15 operation. And as I said, that's because we need to
16 know both the magnitude and distribution of the
17 fission products within the system over the life of
18 the plant.

19 So, to do that, the first thing we need to
20 do is, you know, be able to calculate the steady state
21 of the plant. And to do that, we need the box labeled
22 "Nuclear Data Preprocessing."

23 This is the province of the SCALE code.
24 Mourad is going to talk about that right after me.
25 So, I'm not going to say much there.

1 But one of the primary outputs of that -
2 let's see. I don't have a pointer here. So, few-
3 group cross-sections.

4 And in this case for, you know, modern-day
5 calculations for gas reactors, we're talking about
6 like 23 to 26 groups. So, it's not the two to four
7 groups that you might be more familiar with, with
8 Light Water Reactors.

9 So, those are handed off to the box
10 labeled "Normal Operation." And PARCS is our core
11 neutronics simulation code. AGREE is a thermo-fluids
12 module for gas reactors.

13 I have a presentation on those. So, I
14 won't say too much in this one about those, but
15 they're intimately coupled.

16 CHAIRMAN BLEY: Are these codes all
17 appropriate now for doing these calculations or are
18 you having to modify most of them?

19 MR. KELLY: Well, all of the codes with the
20 exception of AGREE are the NRC Light Water Reactor
21 codes.

22 CHAIRMAN BLEY: Right.

23 MR. KELLY: So, we're modifying all of
24 them. And I'll discuss what some of the main
25 modifications are later in my presentation.

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1 CHAIRMAN BLEY: Okay. And if you could at
2 some point, mention where you stand in that and what
3 the schedule looks like for it.

4 MR. KELLY: Okay. At the top of the Normal
5 Operation box, there's a little box that says "Driver
6 (SNAP Plugin)."

7 And the reason we have a driver here is
8 because we need to not just have one steady state, but
9 have the evolution of that steady state over the fuel
10 cycle whether you're searching for an equilibrium core
11 in a pebble-bed or whether you're following the
12 operation of a prismatic as you do the fuel shuffling
13 and the cooling of the control rods. So, that box is
14 a little more complicated than normal.

15 One of the main outputs from that is the
16 power distributions. And those along with bypass flow
17 go over to the box called "Fission Product
18 Preprocessing."

19 And so what the job of this is, is to
20 determine the magnitude and distribution of those
21 fission products by first calculating the core-wide
22 fission product release - and that will be done with
23 MELCOR - and then the distribution of those released
24 fission products within the system.

25 And Hossein is going to talk about that.

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1 So, I'll pretty much skip over it.

2 MEMBER CORRADINI: Can I go back to your
3 box -

4 MR. KELLY: Yes.

5 MEMBER CORRADINI: -- just so I understand?

6 So, the thing that always concerns me
7 about the gas reactor is the change in geometry with
8 irradiation.

9 So, where is that being done or is that
10 left to DOE?

11 MR. KELLY: Well, that's a good question,
12 actually. One I glossed over.

13 There's a box labeled "Thermal &
14 Irradiation Geometry Changes." And of course the main
15 reason that's important is because of its affect on
16 bypass flow.

17 Bypass flow then determines your peak fuel
18 temperatures. The peak fuel temperatures affect the
19 fission product release during normal operation. So,
20 that's something we have to handle.

21 To do that calculation, you need three
22 parts. One part is a numerical scheme to handle
23 bypass flow. I'll show that in the talk on
24 PARCS/AGREE.

25 The second part are the constitutive

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1 models for the loss coefficients, et cetera. And I'll
2 show you something on the supporting experimental
3 programs for that.

4 But as Mike said, the more important part
5 is actually how much does the prismatic - well, let me
6 just say "prismatic" for the moment - distort?

7 Well, to get those bypass gaps, typically
8 there are three different things. The first is the
9 as-built gaps. Which in the core, are on the order of
10 one millimeter.

11 Then there is the differential thermal
12 expansion. They're designed to try to bathe all the
13 metallic components with helium at T-inlet. So, it's
14 like 260 degrees C.

15 But even with that, the metallic
16 components expand a lot more than the graphite
17 components and are, in fact, pulling apart the fuel
18 element stacks a little bit and opening those gaps up
19 to something in the order of two millimeters.

20 Then you have the irradiation-induced
21 damage, and this is the big one. Now, later on today
22 Srini is going to talk about graphite. And he does
23 have a program at Argonne National Labs to do a
24 irradiation damage structural analysis of one fuel
25 element.

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1 Actually, trying to model all of the fuel
2 elements in the core together, that's a huge research
3 program that we at the NRC are not going to be able to
4 do. DOE or Idaho is trying to develop a full-core
5 model, but that's in the future.

6 The more traditional method is to model
7 each assembly by itself and calculate the distortions
8 of that.

9 Srini will be giving us, if you will, a
10 numerical benchmark. So, a number of different
11 calculations at different, you know, thermal
12 gradients, different fluences and fluence gradients.

13 But then as part of the evaluation model,
14 we'll have to have a simpler way of calculating that.
15 So, it would be something like a multi-grain problem.

16 MEMBER CORRADINI: But to make sure I
17 understand, so if I knew the gradient and if I knew
18 the irradiation history, I could with the proper
19 graphite, predict the swell or the change in
20 dimension.

21 Is that a given?

22 MR. KELLY: Well, once we have the
23 graphites and once the AGC program is done, yes.

24 MEMBER CORRADINI: Okay. So, then it's not
25 so much that as -- so, you have the benchmark there.

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1 It's a matter of putting it together with multiple
2 blocks or multiple things under a known temperature
3 gradient and irradiation history.

4 MR. KELLY: Right. And then you have these
5 blocks stacked on top of each other, each one
6 distorted a little bit.

7 And as you know at the reflector boundary
8 where the fluence gradient is very sharp, one side of
9 a block can shrink more than the other side. So, then
10 you can open up web-shaped gaps and the possibility
11 for the columns to bow.

12 But actually trying to calculate the
13 interference of one column with the next is a huge
14 research program, and that's something that Idaho is
15 working on. It's beyond the scope of something that
16 we're able to do here.

17 So, then you have to say, well, how can
18 we, if you will, simulate all of these little wedge-
19 shaped gaps?

20 Do we close them all up and have big ones
21 top and bottom? Do we distribute them? And that's
22 probably going to be done in some kind of
23 probabilistic way, but we're not there yet.

24 MEMBER CORRADINI: Okay.

25 MEMBER ARMIJO: Well, these issues existed

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1 for Fort St. Vrain.

2 MR. KELLY: Yes.

3 MEMBER ARMIJO: And they were addressed
4 somehow in the regulatory process. And at some point
5 going back to Harold's point, I'd like to know what we
6 learned from that and what the deficiencies were at
7 that time that we're resolving with this new research.

8 MEMBER CORRADINI: Or they just took a very
9 -- equivalent of a very bad hot channel factor and
10 essentially have to live with a large margin.

11 MEMBER ARMIJO: Sure.

12 MEMBER CORRADINI: Right.

13 MR. KELLY: In the licensing basis, I don't
14 know. And that's something that NRO will be looking
15 at.

16 I did learn how GA went about calculating
17 those gaps, which is why I know the little bit that I
18 do know on that subject.

19 Because as Mike noticed, I know more about
20 two-phased flow than I know about gas reactors. I'm
21 learning.

22 CONSULTANT KRESS: Before you leave, one
23 other question on that box.

24 The pebble-bed reactor has spheres flowing
25 by gravity down through it going in at the top and

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1 coming out at the bottom.

2 That's a complicated flow pattern and I'm
3 worried about spheres getting stuck in there and not
4 moving and things like that.

5 I didn't see anything in the plan that
6 talked about actual experiments, a picture with real
7 pebbles that may address the modeling for that.

8 Do we have models for that kind of flow
9 through?

10 MR. KELLY: Well, people are using discrete
11 element mechanics codes to model pebble flow. And
12 that's - the Idaho Lab has their own version called -
13 I think it's called PEBBLES.

14 CONSULTANT KRESS: Is this a probabilistic
15 model?

16 MR. KELLY: No, it actually calculates all
17 the forces between each and every pebble and the
18 rolling friction and so on. But of course you need
19 the sliding friction factors of the graphite at
20 pressure and temperature, and that has to come -

21 CONSULTANT KRESS: And they may change in
22 dimensions also.

23 MR. KELLY: Yes, they'll probably change
24 more in dimensions due to, you know, the -

25 CONSULTANT KRESS: But are there plans for

1 experiments to look at this or are we just going to -

2 MR. KELLY: Not at the NRC. That would
3 have to come from the applicant or DOE.

4 MEMBER REMPE: Joe, could you kind of just
5 clarify this is like a joint DOE-NRC analysis approach
6 or is this the NRC one? And then what does industry
7 do, and just kind of give us an overview of the
8 different ways people have been -

9 MR. KELLY: This is the NRC one.

10 MEMBER REMPE: Entirely.

11 MR. KELLY: Entirely.

12 MEMBER REMPE: Not using any of the DOE
13 analysis.

14 MR. KELLY: No.

15 MEMBER CORRADINI: So, just to push that
16 point since some of us will be asking that of the
17 other side, so the blue is NRC.

18 So, there's a red version of this that DOE
19 has that will be handed off to the industry, or you
20 don't really care about that. Somebody is going to
21 provide you a red version of this.

22 MR. KELLY: Yes.

23 MEMBER CORRADINI: Okay.

24 MR. KELLY: And we'll be using this to, you
25 know, check those - to audit those -

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1 MEMBER REMPE: There will be some back and
2 forth.

3 MEMBER CORRADINI: Right.

4 MEMBER REMPE: And how that's going to work
5 is DOE's business, and I don't know.

6 MEMBER CORRADINI: Okay.

7 CHAIRMAN BLEY: Let me follow up Tom's
8 question.

9 MR. KELLY: Sure.

10 CHAIRMAN BLEY: If applicant is happy with
11 detailed calculations for this possibility of the
12 pellets/balls not moving like you'd expect them to, do
13 you foresee NRC needing to see some kind of
14 experimental verification or does that kind of
15 modeling strike you as complete enough to be confident
16 that we won't have significant problems in that area?

17 MR. KELLY: Well, see, it depends. It
18 depends on a lot of things.

19 If you look at the history of something
20 like THTR or ABR, they had very different pebble flow
21 profiles inferred from their burn-up than they
22 actually, you know, thought they were going to have
23 ahead of time.

24 And from the THTR, they did have problems
25 or appeared to have problems with pebbles getting hung

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1 up, but part of that's because they were crushing
2 pebbles by inserting the fuel rods down through the
3 core, you know, basically a hydraulic ram on the
4 control rod. So, that's not a good idea to have large
5 pebble fragments in your discharge chutes.

6 How important it is, we don't yet know.
7 Our calculational tools are not yet at the point where
8 we can do a lot of sensitivity analysis to check it.

9 That's one of the things we will be doing.
10 And depending upon how important it ends up being,
11 then the requirements for what an applicant might have
12 to show us will change.

13 Now, for example, the initial - not the
14 initial, but when I started this, the pebble-bed
15 design was the PBMR-400 and that's an annular core.
16 Relatively thin annular core.

17 So, if you talk about a radial pebble
18 velocity profile, well - but you had to worry about an
19 azimuthal one. And I don't know of any data on an
20 azimuthal velocity profile, but that design has since,
21 if you will, devolved back to something that looks a
22 lot more like the old HTR model, which is a
23 cylindrical core. And so, now you're back to a radial
24 flow which we have more experience with.

25 And Sud alluded to the possibility of an

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1 agreement between us and China on exchanging data, you
2 know, tools for data with HTR-10.

3 And so, if you can get burn-up data on the
4 pebbles coming out of HTR-10, then we've got a pretty
5 good idea of what's actually happening in a real
6 reactor under prototypic conditions.

7 So, you know, we're not - I don't have the
8 answers yet.

9 MEMBER ARMIJO: Does NRC have the data from
10 the ABR on their burn-ups and, you know, they operated
11 for a long time. And so, they should have had a lot
12 of data.

13 MR. KELLY: Yes, I think we do have some of
14 it. But as you know, the AVR has a very long history,
15 but it's also a very complicated history. Many, many
16 different fuel types and things like water ingress
17 events.

18 But you're right. That's one of the
19 starting points to look at, yes.

20 MEMBER ARMIJO: Okay.

21 CONSULTANT KRESS: The burn-up data, can
22 that be done - is that going to be done online?

23 MR. KELLY: Yes. They have a burn-up
24 measurement system. So, when the pebbles roll out -

25 CONSULTANT KRESS: Specially at cesium, for

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1 example, that would tell you how long -

2 MR. KELLY: Dave Petti is shaking his head.

3 So, I'll go with Dave.

4 MR. PETTI: Tom, it's a cesium to a
5 nonvolatile like psyllium, something like that. They
6 have that ration and they've got a very tight window,
7 you know, to make the measurement and make the
8 decision.

9 CONSULTANT KRESS: That would tell you how
10 long the pebbles have been in -

11 MR. PETTI: Right, right.

12 MR. KELLY: So, when you break that down,
13 these are the tasks we have. The first is code and
14 model development. And that's where we've been
15 spending most of our time today. And that's pretty
16 well along, and hopefully I'll be able to give you an
17 idea of some of that in the course of these five
18 presentations.

19 The next is code integration. And that's
20 to put all those codes together into an automated
21 workflow.

22 Third is an uncertainty analysis, because
23 we plan to do this as best estimate plus uncertainty.
24 And we'll be using a statistical approach. We're just
25 starting a task on that now.

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1 Finally, code assessment. And we're
2 likewise just beginning that now to assess the MELCOR
3 code against the existing database. And that will
4 continue between now and the end of the program. And
5 the final product is of course a validated EM with a
6 code applicability report.

7 So, MELCOR is the NRC severe accident
8 code. It gives us a two-dimensional flow, heat
9 transfer and fission product transport capability.

10 I'm not going to say too much about this
11 because Hossein is going to come along in just a few
12 minutes, but you can see the completed development
13 tasks and then the ongoing development tasks on this
14 slide and I'll just make a couple of points.

15 The first is one that's completed is new
16 core models. One for the pebble-bed and one for the
17 prismatic. And, actually, I'm going to show a very
18 quick example for the prismatic.

19 They've also installed graphite oxidation
20 models and what's called a stratified counter-current
21 flow model for air ingress.

22 I won't be showing the MELCOR model for
23 that, but I will be showing you a slide from an
24 experiment on that.

25 CONSULTANT KRESS: The graphite oxidation,

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1 is that for water ingress and air ingress?

2 MR. KELLY: This is for air ingress. The
3 water ingress is something that's going to be
4 addressed.

5 CONSULTANT KRESS: Because the water will
6 react with the graphite also.

7 MR. KELLY: Yes.

8 And then for the ongoing tasks, and this
9 is what Hossein will be talking about where most of
10 the effort is going today, is the fission product
11 release and transport. And then future tasks are
12 things like extending the aerosol model to be able to
13 model dust.

14 So, this is a very simple - it's the
15 result of a numerical benchmark. So, this is the new
16 - or PMR core model.

17 And so, what we're looking at is a
18 conduction problem at what we call the Meso-Scale.
19 So, we're talking about the heat transfer resistance
20 between the fuel compact and the coolant channel. So,
21 going across the graphite web to the coolant channel.

22 This is important for normal operation.
23 To get this right is important for normal operation,
24 because it sets your fuel temperatures and your
25 moderator temperature.

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1 Well, I said MELCOR is a 2D code, and you
2 can see the unit cell it uses for this. This is its
3 core model. So, it's basically a fuel rod with a gas
4 gap.

5 The clad in this case is now the graphite
6 moderator. So, that's what's going to be calculated
7 in MELCOR.

8 On the right, I have a finite element
9 model of a unit cell taken out of a prismatic block.
10 So, in each prismatic block there are two fuel
11 compacts for every coolant channel.

12 And they come in this if you make a little
13 right triangle here with a sixty-degree angle and a
14 thirty-degree model, but I modeled the whole one here.

15 So, you have the fuel compact, a small gas
16 gap, and then the three coolant channels. And for the
17 purposes of a numerical benchmark, we're specifying
18 the gas temperature and heat transfer coefficient to
19 be the same between MELCOR and the finite element
20 calculation.

21 And so, what we're trying to do is see how
22 well this relatively course 1D conduction model -
23 1D/one-parameter conduction model actually does a 2D
24 problem.

25 And so what we get from MELCOR is the

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1 average fuel temperature and the average moderator
2 temperature. And you can see the discrepancies.

3 This is with a radial power factor of one.
4 It's only a couple of degrees. It's surprisingly
5 good. So, that's good news.

6 The SCALE/AMPX, this is our nuclear
7 analysis code suite. And this is what Mourad, who
8 will be the next speaker, will be talking about.

9 So, this is where we go from the in-depth
10 nuclear data libraries to actual cross-sections that
11 can be used in the PARCS code.

12 And so, SCALE gives us the lattice physics
13 capability, as well as depletion capabilities. So,
14 that gives us what we're calling few-group, or I
15 should say multi-group cross-sections. The decay
16 heat, as well as the fission product inventory.

17 One of the big things - accomplishments in
18 that was being able to model the double-het model for
19 both the pebble-bed and the prismatic fuel, and Mourad
20 can talk about that.

21 A lot of the current work is on doing
22 benchmarking both the HTTR and HTR-10 primarily, and
23 Mourad will show some of that.

24 And as well as improving and validating
25 the interface to the PARCS code, and I'll show some of

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1 that when I get to the PARCS/AGREE presentation.

2 I said I'm going to have a presentation on
3 PARCS-AGREE. Since I'm already running overtime, I'll
4 skip this slide and talk about them when I get to
5 that.

6 SNAP, which stands for Symbolic Nuclear
7 Analysis Program, is the graphical user interface for
8 the NRC codes. And so, we will be using it in the
9 normal, traditional way for both pre and post-
10 processing for MELCOR and PARCS/AGREE.

11 But we're going to be using it a lot of
12 other ways as well, because it has an extensive plugin
13 capability. So, as I mentioned, we'll be using it as
14 the driver code for things like a search for the
15 equilibrium core in a pebble-bed, or for handling the
16 fuel shuffling methodology in a prismatic.

17 We'll also be using it as the glue to
18 stick all these codes together. So, when you have to
19 take the output from one code and massage it to make
20 it be the input for the next code in a chain of
21 calculations, all that will be done by a SNAP plugin
22 instead of human intervention.

23 It also has what's known as an auto
24 validation tool. So, when we do code assessment, we
25 don't expect to just do it once because, you know, you

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1 will come up with code deficiencies, you'll remediate
2 them and have to repeat the calculation.

3 This will allow us to repeat those
4 calculations very easily to minimize the engineering
5 time that is done, as well as due to the uncertainty
6 analysis tool.

7 And so, the code and model development
8 tasks are well underway. As we go through each of the
9 next four - three presentations, you'll get a better
10 idea of that.

11 Preliminary code assessment against the
12 existing database is beginning now, and we plan to
13 have our independent confirmatory analysis capability
14 ready by the end of 2013.

15 And so with that, I'll hand off to Mourad.

16 CHAIRMAN BLEY: Okay. Thank you.

17 MR. KELLY: You're welcome.

18 CHAIRMAN BLEY: You're right. That did
19 take a little longer. Are some of these - are they
20 all five about the same length or is it some of them
21 will be shorter?

22 MR. KELLY: Well -

23 CHAIRMAN BLEY: We need to pick it up just
24 a little bit, or we're going to stretch on a little
25 late.

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1 MR. KELLY: Okay.

2 (Off-record discussion.)

3 MR. AISSA: Good morning. My name is
4 Mourad Aissa. I will be talking about the neutronics
5 analysis part of our campaign.

6 First, the big picture, and Joe already
7 talked a little bit about this process. We'll start
8 with the ENDF data. Right now it's the ENDF-7.

9 And the AMPX 2000 generates your problem
10 independent cross-section, but are continuous for the
11 stochastic codes and the multi-group for the
12 deterministic codes.

13 Right now we have one that's 238 groups at
14 which we devote most of the validation results that I
15 will be presenting. And we have an alternative 81
16 groups that we are most getting ready for production
17 mode.

18 TRITON is one of the control modules in
19 SCALE. SCALE has several control modules. So, one
20 can insert SCALE for TRITON for the purpose of this
21 talk, the equivalent.

22 Those planned cross-sections are processed
23 for resonance by BONAMI and CENTRM for any resolve
24 resonances and resolve organizes respectively. BONAMI
25 does the end result. CENTRM does data result.

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1 Once you prep your cross section then you
2 go to the lattice codes. One is 1D for PPR XSDRN, and
3 NEWT is 2D for the prismatic. And you get your sets
4 of few-group cross-section that you can use by the
5 nodal core simulator. In this case, PARCS.

6 Some of the major activities that we've
7 been involved in, like I say, we just finalized an 81
8 energy group which is optimized for HTGR spectra. We
9 already have one working group for 20, 30 years
10 because it takes longer to process problems with a
11 finer energy cross-section.

12 The multi-group resonance processing
13 methods have been improved successively. We had the
14 double-heterogeneity (DH) self-shielding method that
15 was based on running CENTRM, which is the result
16 resonance core. And it was excessively taxing time-
17 wise.

18 There was an alternative method that's
19 based on intermediate resonance, basically assuming
20 narrow resonance treatment of the - below unresolved
21 resonance region. The narrow resonance would give you
22 better results and also speed up the execution by a
23 factor of four to seven.

24 The other item of note is we included a
25 continuous energy, KENO, which is a Monte Carlo

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1 Stochastic code. And in it, we included the resonance
2 upscattering treatment for the U-238, which improves
3 the k-effective by 200 to 400 pcm. And also, this
4 would be added to CENTRM.

5 The lattice physics code, before we had
6 only NEWT that does lattice in a rectangular geometry.

7 We kept NEWT and we made it functional for
8 the hexagonal geometry of the prismatic and improved
9 quadrature sets to allow hexagonal reflections, and
10 accelerated the CMDF, which of course masked the
11 difference to address the slow convergence of the
12 graphite reactors.

13 And for the PBR, we added to the TRITON
14 the XSDRNPM, which is also a discrete ordinate
15 transport code just like NEWT.

16 The Monte Carlo depletion along with the
17 continuous energy, KENO, we have a multi-group KENO
18 which will test those cross-sections that we develop
19 for use for PARCS later on.

20 There is the benchmark. First, this is a
21 fuel block for HTGR. And there's more of a code-to-
22 code validation or comparison.

23 The KENO continuous energy and the multi-
24 group are compared to MCNP5 continuous energy. As you
25 see, there really are acceptable results. About 85

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1 pcm between the two continuous energy codes. And 336
2 pcm for the multi-group, which is an acceptable
3 result.

4 MEMBER CORRADINI: I don't know what I'm
5 looking at. I think I do, but I'm really not sure.

6 So, that's a cartoon prismatic block on
7 the left?

8 MR. AISSA: It's just a block, yes.

9 MEMBER CORRADINI: What's the thing on the
10 right?

11 MR. AISSA: This is a KENO model of it.

12 MEMBER CORRADINI: Of what, though? I
13 guess I don't know of what. The thing on the right is
14 a model of what?

15 MR. AISSA: No, no, I'm sorry. This is
16 just the schematic diagram of the annular fuel pellet.
17 So, this is just like it says. The TRISO that has the
18 particles, and the helium channels that - it's
19 basically just a blowup of the -

20 MEMBER CORRADINI: But I guess -- I'm
21 sorry. This is not relevant to our discussion. I was
22 just trying to understand.

23 So, the prismatic block doesn't look like
24 that. So, is there a homogenization, is there a
25 modeling simplification that's made to do this?

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1 Because you've got the - you've got the
2 fuel compacts, you've got the helium, you've got the
3 graphite between them.

4 You've got to do some sort of
5 heterogeneous calculation, homogenize that.

6 MR. AISSA: Yes.

7 MEMBER CORRADINI: And then take that
8 homogenized thing and grow it to a bigger homogenized
9 block.

10 MR. AISSA: Yes.

11 MEMBER CORRADINI: So, is this a benchmark
12 or -

13 MR. AISSA: No, no, is not a benchmark. Is
14 just a geometric representation of the actual physical
15 condition of it because it's just -- it shows the -

16 MR. PETTI: Let me just point out to the
17 panel, not to be confused, HTTR has a prismatic
18 configuration that is not like NGNP or any of the US
19 prismatic. It's an annular fuel.

20 Okay. So, --

21 MEMBER CORRADINI: Those are unique.

22 MR. PETTI: Right. It's unique, but it's
23 what we have the benchmark on. So, it's the right
24 thing to do.

25 MEMBER CORRADINI: Thank you. Thank you.

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1 MR. PETTI: So, don't get confused on the
2 geometry.

3 MR. AISSA: The fuel pellet has a hole in
4 it. I'm sorry about that. I didn't realize.

5 MEMBER CORRADINI: Thank you, Dr. Petti.

6 MR. AISSA: And for the full result, this
7 is actual experiment based on the IAEA benchmark.

8 And in here, we don't have as good results
9 because as we see, the - both MCNP and KENO have a
10 bias between 1.5 to 2.0 percent k-effective. And this
11 has been also observed by other people who did the
12 benchmark.

13 It's still being analyzed, but we suspect
14 maybe that the graphite has some impurities, boring
15 impurities. And other people are saying maybe the
16 ENDF carbon cross-sections in the thermal region is
17 not captured right.

18 And some people say when you use the JNDL,
19 which is the Japanese Nuclear Data Library, you should
20 get a little better results, but this we still are
21 working on it. But I don't think it will move too -

22 CHAIRMAN BLEY: Before you go, let me ask
23 a naive question.

24 So, these are one experiment and three
25 calculations on k-effective?

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1 MR. AISSA: Yes.

2 CHAIRMAN BLEY: With sigmas that imply
3 they're tracking the uncertainty, but they don't fall
4 within each others' bounds. So, the sigmas are in
5 some fashion, a great underestimate of the
6 uncertainty, it appears to me, unless I'm too naive in
7 the way I'm looking at this.

8 MCNP5 has a sigma of 0.0001, and yet it's
9 off by a factor by 0.02 from the experiment. So, the
10 sigmas don't seem related to any real uncertainty.
11 There are some other -

12 MR. AISSA: Actually, the way it was given
13 to, actually it's off by more than that. It's off by
14 2200 pcm.

15 CHAIRMAN BLEY: Right.

16 MR. AISSA: Yes.

17 CHAIRMAN BLEY: So, what are the sigmas?
18 What kind of uncertainty are they talking about? is
19 that just an uncertainty in the calculation?

20 MR. AISSA: The sigma, that's your code
21 gives you.

22 CHAIRMAN BLEY: The code gives you that?

23 MEMBER CORRADINI: At least -

24 (Simultaneous speaking.)

25 MR. AISSA: It's a statistical.

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1 MEMBER CORRADINI: Okay.

2 CHAIRMAN BLEY: Okay.

3 MR. AISSA: They used -

4 CHAIRMAN BLEY: So, it's an uncertainty on
5 the calculated number from the trials.

6 MR. AISSA: Yes, yes.

7 CHAIRMAN BLEY: I don't know what the sigma
8 on the experiment is. That's not on trials. That's
9 some other sigma.

10 MR. AISSA: That is in the benchmark, the
11 IAEA benchmark is what that was given.

12 MEMBER CORRADINI: But does that mean that
13 that's the sigma of actually a set of multiple
14 measurements of k-effective?

15 What does that mean? I think that's what
16 Dennis is asking.

17 CHAIRMAN BLEY: Yes, what does that sigma
18 stand for?

19 I get the one that's on the calculations
20 now.

21 MR. AISSA: It is a measurement of
22 uncertainty. How many measurements does it capture?
23 I don't know.

24 MR. PETTI: It's the Japanese team's
25 estimate of the uncertainties of the experiments that

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1 were done. All the classical experimental
2 uncertainties aggregated.

3 CHAIRMAN BLEY: Okay. Thank you.

4 MR. AISSA: Now, for further results, the
5 control rod worth results were -- show a very good
6 agreement between the experiment and the KENO CE and
7 KENO MG.

8 The temperature coefficient results that
9 are plotted here, many can see the - probably that
10 will answer some of your questions about uncertainty
11 measurement.

12 As you see at 150 C, there was a huge
13 measurement uncertainty that - this would show very
14 good agreement between MCNP and SCALE whereas the
15 measurements are just had a little bit.

16 The shutdown margin results for all
17 control rod in, there was very good agreement. When
18 the reflector control rods are in, there was a bias
19 where we have less by three percent k-effective.

20 Moving on to HTR-10 first critical core
21 benchmark results, those - basically, the measured was
22 as close to one.

23 And this would -- looking at what the MCNP
24 or the International Reactor Physics Evaluation Group
25 has come up with and compared it to our SCALE/KENO and

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1 with very good agreement. 121 pcm. And just
2 comparing our KENO to our MCNP, that's minus 162 pcm.
3 So, those are also acceptable results.

4 The PROTEUS benchmark results, we are
5 still working on them. Those are experiments taken at
6 the Paul Scherrer Institute in Switzerland. and
7 PROTEUS is a very flexible experiment and it was
8 reconfigured for pebble-bed reactor.

9 And I see 1, 1A, 1A(2) and 2, 3. Those
10 are configurations of how many combinations of fuel
11 pebble, modulator pebble.

12 And as you see, those also show acceptable
13 results where the average delta k-effective is 252
14 pcm.

15 SCALE-PARCS integration, Joe is going to
16 talk a little bit more about the detail of some of the
17 PARCS pictures.

18 And, also, Joe mentioned that SCALE
19 provides sets of cross-sections that are in 23 groups,
20 which is compared to four groups to LWR or even two
21 groups for LWR cases.

22 And, also, we're doing some work for HTR-
23 10 to ensure --just a sanity check. There were
24 exercises -- sets of exercises using block models and
25 2D core models that were run both by SCALE and by

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1 PARCS with acceptable or very good agreement.

2 Ongoing activities, we complete PROTEUS
3 validation work. And, also, we're still working on
4 the HTGR benchmark, the one -- I'll show you.

5 Publish NUREG/CR on HTGR validation with
6 SCALE addressing the three experimental sources.
7 Complete SCALE-PARCS integration.

8 Continue work on space-dependent reaction
9 rates in both the - engage in any kind of reflectors,
10 evaluate code prediction biases and uncertainties, and
11 update Version 6.1 of SCALE code system and
12 documentation to be released for fission. Thank you.

13 CHAIRMAN BLEY: Okay. I just want to make
14 one comment to you.

15 That one chart really bothered me. It
16 looks like a presentation that's showing uncertainties
17 in calculations when it's really not. Those things
18 mean different things.

19 MR. AISSA: Which one?

20 CHAIRMAN BLEY: the one I asked you about.
21 Slide 6, but you don't need to go to it.

22 MR. AISSA: Yes.

23 CHAIRMAN BLEY: It's just the sigmas mean
24 very different things and they're talking about
25 different things.

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1 The ones on the code aren't estimates of
2 the uncertainty in the calculation. They're estimates
3 in how well you're coalescing to the value in the -
4 they're very different things.

5 MR. AISSA: Yes.

6 CHAIRMAN BLEY: And it gives the impression
7 that they're really uncertainty in the result like the
8 uncertainty in the measurement.

9 So, I think you need to think about how
10 you present uncertainties in the future.

11 MR. AISSA: I agree. That could be
12 misleading and the point is taken.

13 CHAIRMAN BLEY: Thank you. I think we
14 better move on unless somebody wants to - we're
15 catching up a little bit. We're five minutes behind,
16 I think.

17 Thank you.

18 MR. AISSA: Thank you.

19 CHAIRMAN BLEY: Do you have your next - you
20 can find your name tag while he's setting you up.

21 (Off-record discussion.)

22 MR. ESMAILI: Okay. As Joe said, my name
23 is Hossein Esmaili. I'm in the Office of Research.
24 As Joe said, I'm going to be mainly focusing on MELCOR
25 fission product modeling, what we are doing right now

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1 and provide you with some status report on where we
2 are at.

3 The main objective of the present work
4 that we are doing is to develop HTGR-specific models
5 for fission product release and transport.

6 We already have MELCOR. It's a system
7 level code. We already have the infrastructure. So,
8 the idea was to use the existing MELCOR models for
9 transport and deposition in primary system and into
10 containment, but develop additional models as needed
11 to answer specific HTGR phenomena.

12 These are develop diffusional release
13 models for TRISO fuel particles, develop diffusional
14 release models for release of fission products through
15 the matrix and graphite block for the prismatic, and
16 also develop additional transport model. Mainly,
17 lift-off, you know, this is important for HTGR. We
18 don't have to live with that in LWR. Turbulent
19 deposition is important in pipes and agglomeration,
20 I'm going to get into that, and most importantly dust,
21 you know, dust generation and deposition.

22 The models that we are developing has to
23 be applicable to both pebble-bed and prismatic
24 designs. And the code should be able to calculate
25 releases both during normal operation and during

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1 accident conditions.

2 MEMBER ARMIJO: All right. In the release
3 models, you say diffusional release.

4 Do you have any other sub-model to address
5 the releases for, let's say, fractured or imperfect
6 TRISO fuel particles?

7 Does this analysis assume that every TRISO
8 particle is sound as designed or -

9 MR. ESMAILI: No, we do have - well, the -
10 I can get into that a little bit later, but we do have
11 models for intact particles, you know, all the layers
12 are there, models where only it's a bare kernel, none
13 of the layers are there, or we can do any combination
14 of -

15 MEMBER ARMIJO: Okay. So, you have several
16 models and you can -

17 MR. ESMAILI: That's right.

18 MEMBER ARMIJO: -- mix as you -

19 MR. ESMAILI: That's right. We have that
20 capability.

21 Okay. So, this is an example of what not
22 to put on a viewgraph, but I just wanted to make a
23 point here that in MELCOR space we do have, you know,
24 different packages.

25 What I'm referring to here is that how we

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1 are doing things in what is called a radionuclide
2 package.

3 So, at the start of the timestep, we
4 calculate releases, you know, fuel from the core. In
5 the case of LWR, from the cavity. And what you see on
6 the left-hand side is what we are changing in the
7 infrastructure of the code.

8 In this case for LWRs, we are using, you
9 know, CORSOR-Booth model because that's, you know, the
10 time of interest is only of a few hours or more.

11 But in HTGR we care about, you know,
12 during the normal operation and accident conditions.
13 So, here we are doing a more detailed model of
14 diffusion for all the layers.

15 After that, you know, you already have
16 aerosol dynamics model. That takes care of, you know,
17 how the fission products gets out of the fuel, you
18 know, they can condense from aerosol deposit.

19 So, these are all based on MAEROS
20 equations. They have already been integrated into the
21 code. So, we are using most of the, you know, the
22 models that's already in there, but we are developing,
23 as I said before, a turbulent deposition model, a
24 lift-off model, you know, during depressurized loss of
25 coolant accidents, and dust generation.

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1 Dust generation since we don't have much
2 data or a good, you know, first-order model, we are
3 going to rely on a parametric model, you know. Dust
4 would be formed as an aerosol and injected into the
5 air.

6 CONSULTANT KRESS: So, it's amount and -

7 MR. ESMAILI: And the amount and -

8 CONSULTANT KRESS: -- size.

9 MR. ESMAILI: That's right. That's right.

10 CHAIRMAN BLEY: An administrative question,
11 not a technical one, but we're calling these modified
12 Light Water Reactor codes by their old names, and
13 they're quite different. I'm just wondering if we're
14 going to get into confusion in the future.

15 Are you going to rename them as you go
16 along?

17 MR. ESMAILI: No, because MELCOR is one
18 code. So, all you have to do is that, you know, we
19 are not - we don't have a MELCOR LWR version and a
20 MELCOR HTGR version. It's all in a single code.

21 The only thing you have to do, if you
22 specify what type of reactor you're modeling. Right
23 now we do have -

24 CHAIRMAN BLEY: The whole thing is built
25 into the one code?

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1 MR. ESMAILI: That's right. Once the user
2 says, you know, I have a BWR, PWR, PBR or PMR, the
3 code already goes and adjusts and uses the appropriate
4 models.

5 CHAIRMAN BLEY: Okay.

6 MR. ESMAILI: So, the whole idea of MELCOR
7 is that it has to be an integrated code so we don't
8 want to -- make sure we know we have QA and, you know,
9 version control and everything.

10 CONSULTANT KRESS: I mean, are you using
11 the same fission product groups that -

12 MR. ESMAILI: That's right. The whole idea
13 is that we are using the fission product classes -

14 CONSULTANT KRESS: Same species.

15 MR. ESMAILI: Same species. But as you
16 know, you know, we can generate our own classes. So,
17 for certain amount of, you know, isotopes like cesium-
18 137, we are going to track them individual. So, we
19 built different classes, okay, for certain isotopes.
20 The rest of them we are grouping together.

21 But for example, you know, cesium-137
22 would have it's own class with everything. All the
23 other isotopes, you know, would be in the class of,
24 you know, cesium class.

25 So, you know, we have flexibility how we

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1 can do this class transfers or, you know.

2 MEMBER CORRADINI: So, let me ask a
3 different question. So, you can hit a button and the
4 code knows what to do, in theory.

5 Do you freeze it so that you can't
6 accidentally do something wrong?

7 CHAIRMAN BLEY: Or does the output clearly
8 tell you which modules this went through so you know
9 you got the right calculation?

10 MEMBER CORRADINI: If you think back where
11 I'm going from, Hossein, if you think back when they
12 were doing the IPEs, the map basically started as a
13 map for a B and a map for a P, and then eventually it
14 came together.

15 But in some sense, the fact that they
16 separated allowed you not to potentially muck it up,
17 so to speak.

18 Is there a QA control here such as you
19 don't accidentally cross boundaries?

20 MR. ESMAILI: Absolutely.

21 MEMBER CORRADINI: Okay.

22 MR. ESMAILI: Everything is under, you
23 know, QA control. And as a matter of fact, the people
24 who are working on the LWR version, they're, you know,
25 so, they can see whoever is working on the code. So,

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1 you know, you're not going to have that problem.

2 Again, you know, we have, you know, we
3 have done this in the past, you know. We have MELCOR
4 PWR and BWR which was already done with one keyword in
5 the input.

6 Okay. So, water and fission product
7 condensation, evaporation, you know, these are already
8 done in the code. We don't really necessarily have to
9 change anything.

10 Auxiliary models, filters, spray, you
11 know, you don't have to worry about iodine pool, but
12 we don't have to - additional models is not needed.

13 And aerosol and vapor transport within
14 control volumes, this is already done in the code.
15 So, we don't need any specific models for HTGR.

16 MEMBER CORRADINI: Let me ask another
17 question.

18 To go back to what Sud said about the
19 designs now are coming back to essentially a steam
20 generator and we have some sort of in-leakage of
21 steam, is there a qualitative difference of the
22 chemistry in the fission product released in the
23 presence of steam, in the absence of steam?

24 If I had a dry environment versus a wet,
25 a potentially steam environment, does the code

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1 recognize this from a chemistry standpoint so that you
2 would just add steam and you'd see a completely
3 different set of things, or is it subtle or is it not
4 different at all?

5 I don't know enough about the fission
6 products. Do you know what I'm asking?

7 MR. ESMAILI: Yes. Let me see if I can
8 answer you this way: What we have to do for a dry
9 condition which is an HTGR application, which we
10 didn't have to do for LWR, is that in the LWR space,
11 you know, we only cared about, you know, in terms of
12 aerosol particles, the shaped factor of units. All
13 the particles were spherical.

14 Right now as I sit here and talk here for
15 HTGR, we could have a range of shape factors. So,
16 this is what we are really changing.

17 But as far as steam and non-condensibles
18 and other materials, you know, moving through
19 different control volumes or moving through the core,
20 we are using the same modeling approach that we have
21 used -

22 MEMBER CORRADINI: So, it comes down to the
23 shape factor, but the chemistry I would -

24 MR. ESMAILI: Chemistry we have - I can get
25 to in a little bit.

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1 MEMBER CORRADINI: Okay. That's fine.
2 That's fine. I just wanted to make sure because the
3 one thing in terms of the design changes that I was
4 wondering would affect this would be the chance that
5 you would have to then again be concerned with some
6 sort of steam ingress into the -

7 MR. ESMAILI: Air ingress and steam
8 ingress. This is what we are working actually right
9 now.

10 MEMBER CORRADINI: Okay.

11 MR. ESMAILI: Okay. So, I don't know
12 whether Joe talked about it, but we do have a model
13 for air ingress right now. And this is basically, you
14 know, we're taking the model that we have developed
15 for LWR for hot-leg natural circulation and we have
16 actually modeled it into the core.

17 So, we are going to use that to model, you
18 know, air ingress studies. And - okay. As far as
19 input and out requirements, you know, MELCOR is a
20 system level code. It will require some input.

21 The first is fission product inventory.
22 That's coming from the ORIGEN. So, we have to know
23 what, you know, how much fission products we have.

24 Fission product diffusion coefficients I'm
25 going to get to a little bit later. So, we have to

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1 know what the diffusion coefficients are for each
2 layer.

3 And core power shape, of course, you know,
4 this has always been an input into the core, you know,
5 because the code is a 2D code. So, we need the radial
6 and axial profile to see how we are going to assign
7 the powers.

8 And the code is, again, this is a system
9 level code. It's not a fuel performance code. So, we
10 have to rely on empirical data to find out, you know,
11 what the fuel failure rate is. So, this an input into
12 the code.

13 Dust generation, lift-off and fission
14 products, you know, we have to, you know, we have to
15 put certain models in the code, but eventually we have
16 to compare experiments.

17 And fission product release under air and
18 water ingress, we are currently working on them right
19 now. But the infrastructure is there. We just have
20 to tweak things.

21 And as far as fission product speciation
22 and interaction with surfaces, we already have model
23 for chem adsorption. So, we have models for chemical
24 interaction between fission products and surfaces.

25 We just have to, like, for example, cesium

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1 with, you know, stainless steel, et cetera, we just
2 have to make additional models for the HTGR
3 application.

4 CONSULTANT KRESS: Normally those models
5 talk about a surface that's just a boundary to the
6 passageway. But when you go through graphite, you've
7 got an entirely different surface-to-volume ratio.

8 I wonder how you deal with - is that dealt
9 with some way when you -

10 MR. ESMAILI: At this point, what I'm
11 talking about here is that, you know, fission product
12 and dust that gets deposited on the pipe walls and -

13 CONSULTANT KRESS: Oh, after it gets out of
14 the -

15 MR. ESMAILI: Yes, once it gets out of the
16 - how it interacts. You know, once it gets to -

17 CONSULTANT KRESS: So, you're treating it
18 going through graphite as a diffusion process.

19 MR. ESMAILI: Right, right.

20 CONSULTANT KRESS: Which may or may not be
21 right.

22 MR. ESMAILI: That's what we have to - yes.

23 Okay. The whole idea for this MELCOR
24 fission produce is based on a diffusion model. This
25 is basically a 1D diffusion model. We are applying it

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1 both to cylindrical geometries as in case of the
2 prismatic, or spherical geometries as in case of the
3 pebble-bed.

4 We also use the same equation to model
5 diffusion through the different layers.

6 CONSULTANT KRESS: Let me ask you a
7 question about that.

8 Now, the Booth model that's already in
9 MELCOR has an effective diffusion coefficient for
10 cesium.

11 MR. ESMAILI: Right.

12 CONSULTANT KRESS: And it calculates the
13 cesium release by that Booth model. And then to get
14 all the other groups, it uses a scaling factor.

15 MR. ESMAILI: It uses -

16 CONSULTANT KRESS: It doesn't have a
17 diffusion coefficient for each of the groups.

18 MR. ESMAILI: Correct.

19 CONSULTANT KRESS: And my question here is,
20 do you intend to develop a new scaling factor or will
21 you have diffusion coefficients for each fission
22 product group?

23 MR. ESMAILI: We are - as part of the
24 experiments, we are hoping to get diffusion
25 coefficients for the major isotopes like strontium,

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1 cesium.

2 We have to make a decision once we are
3 going to apply to different isotopes in different
4 classes, then a decision has to be made there, you
5 know.

6 CONSULTANT KRESS: Yes, I hesitate to think
7 you will get effective Booth coefficients for all of
8 the groups. I don't -

9 MR. ESMAILI: Well, maybe, you know, they
10 are planning to - they are planning to measure
11 diffusion coefficients for each layer for certain
12 isotopes.

13 CONSULTANT KRESS: Yes, you could have a
14 different diffusion coefficient for each of your
15 layers.

16 MR. ESMAILI: That's right.

17 CONSULTANT KRESS: Or if it was like the
18 Booth models for LWRs, it's an overall effective -
19 it's an empirical coefficient.

20 MR. ESMAILI: It's an empirical, that's
21 right.

22 CONSULTANT KRESS: Yes, I wasn't sure
23 whether you were going to give one for each layer, or
24 an overall one.

25 MR. ESMAILI: No, we are going to get one

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1 for each layer. I'll show it to you on the next
2 slide.

3 MR. PETTI: Tom, the plan that we have gets
4 you the kernel, gets you diffusion coefficients in the
5 matrix and graphite and, in some cases, in some of the
6 layers.

7 CONSULTANT KRESS: The kernel treats it as
8 one -

9 MR. PETTI: A d-prime.

10 CONSULTANT KRESS: Yes, just like the Booth
11 model.

12 MR. PETTI: Just like a Booth model.

13 CONSULTANT KRESS: Okay.

14 MR. PETTI: Yes.

15 CONSULTANT KRESS: That, I wasn't sure of.

16 MR. PETTI: Yes, that's how -

17 MEMBER CORRADINI: What are you guys saying
18 over there? I didn't hear that.

19 MEMBER ARMIJO: I missed that.

20 MR. PETTI: There's an effective diffusion
21 coefficient for the kernel.

22 MEMBER CORRADINI: Okay.

23 MR. PETTI: In the Booth model, there's a
24 diffusion coefficient divided by an A, a nominal
25 length scale squared. And that's sometimes called d-

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1 prime, reduce the diffusion coefficient. That's what
2 we will provide -

3 CONSULTANT KRESS: Would that be the radius
4 in the kernel, you would think?

5 MR. PETTI: No, I seriously doubt it will
6 be the radius of the kernel because, you know, this
7 stuff goes to really high burn-up fuel. The path
8 length's going to get shorter and shorter over time.

9 We will be able to track that for fission
10 gases. We'll see that as a function of burn-up very
11 clearly. For the metallics, you just can't - you
12 can't measure it. All you know is how much was
13 released over the entire -

14 MEMBER CORRADINI: So, your intent just to
15 make sure I understand, the coupling here is that as
16 we've said generally, is you guys are running the
17 experimental data.

18 But in some sense, in some sense just to
19 get back to it, you're going to do test to failures
20 with various burn-up groups so that you'll know how
21 this diffusion - what did you call it? D-prime? Is
22 going to be affected by burn-up.

23 MR. PETTI: Yes.

24 MEMBER CORRADINI: Okay. And then you also
25 then scale off of the elemental radioisotope since

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1 you'll have it just for one, or one lead. And then
2 look at the others and scale it off of that.

3 MR. PETTI: Right. Based on what we
4 understand about the chemistry of the kernel, the
5 chemical form, you know, which groups - the groups are
6 not the same as LWR groups. There will be some slight
7 changes.

8 For instance, you know, we have to worry
9 about silver, which nobody has to worry about in LWR
10 space.

11 And so, whether we have truly cesium
12 iodide, for instance, is an interesting question. The
13 data that's out there historically suggests that it
14 behaves like a noble gas.

15 MEMBER CORRADINI: You mean iodide does.

16 MR. PETTI: Iodide. So - but, again, in
17 the oxycarbide system, some stuff's carbide, some
18 stuff's oxides. It can change over burn-up.

19 MEMBER CORRADINI: Okay.

20 MR. PETTI: We think we understand that
21 well enough to be able to -

22 MEMBER CORRADINI: But I guess I'm going
23 with this to kind of couple it back to what Hossein is
24 answering.

25 In some sense, the database that will

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1 essentially nail down the empiricism of this model is
2 the same database that is going to be used and
3 generated by DOE, but also is going to be used by the
4 licensee.

5 MR. PETTI: Yes.

6 CONSULTANT KRESS: It's interesting that
7 the Booth modeling MELCOR for LWRs doesn't know
8 anything about burn-up.

9 MR. PETTI: Right.

10 CONSULTANT KRESS: You're talking about
11 having Booth models release kernels that include burn-
12 up, because you may have lots of ranges of burn-up.

13 MR. PETTI: Sure. Yes.

14 CONSULTANT KRESS: Do you expect to get
15 experimental data for that somehow?

16 MR. PETTI: The current experiment plan has
17 an irradiation in which we're going to get fuel of a
18 variety of burn-ups with failed fuel. What we call
19 designed to fail. It will fail early so it will leak
20 over its entire irradiation.

21 CONSULTANT KRESS: Are these in-pile tests?

22 MR. PETTI: Yes, these are in-pile tests.
23 The AGR tests.

24 CONSULTANT KRESS: Yes.

25 MR. PETTI: So, you know, will I have

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1 something at two percent, four percent, eight percent?
2 No. I'll probably have stuff at, you know, ten
3 percent, 12 percent, 14 percent and 16 percent, you
4 know.

5 Because you've got an axial cosine in the
6 reactor, I can't get the really low - now, the fission
7 gas I'll get continuously. And so, that will tell us
8 a little bit about any changes with burn-up. That
9 will be probably the most interesting, you know.

10 Whether you decide to modulate based on
11 that for the other ones, you could do that, you know.
12 Let's see what the data says.

13 MEMBER REMPE: While we're talking about
14 data, on your table on Page 4 you talk about a lot of
15 experiments. And in the research plan that was
16 distributed to us earlier, they have a table and they
17 talk about experiments that DOE has proposed and will
18 be doing and then there's - this isn't probably a fair
19 question to you. Maybe it should go back to Sud, but
20 other experiments the NRC will be planning, and will
21 that be discussed today by someone?

22 MR. ESMAILI: I think Stu is going to speak
23 this afternoon. He has 45 minutes.

24 MEMBER REMPE: Good.

25 MR. ESMAILI: I only have twenty minutes.

1 So, he can give much more detail about the
2 experiments.

3 MEMBER REMPE: Okay.

4 MR. ESMAILI: My role is here how we are
5 doing things in MELCOR space.

6 MEMBER REMPE: But his topic is on fuel
7 performance and fission product behavior, and yet
8 there's a broader range of experiments. And so, I
9 hope that we'll discuss that.

10 MR. BASU: The experiments I was alluding
11 to in one of my slides, are the experiments that Joe
12 will be talking about in his - one of his
13 presentations.

14 MEMBER REMPE: Okay.

15 MR. BASU: And Stu will talk about the INL
16 AGR program a little bit.

17 MEMBER REMPE: Okay.

18 MR. ESMAILI: The only other thing I want
19 to say about the Booth model that you mentioned, is
20 that the Booth model is a solution to this diffusion
21 equation anyway. So, I mean, knowing the deal, you
22 know, they both should give the same answer.

23 CONSULTANT KRESS: I think Dave Petti
24 missed it, but what is your intention for -- there is
25 a use for R in these equations?

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1 MR. ESMAILI: They have to give us the
2 diffusion coefficient and knowing what their, you
3 know, that the reduce diffusion coefficient is $D(T)$
4 over some A squared. The A square for LWR is some gas
5 bubble in the radius -

6 CONSULTANT KRESS: Six microns.

7 MR. ESMAILI: Six microns or what have you.

8 Once we know that, we can always get the
9 diffusion, you know, diffusion coefficient. That's a
10 constant. I don't think, you know, depending on how
11 they normalize it, you know, we can always get the D
12 back from there, you know.

13 As we are developing the MELCOR models, we
14 are doing, you know, incremental assessment of, you
15 know, the models that we are putting in for sanity
16 check to see whether, you know, the models are
17 producing the results we want.

18 So, here I'm showing you some of the
19 results, you know. You look at the third row which is
20 US/SNL, US/Sandia National Lab, this is the MELCOR
21 results.

22 CONSULTANT KRESS: Are these release
23 fractions?

24 MR. ESMAILI: These are release fractions.
25 That's correct. These are release fractions. This is

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1 particles at a certain temperature.

2 For example, in Case 1a, it's just a bare
3 kernel. Somebody asked this question before. At 1200
4 degrees C, you know. In Case 1b, it's just a kernel
5 at 1600 C for 200.

6 So, these are release fractions and we are
7 comparing code-to-code comparison.

8 CONSULTANT KRESS: These are release
9 fractions of what? Cesium?

10 MR. ESMAILI: This is cesium. That's
11 correct. This is cesium.

12 CONSULTANT KRESS: This is cesium.

13 MR. ESMAILI: This is cesium-137.

14 And for this we use, you know, we use the
15 diffusion coefficient that was already published in
16 TECDOC 978, you know. This is based on the old - this
17 is based on the old data. As you mentioned, you're
18 right. This is cesium.

19 So that you know, INL is a PARFUME code,
20 you know. We try to be as close as possible to the
21 diffusion coefficient. And we are seeing results
22 very, very comparable to the issues that, you know, we
23 can solve the diffusion equation.

24 Now, I just want to get into, you know,
25 how we are doing this during normal operation. Again,

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1 as I said, MELCOR is a system level code.

2 So, once you create an input that you have
3 heat structure, you have piping, you have, you know,
4 the fission products are going to get deposited, it's
5 very, very difficult to specify how much dust or
6 fission products are going to be on different surfaces
7 in the NQA deck.

8 So, what we decided to do is an
9 accelerated steady state normal operation type of
10 calculation. So, let the code calculate during normal
11 operation, how much fission products and dust gets
12 released and gets deposited on various surfaces.

13 That would then be the initial condition
14 for any transient calculation.

15 CONSULTANT KRESS: What is meant by
16 accelerating?

17 MR. ESMAILI: By accelerated steady state,
18 we mean that we are not going to go through, you know,
19 like a two-and-a-half year, you're not going to
20 calculate two-and-a-half year or ten year. Ten year,
21 you know, doing burn-up cycle or operating time.

22 What we are going to do is that we would
23 run the code long enough to find out what the
24 equilibrium conditions are, you know. How much gets
25 released? What is the circulating activity? Because

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1 what gets released is getting deposited.

2 So, we are expecting to get to some
3 equilibrium conditions. And as things are getting
4 released, they're going to get deposited on heat
5 structure. So, you know, that the amount on heat
6 structure increases, which is coming actually on the
7 next - so, if you can do this for certain amount of
8 time, we can just scale it up to, you know, to
9 operating.

10 So, for ten years, you know, just we are
11 this much more. And this is - this is really up to
12 the user.

13 So, in the first step, you know, we want
14 to do a system thermal hydraulic. So, we want to get
15 in steady state in terms of core, you know. Core
16 temperature is a function of R and C.

17 Once we know the core temperatures, then
18 we can run the diffusion calculations, find out what
19 the distribution of fission products are.

20 So, you can see here on the top in the
21 three-dimensional graph, this is the concentration of
22 cesium. When you saw the diffusion equation in the
23 kernel versus into the buffer layer, do you see that
24 slope? And in the outer layers, it goes almost to
25 zero.

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1 And once we solve this thing for, you
2 know, for burn-up time of about two-and-a-half years,
3 then we know how much has been released.

4 What gets released goes into the matrix.
5 And for prismatic, it goes to the graphite block and
6 gets finally into the coolant. So, once we solve
7 that, so now we know we have the distribution of the
8 fission product.

9 The reason we did solve that detailed
10 diffusion equation is to get this distribution to see
11 where everything is. Because during the accident, you
12 know, particles fail. So, you know, whatever is in
13 the buffer now becomes a source into the matrix.

14 MEMBER ABDEL-KHALIK: Can we go back to the
15 previous slide, please?

16 Do we understand the reason for the large
17 differences in Case 3a?

18 MR. ESMAILI: In Case -

19 MEMBER ABDEL-KHALIK: 3a.

20 MR. ESMAILI: 3a.

21 MEMBER ABDEL-KHALIK: Intact, 1600 degrees
22 C, 200 hours.

23 MR. PETTI: Let me talk to that, Said.

24 No, I mean, actually we think it's
25 numerical problems in the codes the way they are -

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1 MEMBER ABDEL-KHALIK: Numerical?

2 MR. PETTI: Numerical problems.

3 Some of these codes, the German code, for
4 instance is, you know, sort of a 1970s vintage. And
5 so, if you were to show the time dependence, you'd see
6 some differences.

7 And so, we think it's these, you know,
8 everyone should get the right answer because these are
9 the thought problems. These aren't experiments.
10 These are thought problems.

11 MEMBER ABDEL-KHALIK: That's right.

12 MR. PETTI: And they vary, and so we think
13 there's a numerical issue. And so, actually it's
14 something we're going to pick up inside of our Gen-4
15 collaboration because the IAEA collaboration is
16 complete, but to try to get a better handle on it.
17 So, it's a numerical - these are very difficult
18 problems, because the diffusion coefficients vary, you
19 know, so much lay of the land.

20 MEMBER ABDEL-KHALIK: But this is the one
21 case that you want everybody to get right.

22 MR. PETTI: Right. Exactly. Exactly.

23 MR. ESMAILI: But the important thing is
24 that, you know, when we compare our results with INL
25 making sure that we have all the diffusion

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1 coefficients right, we get very, very close results.

2 MEMBER ABDEL-KHALIK: Well, but -

3 MR. PETTI: I'm not convinced those
4 calculations are right, you know.

5 CONSULTANT KRESS: Those are such small -

6 MR. PETTI: Small numbers, yes.

7 CONSULTANT KRESS: You wouldn't expect the
8 error there to really overwhelm everything.

9 MR. ESMAILI: What we have to do is that,
10 you know, in the silicon carbide layer, you know, we
11 play around with the meshing, you know, that that can
12 affect it.

13 MR. PETTI: It's actually the kernel - we
14 found the kernel meshing is absolutely critical. You
15 need a heck of a lot of nodes in the kernel to get it
16 right. And then probably second is silicon carbide.

17 And not everyone just maybe uniformly, you
18 know, maybe that's the way -

19 CONSULTANT KRESS: About how many nodes in
20 that kernel? The kernel goes out to what? 0.2?
21 That's the end of the kernel?

22 MR. ESMAILI: This is the kernel.

23 CONSULTANT KRESS: And about how many nodes
24 do you use?

25 MR. ESMAILI: This is the buffer.

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1 CONSULTANT KRESS: Yes, okay.

2 MR. ESMAILI: There's a big, big gradient
3 that is continuing there. So, you have to put more
4 nodes, as he says, near the surface of -

5 CONSULTANT KRESS: The kernel sort of gives
6 the distribution?

7 MR. ESMAILI: The kernel is just to give
8 you a contrast. To give you a contrast of whatever
9 you -

10 CONSULTANT KRESS: But it's sort of a
11 distribution measure also.

12 MR. PETTI: I think so.

13 MR. ESMAILI: And, you know -

14 MEMBER ARMIJO: Where is the silicon
15 carbide on that? Is that part of the buffer?

16 MR. ESMAILI: Right outside here. It's
17 this thin layer here. So, nothing is getting out.

18 MEMBER ARMIJO: Okay. So, that's really
19 what's controlling the release -

20 MR. ESMAILI: That's the controlling.
21 That's right.

22 MEMBER ARMIJO: Okay.

23 MR. ESMAILI: You look at the - like, for
24 example, if you look at the same thing for strontium-
25 90, you would see there is practically nothing in the

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1 outer layers. It would be just like a box.

2 What you see in the kernel is just like a
3 box. So, everything is actually - you see that the
4 retentive, you know, how much - how much gets - is
5 still inside the kernel after two-and-a-half years.
6 So, not much has gotten out.

7 And as a matter of fact on the bottom
8 here, you see that, you know, like if you solve this
9 in one to one-and-a-half year, you don't get anything
10 outside of the fuel, you know. It just keeps going up
11 until it builds up enough to get out. But, again,
12 this is for an intact fuel.

13 Okay. So, once we do those normal
14 acceleration, now we know the distribution of fission
15 products inside the kernel, inside the matrix,
16 everywhere. And so, we can do our transient
17 calculations.

18 CONSULTANT KRESS: Is your expectation that
19 when you get to the transport, the major component of
20 mass and the moving around is the dust? It's
21 overwhelming all the fission products.

22 MR. ESMAILI: I'll show you some results on
23 the next - I don't know at this point. This is what
24 we are doing right now. What we are doing right now,
25 we are just doing a test calculation. And I'm just

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1 going to show you some results during normal operation
2 with cesium.

3 But in this assumption, we just had
4 cesium. All the particles were intact. Fission
5 product is coming up as a vapor actually in the piping
6 and -

7 CONSULTANT KRESS: So, there's dust in
8 this.

9 MR. ESMAILI: So, there's dust in the
10 system and it remains. In this calculation, it
11 remains. But we had to make an assumption about the
12 temperature of the structures, et cetera.

13 MR. PETTI: You know, the total mass coming
14 out of this core is incredibly tiny. The partial
15 pressures of these fission products are between ten to
16 the minus ten and ten to the minus twenty atmospheres.

17 CONSULTANT KRESS: Yes, you get ten to the
18 minus -

19 MR. PETTI: It's rare gas, yes, I mean -

20 CONSULTANT KRESS: I would expect the dust
21 to overwhelm -

22 MR. PETTI: Absolutely. The dust will
23 overwhelm, I think. And it's a timing issue though,
24 you know, when the dust is, where it is relative to
25 when the fission products get out, all those sorts of

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1 system issues. But also, you know, how things
2 interact with surfaces.

3 I think a lot of the LWR models are wrong.
4 I mean, they're talking about they have bulk phases.
5 I mean, you've got enough cesium coming out of an LWR
6 that you can -

7 CONSULTANT KRESS: They're huge.

8 MR. PETTI: It's a huge amount.

9 CONSULTANT KRESS: Yes, compared to this.

10 MR. PETTI: That is not the situation here.

11 MR. ESMAILI: No, we don't see -

12 MR. PETTI: So, it's a completely different
13 physics in terms of where you are in terms of how
14 things deposit and the like.

15 MR. ESMAILI: For these example problems,
16 you're right. As a matter we don't see, you know,
17 that the concentrations are so low that it never
18 condenses into an aerosol form.

19 So, it just goes into circulating vapor
20 and it just condenses on the surface as fission
21 product. It's a different picture than LWR, but this
22 is during normal operation.

23 CONSULTANT KRESS: So, just to give you an
24 example, do your surfaces ever saturate or you don't
25 have enough material to do that?

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1 MR. ESMAILI: I don't think we have enough
2 material to do that, no. You know, and talking about
3 dust, we are talking about ABR, you know, three
4 kilograms per year. So, even dust is not a very huge
5 number, you know.

6 CONSULTANT KRESS: It's huge compared to
7 the fission products.

8 MR. ESMAILI: It's huge compared to the
9 fission products, but still a very, very low number,
10 you know. So, it's going to be a very, very thin
11 layer.

12 So, in order to test, you know, this, what
13 do you call, normal operation mode, we already have a
14 model for the core. You are seeing here, you know,
15 the axial levels and radial rings in the core.

16 And we just - this is just a test. So, we
17 are just adding certain control volumes to model the
18 piping.

19 So, it goes out from the core and it goes
20 around just to see how this normal axillary to steady
21 state works. It doesn't mean - it doesn't intend to
22 be a representative, you know, design which we are
23 building right now, but this is for the test purposes
24 right now.

25 So, here's a result for the PBR400 cesium

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1 distribution in the primary system. So, once we got
2 the fission product distribution, now this is what
3 gets released into the coolant.

4 So, what you see on the left-hand side,
5 this is a circulating cesium mass. Okay. And after
6 some time you see it comes to a steady state
7 equilibrium condition.

8 So, whatever gets released, either its
9 condensing or gets out, but whatever builds up on the
10 heat structures, and on the right-hand side you see
11 the cesium mass that's deposited on different heat
12 structures, it just keeps going up.

13 So when I said, you know, we scale it,
14 that means that we need to run this thing for a brief
15 period of time, however that is, and come up with some
16 equilibrium conditions. And the MELCOR, then we use
17 that as a restart to do the accident calculation.

18 So, if I'm running this thing for about
19 maybe 2,000 seconds, you know, again, these are like
20 representative. But if I want to know how much it is
21 going to be build up over ten years, it would just be
22 an extrapolation of what it is.

23 CONSULTANT KRESS: Just a draw a line on -

24 MR. ESMAILI: It just goes up, right.

25 CONSULTANT KRESS: Yes.

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1 MR. ESMAILI: We have to do a little bit
2 differently for the nobles and, you know, that they
3 don't deposit, but those, you know, decay. But that
4 decay is already taken into account.

5 So, that's where we are. We are using the
6 same models for the accident calculations also. And
7 we are hoping to have the MELCOR - all the models in
8 MELCOR by the end of this calendar year. The work is
9 continuing on deposition and, you know, lift-off, et
10 cetera, models. These are currently undergoing, you
11 know, development.

12 CONSULTANT KRESS: Now, the meeting of
13 protective action guidelines, maybe I'm asking the
14 wrong person here, at the site boundary is, seems to
15 me, like dominated by the normal releases.

16 When you depressurize and stuff, the
17 normal stuff that you're looking at here that
18 dominates that rather than additional releases; is
19 that correct?

20 MR. PETTI: Yes.

21 CONSULTANT KRESS: So, you have to get this
22 part right.

23 MR. PETTI: Yes, but that's not the hard
24 part. That's pretty easy.

25 MEMBER REMPE: Did they do a COMEDIE test?

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1 Did it finally go through? I know they talked about
2 it, and so are you benchmarking against it for
3 something like this?

4 MR. PETTI: Yes, there were a couple of
5 COMEDIE tests done before that was shut down. So, they
6 had done some additional benchmarking, but they would
7 like to do more.

8 MEMBER REMPE: They would like what? I
9 didn't hear.

10 MR. PETTI: To do more. They want us to
11 set up a loop.

12 CHAIRMAN BLEY: Okay. Thank you very much.

13 MR. BASU: Chairman, I'm looking at the
14 clock. What would you like to do?

15 CHAIRMAN BLEY: I'm expecting Joe to go
16 through thirty slides in ten minutes. Do you think
17 you can do that? Maybe we should have started at 8:00
18 this morning instead of 10:00.

19 Joe, you got two packages.

20 MR. KELLY: Yes.

21 CHAIRMAN BLEY: How about we do one of them
22 before lunch, and one after, and we'll shorten lunch
23 a little.

24 MR. KELLY: That sounds perfect.

25 And so since we've been talking about

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1 computer codes, I'll continue on that line and go with
2 the PARCS/AGREE presentation now.

3 Then after lunch, we'll do the supporting
4 experimental programs. Okay?

5 CHAIRMAN BLEY: Yes.

6 MR. KELLY: And so just what I said, I'll
7 be talking about the PARCS/AGREE development. And so
8 now what we're talking about is core analysis.

9 Here's my infamous schematic again. And
10 the point here is just to remind you that we use the
11 PARCS/AGREE codes for both the normal operation steady
12 state, and for reactivity insertion transients where
13 we need a 3D kinetics capability.

14 So, PARCS is the NRC's core neutronics
15 simulator. It's three-dimensional. It has both a
16 cylindrical and hexagonal geometry. And it already
17 had some preliminary validation work done for pebble-
18 beds. So, we weren't starting from scratch there.

19 But to make it applicable to prismatic,
20 what we're doing is implementing a triangle-based
21 polynomial expansion method which they call TriPEN.
22 And so, that's for prismatics. And I'll show you what
23 that is.

24 We also have to improve the cross-section
25 generation capability. And what we're talking about

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1 now is how you go from SCALE to PARCS. And in
2 particular, implementing what are called assembly
3 discontinuity factors. And I'll give you an idea.

4 They're correction factors that allow a
5 homogeneous nodal code to match both the flux, which
6 is over the node, and the currents, which are on the
7 boundaries, match what you would get from a
8 heterogeneous transport code.

9 And since I'm a thermo-hydraulics person
10 and not a reactor physics person, that's about all I
11 can say on that.

12 The other things that they're working on,
13 well, for the future, they haven't started it yet, is
14 the microscopic depletion capability. And this is
15 needed so that you can follow a core over its three-
16 year life.

17 And then we'll be participating in a new
18 OECD benchmark that's being led by Idaho. And that's
19 for the MHTGR-350 design. And so, that would be
20 similar to what was done very successfully through the
21 PBMR400.

22 So, this is what TriPEN looks like. So,
23 you see a fuel element. And this fuel element not
24 only has the coolant channels and fuel compacts in it,
25 but there is a very large, almost four-inch diameter

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1 hole, which can be for the reserve shutdown system or
2 for control rod, depending upon which fuel element
3 design you're talking about. So, consequently there
4 even within this one fuel assembly, there are a lot of
5 heterogeneities.

6 So, what we're doing now instead of
7 averaging the cross-sections over the entire fuel
8 element or hexagon, it's breaking that hexagon into
9 six triangular sectors and averaging the cross-
10 sections over each sector. And then doing a nodal
11 solution for each of these triangles and matching
12 those up.

13 And so, what I'm going to show now is a
14 benchmark for the HTTR. In this case, it's a
15 numerical benchmark. So, the truth in this case is
16 going to be a Monte Carlo transport code, which what
17 we'll be using is KENO.

18 And what we'll be doing is comparing the
19 nodal diffusion solutions of PARCS to the Monte Carlo
20 transport solution.

21 So, we're going to use the HTTR geometry,
22 that's the high-temperature engineering test reactor
23 in Japan. It's an operating reactor. But we're going
24 to simplify the geometry and we're going to look at a
25 2D plane.

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1 So, Case 1 is very simple. It's five
2 rings of fuel elements with uniform enrichment, and
3 just one ring of a reflector.

4 Case 2 is four rings uniform enrichment.
5 Two rings for the reflector.

6 Case 3 is now starting to look more like
7 what the HTTR actually looks like, because they have
8 reflector blocks sitting inside the core region and
9 there are four different enrichments in this core at
10 the mid-plane. So, those are shown in the middle of
11 the slide.

12 Case 4 was added to be able to compute the
13 control rod worth. And so in those reflector
14 assemblies which are inside the core, you will now
15 notice the open circles which are instrumentation
16 guide tubes, and the dark blue closed circles which
17 are the locations of the control rods.

18 And these are the results. So, I'm going
19 to show results for both k-effective, and then the
20 delta pcm for all four cases.

21 KENO is the Monte Carlo model that's built
22 into the SCALE package. And so KENO-CE is a
23 continuous energy version which Mourad talked about.
24 And so for our purposes, that's the truth because
25 we're doing numerical comparisons here.

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1 KENO-MG is the same thing, but now
2 breaking the cross-sections up into different energy
3 groups.

4 So, by comparing the multi-group to the
5 continuous energy and comparing those errors, and that
6 would be this line where they're all in the order of
7 negative two to 300, that's about as good as we could
8 hope to do. This kind of defines, if you will, how
9 good our codes have to be. So, if the PARCS code can
10 get within those values, we're doing very good.

11 The next row is labeled "TRITON/PARCS."
12 TRITON is the lattice physics code inside of the SCALE
13 package. And so, that's what's used to actually
14 compute the multi-group homogenized cross-sections
15 that PARCS uses.

16 So, if you don't have the reflector ADFs,
17 you get relatively large errors in the pcm.
18 Unacceptably large. And this is what drove them to
19 have to use the assembly discontinuity factors.

20 And when those were put in, we get very
21 good comparisons here for all four cases, including
22 the rodged case, but this isn't all of the story.

23 The fluxes in the thermal region are not
24 as good as these numbers. So, there's more work to
25 do, and that's what they're working on now.

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1 AGREE, which stands for Advanced Gas
2 Reactor Evaluator, is the thermo-fluids module of
3 PARCS - although, actually, it's the other way around.
4 AGREE becomes the main code, and PARCS becomes a
5 library that it calls. And we did this having to do
6 with configuration management.

7 Because if you were sitting in, say, the
8 EPR or one of the BWR MELLA-plus presentations, you
9 would hear about TRACE/PARCS. So in that case, TRACE
10 is the driver of PARCS' two-phased flow code using
11 PARCS as a library.

12 So, that's how we do the coupling to
13 maintain the configuration control between different
14 reactor types.

15 AGREE started out as a three-dimensional,
16 two-temperature porous medium approach. It was
17 developed to have a pebble-bed capability.

18 So if you will, it's a modern, rewritten
19 version of the legacy THERMIX/DIRECT codes. And so
20 we took this and it already had some validation for
21 pebble-bed, because that's what it was developed for,
22 and we're extending it to prismatic.

23 The very first thing we did was extend it
24 to model a prismatic using the existing r-theta-z
25 geometry. And I'm going to show you some results from

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1 that, because we use that to review the scaling of the
2 Oregon State high-temperature test facility. And so,
3 that's an example I'll show.

4 But of course modeling a prismatic reactor
5 in r-theta-z isn't good enough. So, what we're doing
6 is putting a new prismatic capability in, and that has
7 two parts. A bypass flow model, and a three-
8 dimensional triangle-based heat transfer model. And
9 I'll show you what both of those look like.

10 So, this is the bypass - the new bypass
11 flow model. So, you see a drawing of the core on the
12 left and on the right.

13 So, each fuel element is divided into six
14 triangular sectors. Within each of those sectors,
15 there would be one typical fuel compact, and one
16 typical coolant channel.

17 The bypass channels are these new control
18 volumes which are treated like subchannels. So, that
19 models the gap between two fuel elements. And of
20 course there are crossflow junctions between all of
21 these subchannels.

22 At the axial interfaces where two fuel
23 elements come together, due to irradiation damage you
24 can open up gaps here.

25 And so, we have to also allow bypass flow

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1 or crossflows between a fuel element and a bypass gap
2 at those interfaces, as well as potentially between
3 the coolant channels going around a fuel element.

4 So, all of that numerical capability is
5 now there, but we have to develop the constitutive
6 models for it. And then as Mike asked earlier, we
7 have to develop a module to describe the distortions.

8 MEMBER CORRADINI: Can you explain the
9 arrows that are going around the clock inside the
10 element?

11 I didn't understand that. I'm sorry.

12 MR. KELLY: Okay. If this is a fuel
13 element -

14 MEMBER CORRADINI: Right.

15 MR. KELLY: -- each triangle will have one
16 typical coolant channel, and one typical compact.

17 MEMBER CORRADINI: Right.

18 MR. KELLY: So, at the axial interfaces if
19 they open up -

20 MEMBER CORRADINI: Oh, I got it. I got it.
21 Okay. I got it now. Okay. Sorry. Thanks.

22 MR. KELLY: No problem.

23 So, for the heat transfer model, we have
24 to model this at three scales. The micro-scale, which
25 is on the order of a transient conduction in a coated

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1 fuel particle, that's important for reactivity
2 insertion because it's the fuel temperature that
3 matters.

4 For the meso-scale, and now we're talking
5 about the heat transfer on the order of the fuel
6 compact through the graphite matrix to the coolant
7 channel, that's important for normal operation because
8 it gives us our fuel temperatures and our moderator
9 temperatures.

10 The macro-scale is now the heat conduction
11 radiation either between these triangular sectors or
12 from one fuel element to the other to get on out to
13 the reactor vessel wall. And those are important in
14 the conduction cooldown scenarios.

15 This is what the meso-scale model looks
16 like. And this is similar to what I showed you for
17 MELCOR earlier.

18 So in AGREE, we go ahead and model the
19 fuel compact with a 1D radial conduction solution, but
20 then we used a lumped parameter model for the graphite
21 moderator. So, the graphite just has one temperature,
22 and then we have to specify appropriate conductances
23 between the surface of the fuel channel and the
24 graphite, and then the graphite to the coolant
25 channel.

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1 And so, we've compared these to 2D finite
2 element solutions and found a way to specify those
3 conductances.

4 The macro-scale, and now what we're
5 talking about, as I said, is the conduction paths
6 between the triangles within a fuel element, and then
7 going across the gaps to the adjacent fuel element.
8 And here we have to model not just conduction, but
9 convection to the flow and the bypass gap and
10 radiation across that gap.

11 So, we needed a special treatment for that
12 because of the radiation. We need to know the
13 temperatures on those two surfaces. So, all of that's
14 being worked on. Should be finished by the end of the
15 summer.

16 Now, the example I'm going to show
17 compares a calculation done for the MHTGR, which is
18 the prismatic design of General Atomics, and the
19 Oregon State test facility.

20 And what I'm going to do is a
21 depressurized conduction cooldown. And the objective
22 of this was to check the scaling of the thermal
23 resistances in the core of an OSU facility.

24 Since that's a reduced-scale facility, we
25 also had to scale the thermal conductivities. If we

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1 put something that look like graphite in it, the
2 thermal conductivity would be way too high and we
3 wouldn't get the right temperature rise over the core
4 and the reflectors.

5 So, you subtract the scaling -

6 MEMBER ARMIJO: Before you do that, could
7 you tell us a little bit about the OSU facility, what
8 it is and -

9 MR. KELLY: Next presentation.

10 MEMBER ARMIJO: Okay.

11 MR. KELLY: Okay. Sorry.

12 It's, you know, chicken and egg kind of
13 question. That's hard to do, but you'll see a little
14 bit of it in just a second.

15 It's made to look like the MHTGR. Okay.
16 So, at the time I did these calculations, the only
17 thing that was available was the r-theta-z model. The
18 cylindrical geometry extended to the PMR.

19 And so rather than try to compare two
20 transient - conduct transient solutions, I did a
21 quasi-steady approach taking the decay heat at about
22 the time of peak power.

23 So, it's about half the percent decay
24 heat, and do a steady state to generating this decay
25 heat in the core. It has to go out through the outer

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1 reflector core barrel to the reactor pressure vessel.
2 And then radiated convected from that to the RCCS.

3 And so, I'm going to compare MHTGR and the
4 HTTF. This is what the MHTGR looks like. It's not a
5 very clear picture.

6 And then on the right-hand side is the
7 AGREE model of it. Remember, this is r-theta-z. So,
8 I had something like 14 radial rings, 12 azimuthal
9 sectors and 30 some axial nodes.

10 MEMBER CORRADINI: So, just so I'm clear,
11 the MHTGR-350 is what NRC has partially reviewed back
12 in the '80s?

13 MR. KELLY: It wasn't a 350 then, but yes.

14 MEMBER CORRADINI: Okay. Because there is
15 an SER published on this, right?

16 MR. KELLY: Yes.

17 MEMBER CORRADINI: Okay.

18 MR. KELLY: It's very similar to that.

19 MEMBER CORRADINI: Okay.

20 MR. KELLY: And that's - I don't want to
21 speak for DOE, but it looks like that's the direction
22 the General Atomics design is evolving to.

23 MEMBER CORRADINI: Okay. That's fine. I
24 just wanted to make sure I understood the connection.

25 MR. KELLY: Yes.

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1 MEMBER CORRADINI: Thank you.

2 MR. KELLY: No problem.

3 And these are the results. So, on the
4 left-hand side for the full-scale prototype, and the
5 right-hand side the reduced-scale model, these are
6 isotherms calculated at the core mid-plane.

7 The center region is at 1600, and these
8 are at 100 degree C increments. And they look very
9 much similar with the minor exception of a temperature
10 drop between the core barrel and the reactor pressure
11 vessel.

12 And that has to do - it's kind of hard to
13 scale emissivities and you have too much surface area
14 in a reduced-scale facility.

15 And this is an axial slice. And, again,
16 they look very similar. There are few discrepancies.
17 You'll notice these isotherms in the reduced-scale
18 facility are too close.

19 At that time, their top reflector wasn't
20 thick enough. They had a little scaling problem. The
21 other one, you can't see the colors as well here.
22 There's a slight color difference in the top here.

23 In the full-scale, there was a very small
24 recirculating flow that didn't show up in the test
25 facility. And that's something that we'll be looking

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1 at. And that's all.

2 CHAIRMAN BLEY: Anything from the
3 Committee?

4 Okay. Well, if it's okay with all of you
5 we're not creating a problem, I think we'll take our
6 lunch break here and we'll meet back here -- we'll
7 start promptly at one o'clock. Try to get back just
8 a few minutes before that so we can start promptly at
9 1:00.

10 Okay. At this time, we will recess until
11 one o'clock.

12 (Whereupon, the proceedings went off the
13 record for a lunch recess at 12:17 p.m. and went back
14 on the record at 1:01 p.m.)

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1 A-F-T-E-R-N-O-O-N S-E-S-S-I-O-N

2 1:01 p.m.

3 CHAIRMAN BLEY: The meeting is back in
4 session, and I'll give it back to Joe to continue
5 where we were this morning.

6 MR. KELLY: Okay. I will start with the
7 presentation on the experimental support for the NGNP
8 evaluation model.

9 And I should make the point that what I'm
10 going to be talking about are NRC experimental
11 programs. I'm not going to be describing the entire
12 DOE effort.

13 So, we expect that the majority of the
14 experimental database will be provided by DOE and/or
15 the applicant. And obviously the fuel qualification
16 program is an example of that.

17 Another example would be the full --
18 almost full height RCCS experiment that's going to be
19 done at Argonne National Laboratory.

20 So, those are programs that we would not
21 replicate.

22 CONSULTANT KRESS: Let me ask you about the
23 fuel qualification program.

24 MR. KELLY: Yes.

25 CONSULTANT KRESS: Will you not have to --

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1 when they get ready to load the fuel into the reactor,
2 will you not have to have the capability to say, yes,
3 that fuel meets the standards we'd like it to have?

4 So, you would have to have some program of
5 fuel qualification.

6 MR. KELLY: Yes, yes. There was - you're
7 really asking the wrong person. And, Stu Rubin, if
8 you want to chime in, but I know that they did a
9 program with Oak Ridge to come up with how to monitor
10 the manufacturing process for the fuel and for the QC
11 program that that has to go through.

12 What I'm talking here is the AGR
13 irradiations and the subsequent PIE testing. And Stu
14 will actually talk about that some in his
15 presentation.

16 CONSULTANT KRESS: Okay. I'll wait.

17 MR. KELLY: So, the objective of this
18 presentation is to give you a very high-level, quick
19 overview of the experimental program that the NRC is
20 supporting.

21 And of course we will come back to you at
22 another time and give you detailed presentations on
23 each of these experiments. In 15 minutes, I don't
24 have the time.

25 So, this is what we're talking about.

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1 There are two integral tests. The high-temperature
2 test facility at Oregon State University, and that's
3 actually a joint DOE-NRC program.

4 Then there is a proposed OECD program at
5 the high-temperature engineering test reactor in
6 Japan. It's the LOFC program. So, that would be run
7 by JAEA. That's pending, you know, signatures of all
8 the OECD signatories.

9 Separate effects tests, we have several of
10 them. There's a pebble-bed flow and heat transfer
11 test at Texas A&M. There will be a prismatic core
12 heat transfer also at Texas A&M. That hasn't started
13 yet. So, I won't be addressing it today.

14 Both of those are part of the same
15 cooperative research agreement that spawned the Oregon
16 State high-temperature test facility. So, they were
17 part of a package deal.

18 We also have some air ingress flow tests
19 at Penn State. There was a cooperative research
20 agreement with University of Wisconsin for the
21 emissivity of vessel components. I'll show you an
22 example of that. And a brand new program is on core
23 bypass in the prismatic, and that's also at Texas A&M.

24 So, this is the Oregon State facility.
25 It's an integral effects test. It's co-funded by DOE

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1 and the NRC. Actually, in this case, the NRC funds
2 actually come from the Department of Energy through
3 the Memorandum of Understanding.

4 So, we're running this program together.
5 It's reduce scale. It's quarter height and quarter
6 diameter. So, the L over D matches the prototype.
7 So, that gives it a little bit more than six meters
8 tall and almost two-meter diameter for the vessel.

9 The power level, the max we can go to is
10 2.2 megawatts and has to do with facility
11 infrastructure.

12 It is a full-temperature facility. So, we
13 plan to match both the inlet and outlet temperatures
14 of the prototype. So, the outlet will be almost 700
15 degrees C. That's a mixed mean outlet temperature.
16 Core outlet temperature would be higher.

17 It's a reduced-pressure facility. We'll
18 only be able to go to eight bar. So, when we do a
19 depressurization, we won't be doing the entire blow-
20 down. We'll just be doing the tail end of the blow-
21 down. And of course that's to keep costs manageable.

22 And we're going to - the initial core
23 configuration is going to be prismatic based upon the
24 MHTGR 350 design. That was a joint DOE-NRC decision.
25 And that's what's shown inside the vessel here, is the

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1 prismatic core.

2 But the vessel itself and all of its
3 supporting balance of plant, RCCS, et cetera, has been
4 designed so that we can switch to a pebble-bed, you
5 know, should the need arise in the future.

6 CONSULTANT KRESS: Is this nuclear power?

7 MR. KELLY: No.

8 CONSULTANT KRESS: It's electric?

9 MR. KELLY: Yes. Oh, yes.

10 (Laughter.)

11 MR. KELLY: I should say core simulator
12 configuration, but - so, the HTTF was designed to
13 model a depressurized conduction cooldown transient.

14 And of course in the beyond design basis
15 space, you might be talking about a double-ended
16 guillotine break of the annular hot gas duct.

17 But we also want to look at breaks that
18 are much more probable. Things like CRDMs and
19 instrumentation line breaks. So, we're designing the
20 facility with different break locations and sizes in
21 mind.

22 It's been scaled for four different
23 phases. The depressurization, again that's only the
24 tail end because it's only from eight bar.

25 Then the air ingress by lock exchange, and

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1 actually I'll be showing you a slide of that from the
2 Penn State separate affects experiment later on.

3 Then after the air has flooded the lower
4 plenum, it might thence progress through the core by
5 molecular diffusion eventually leading to a natural
6 circulation. So, all of this at the facility has been
7 scaled for to some extent.

8 It will have a reactor cavity cooling
9 system that's operational, but we're trying to provide
10 a very well-known, well-defined boundary condition for
11 the vessel.

12 So, in our case, we're going to be using
13 forced cooling. So, we're not actually trying to
14 mimic one of the potential designs. That instead will
15 be the job of a DOE program at Argonne.

16 MEMBER ARMIJO: What is lock exchange?
17 What happens there? What do you mean by air ingress
18 by lock exchange?

19 I'm not familiar with that.

20 MR. KELLY: Yes, it's a - I think it's
21 actually a civil engineering term. So, imagine a pipe
22 separating two vessels. One vessel has very heavy
23 liquid, say, water, and the other vessel is air.

24 Open up the pipe. You get a stratified
25 countercurrent flow.

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1 MEMBER ARMIJO: Okay.

2 MR. KELLY: Okay. You can think of that in
3 two-phased flow space, but it looks almost the same as
4 if it's air, which - cold air, which is your heavy,
5 dense fluid, and hot helium, which is your light
6 fluid.

7 MEMBER ARMIJO: Okay.

8 MR. KELLY: So, that's what's called the
9 lock exchange mechanism.

10 MEMBER ARMIJO: Thank you.

11 MR. KELLY: And we've also looked at
12 scaling facilities for both normal operation and
13 pressurized conduction cooldown.

14 We can do a pretty good job of those if we
15 switch simulant gases. So, instead of using helium,
16 we use nitrogen. Then we can match the Reynolds
17 number during normal operation pretty well, and also
18 for the PCC.

19 Now, we can only do normal operation for
20 the prismatic, and it has to do with being able to
21 heat the pebble-bed since we're not generating heat
22 within the pebbles with nuclear -

23 CONSULTANT KRESS: Will you do the air
24 ingress at the high temperature? The 600 and -

25 MR. KELLY: We'll do it at prototypic

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1 temperatures, yes. But we do - I should say our air
2 in this case will be nitrogen.

3 CONSULTANT KRESS: Okay.

4 MR. KELLY: Okay. Because we'll be having
5 graphite heater -

6 CONSULTANT KRESS: I was going to worry
7 about your -

8 MR. KELLY: Our electrodes are going to be
9 graphite. So, it will be helium nitrogen rather than
10 helium air, just for that reason. We want to do more
11 than one test.

12 CONSULTANT KRESS: Yes, that's what I was
13 worried about.

14 MR. KELLY: I don't have a great picture of
15 the core, but this gives you an idea. This is a unit
16 cell. It's one of our fuel elements, if you will.
17 There will be 66 of these. One for each of the fuel
18 elements in the MHTGR design.

19 So, what you have is a hexagon. It's
20 about three-and-a-half inches flat to flat. So, it's
21 1/16th the area of an actual fuel element.

22 There's a graphite electrode in the center
23 with a little gas gap around it. There are also
24 electrodes at the vertices, which means they get
25 shared with the neighboring fuel element.

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1 The white circles are the coolant
2 channels. They're prototypic diameter, which is a
3 good thing. That helps with the Reynolds numbers.
4 And they end up giving us the, also, prototypic
5 porosity. So, we're able to match both of those.

6 MEMBER ARMIJO: How does that work with a
7 pebble-bed?

8 MR. KELLY: Well, we will be using a random
9 - I mean, assuming we go that way at some point, it
10 would look much more like the old SANA test facility
11 in Germany or the HTTU facility that was in South
12 Africa at Potchefstroom.

13 MEMBER ARMIJO: So, you'd use different
14 heater elements that are -

15 MR. KELLY: We would have graphite
16 electrodes probably buried in a central cylinder. And
17 that central cylinder would then be surrounded by a
18 packed pebble-bed.

19 MEMBER ARMIJO: Okay.

20 MR. KELLY: And then you conduct the heat
21 radially outward. That's why you can't do normal
22 operation because the temperature drop between that
23 cylinder and the bed is too large at full-power type
24 conditions.

25 What I haven't mentioned is actually the

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1 blue part in here is our, if you will, graphite
2 moderator. But we can't use graphite in this because
3 the thermal conductivity is too high. So, it's
4 actually going to be a designer ceramic.

5 In order to get the right radial
6 temperature drop during a conduction cooldown, we
7 needed a material with a thermal conductivity 1/8th of
8 the irradiated graphite. So, we're talking something
9 on the order of four in SI units.

10 And so, we're actually building, you know,
11 having a company make a specific ceramic mix for us
12 and then casting it in a mold.

13 The next integral experiment is a
14 potential one. It's pending signature. It's OECD
15 HTTR-LOFC program. And I've already said before that
16 HTTR stands for high-temperature engineering test
17 reactor. Operated by JAEA.

18 It's an actual, real, operating test
19 reactor. 30 megawatts. Prismatic blocks. And, you
20 know, graphite moderated, helium cooled. And it has
21 operated with an outlet temperature as high as 950
22 degrees C.

23 CONSULTANT KRESS: Just out of curiosity,
24 what does LOFC stand for? Loss of fuel cooling or -

25 MR. KELLY: Loss of forced circulation.

1 CONSULTANT KRESS: Loss of forced
2 circulation.

3 MR. KELLY: Okay. So, the program would
4 have three tests. The initial conditions are shown
5 here, but what's more important are the test
6 procedures.

7 So, in all three of these tests, you start
8 by tripping the gas circulators. So, there's no flow
9 at all in the primary system. So, you lose all of
10 your heat rejection capability. All your active heat
11 rejection capability.

12 Then you do not scram the reactor. So,
13 it's an ATWS as well. Instead the reactor is going to
14 shut itself down with its negative temperature
15 coefficient and then xenon.

16 For Test Case Number 3 in addition to
17 those two faults, we're also going to trip - or they
18 are going to trip the pumps on the vessel cooling
19 system, because the RCCS through this plant is
20 actually forced circulation as well.

21 So, by tripping those pumps, they turn off
22 the RCCS. So, that would be a 100 percent failure of
23 the RCCS system. And that's why Run Number 3 starts
24 from a low power or low temperature, because we don't
25 have the passive rejection.

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1 And this is the expected results. This is
2 reactor power versus time. And you will note the
3 scale is focused in.

4 So, the blue curve, for example, started
5 out at 30 megawatts, which of course is not shown
6 here. And the red curve is the nine-megawatt case.

7 And so, what you see is the plant shuts
8 itself down due to the negative temperature
9 coefficient and xenon.

10 Then as the xenon decays away, you can go
11 re-critical and come up to some new steady state power
12 with a much hotter core.

13 And so, it's a very good test for
14 something like PARCS/AGREE coupled, you know, a
15 coupled reactor physics thermo-fluids.

16 MEMBER ABDEL-KHALIK: How does the MTC vary
17 with burn-up?

18 MR. KELLY: I'm sorry, I don't - I can't
19 answer that. I'm sorry. You're right that it does,
20 but it's outside my area of expertise. I'm sorry.

21 MEMBER REMPE: How would the tests differ
22 from what they did years ago at ABR? Because didn't
23 they do a loss-of-flow transient at the ABR?

24 Of course it's a pebble-bed and I know
25 that, and things like that, but how far did they go?

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1 And was it just one test they did or was it multiple
2 tests?

3 MR. KELLY: I don't know. We do have a
4 staff member who actually worked at ABR. So, I can
5 ask him.

6 MR. PETTI: Yes, I think these are very
7 similar. ABR did more tests. HTRR did similar. This
8 is just doing in a prismatic, largely, I think, as
9 sort of -

10 MEMBER REMPE: Right. Okay.

11 MR. KELLY: And it also gives us the
12 opportunity to be able to do post-test analyses with
13 the experimenters in hand.

14 So, when you have a question about how you
15 need to model something, you can get the answer which
16 is sometimes all-important.

17 MEMBER REMPE: Of course.

18 MR. KELLY: Now, we'll talk about the
19 separate affects test. And so, the first is the
20 pebble-bed flow and heat transfer test at Texas A&M.
21 It has four different areas of investigation.

22 The first was just simply pressure drop in
23 a randomly-packed bed. We looked at both annular and
24 circular beds because the design changed in the middle
25 of this. That work is complete.

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1 We also looked at the radial porosity
2 distribution, and I'll show you an example of that.
3 What they're doing now is looking at the radial
4 velocity or, if you will, flow profile. And that's to
5 try to quantify what the wall bypass effect is.

6 And then also a test they're starting now
7 are convective heat transfer for the pebble. So, this
8 is pebble-to-gas-heat transfer. So, not only is it a
9 function of Reynolds numbers you normally see in a
10 textbook, but it is affected by how close the pebble
11 is to the wall. And all of these beds, especially if
12 you go to an annular core, are relatively thin.

13 So, for the radial porosity distribution,
14 what they did, they paired -- matched the index of
15 refraction with laser-induced fluorescence.

16 So, basically the test section were
17 completely transparent. You could look through the
18 bed completely. Then they would shine a very thin
19 laser sheet vertically aligned through the bed while
20 putting a fluorescent tracer in the fluid.

21 So, what happens is now the spheres in
22 that laser plane show up as dark spots, and the fluid
23 is light.

24 So, using image capture and image analysis
25 software, you can see how much of that cross-sectional

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1 area is solid, you know, and move the laser over, you
2 know, and so on, and build up a map of the entire bed.

3 You can actually figure out where each
4 pebble is in a randomly-packed bed. Which if you know
5 when we try to do a CFD model later, it's kind of nice
6 because you know where the pebbles are.

7 MEMBER ARMIJO: Yes. Very slick.

8 MR. KELLY: Now, what you can then also do
9 is take that and integrate it in the axial direction
10 and get the actual radial profile.

11 So, this is kind of nice because it was
12 nondestructive, it was randomly-packed bed. This was
13 a very small bed. So, you notice the wall effect on
14 porosity persists to the center of the bed.

15 On a larger bed such as actually you would
16 see in the HTR module design, you're about 14, 15-
17 pebble diameters or something. So, that effect dies
18 out typically after about five or six pebble
19 diameters.

20 CONSULTANT KRESS: What's the unit on your
21 porosity?

22 MR. KELLY: It's just zero to one.

23 CONSULTANT KRESS: I know, but what's it
24 measuring?

25 MR. KELLY: Volume fraction.

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1 CONSULTANT KRESS: The volume fraction of
2 a given -

3 MR. KELLY: Of the fluid. The volume
4 fraction of fluid, yes.

5 MEMBER CORRADINI: So, this is volume
6 fraction of gas.

7 MR. KELLY: Yes. In this case, it was P-
8 cymene, but, you know.

9 So, this is the slide for the air ingress
10 test at Penn State University. And we talk about it
11 as countercurrent stratified flow, but it can exist
12 not only in a horizontal component, but also a
13 vertical.

14 So, the idea of these tests were to study
15 the geometric effects on the air-ingress flow rate
16 during what we might call lock exchange looking at
17 both the break orientation, the L over D effect on the
18 pipe and the break geometry itself.

19 And we've already completed the scoping
20 studies using water-brine, and that's what's shown
21 here and I'll explain in a second. And we're just now
22 starting scaled experiments with helium air.

23 So, the tank on the right is full of a
24 relatively heavy brine solution. And the tank on the
25 left is pure water.

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1 So, the tank on the left is, if you will,
2 the actual reactor vessel. And the tank on the right
3 is the reactor cavity.

4 And so initially when you open up, there's
5 a fast-acting shutter here and you open it up, the
6 heavier brine flows along the bottom of the pipe while
7 the less dense water comes countercurrent to it back.

8 At the intermediate stage, and this is a
9 fairly high flow rate where the level of this mixture
10 in what would in fact be the lower outlet plenum has
11 reached the crossover duct, the flow rate slows down
12 significantly.

13 And in what they call the final stage
14 where that mixture reaches the top of the crossover
15 duct, basically the flow goes to almost zero.

16 And this is the helium-air test facility.
17 They're just starting these test now. There will be
18 three different break locations.

19 On the left-hand side you see a location
20 for a horizontal break. And actually there's a two -
21 both flanges can have the break.

22 And on the right you see the vessel itself
23 which is to model, if you will, the inlet plenum or
24 upper plenum of a gas reactor with a break location on
25 top. And there are multiple locations for thermal

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1 couples and oxygen sensors. So, all of this is to
2 give us data for code validation.

3 The component emissivity test, that was
4 done as part of a cooperative research agreement with
5 University of Wisconsin. So, this is a system they
6 built, you know, as an infrared irradiation system.

7 The samples were held in a silicon block.
8 There was one black body and I think up to six
9 samples.

10 The optics actually rotated so they go
11 from the black body to all of the samples and back
12 again and do this as a function of time. It wouldn't
13 just measure it once.

14 There was a heater and thermocouples on
15 the block so they could control the temperature to
16 block. There was also gas lines so they could change
17 the atmosphere so they could age a sample. And that's
18 the results I'm going to show.

19 This is for SA 508, which is the candidate
20 material for reactor vessel, and 316 Stainless, which
21 is the candidate material for the core barrel. 316 is
22 also what we're making the reactor vessel at the
23 Oregon State test facility out of.

24 And if you look at the SA 508 at 500
25 degrees C in air, there are four curves here going

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1 from one hour to four hours.

2 I realize you can't see these, but the
3 point of it is the emissivity over the entire
4 wavelength is between 0.8 to a little bit greater than
5 nine. And it ages very quickly.

6 There's not any, you know, definite aging
7 between one and four hours. Once you get to one hour,
8 it's there.

9 When you go to 1700 degrees in an air
10 environment, it's pretty much over 0.9 the whole way.
11 So, typically they use something like 0.84 in safety
12 calculations. So, that would work just fine for 508.

13 For stainless, however, it's different.
14 At 500 degrees, you're down at around 0.35. That's
15 basically bare metal.

16 But if you then take it up to 700 degrees
17 C in air which would be even a little high for the
18 core barrel, it goes up to about 0.5 and it ages very
19 quickly.

20 You notice there's no difference between
21 one and five hours here. So, within one hour of
22 exposure it had fully, you know, gotten as much
23 corrosion on it, oxidation on it as it was going to
24 get. So, this is somewhere between oxidized and bare
25 metal.

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1 This test just started - well, it's in the
2 design phase for the facility right now. It's also a
3 cooperative research agreement. So, it's the bypass
4 flow test.

5 And we'll be using the mixed index of
6 refraction coupled with particle image velocimetry to
7 actually give us flow measurements, you know, both in
8 the axial bypass channels and in the horizontal planes
9 between these.

10 So, the whole facility is going to be made
11 out of an acrylic and then using the P-cymene to make
12 it transparent.

13 There will also be pressure drop
14 measurements both in the bypass and in the coolant
15 channels.

16 It will be three columns, three hexagonal
17 columns, with 18 coolant channels. That's not the
18 coolant pattern we're actually going to use. There
19 are 18 coolant holes in each, and they'll be two
20 blocks high.

21 We will have three different shroud
22 configurations so we can move these blocks apart and
23 vary that gap diameter from something like one
24 millimeter up to five.

25 We can also separate these axially to open

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1 up those cross-flow gaps and make measurements as a
2 function of that gap thickness. We will also have one
3 of these machines so that we can do wedge-shaped gaps
4 at various angles.

5 And so, this test and some of the legacy
6 tests will give us the information that we need to get
7 the loss coefficients to be able to model the bypass
8 flow if we know the geometry or if we know an
9 idealized geometry. And that's all.

10 CHAIRMAN BLEY: Okay.

11 MR. KELLY: Are there any questions?

12 CHAIRMAN BLEY: No. Thank you. Very
13 slick.

14 MEMBER ARMIJO: I like that porosity
15 technique.

16 MR. KELLY: So, I guess the next speaker is
17 Stu. You're up.

18 CHAIRMAN BLEY: Okay.

19 MR. KELLY: Just let me get my memory stick
20 out of here.

21 CHAIRMAN BLEY: So, were you showing us
22 some things that weren't -

23 MR. KELLY: I had some backup slides, but
24 I didn't get any questions that made me to go them.

25 CHAIRMAN BLEY: We slipped up. I'm sorry.

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1 (Laughter.)

2 MR. KELLY: There's always next time.

3 CHAIRMAN BLEY: Next. Stu, your package
4 has your slides, and then it's got some more from
5 Hossein on MELCOR.

6 Is that all one presentation, Stu, or -

7 MR. RUBIN: I'm just going to be talking
8 about fuel performance and fuel fission product
9 release. I'm not sure I understand your question.

10 CHAIRMAN BLEY: Never mind. It's a
11 clerical mistake.

12 MR. RUBIN: All right. My name is Stu
13 Rubin. I'm the senior technical advisor in the Office
14 of Research. And this afternoon I'm going to be
15 talking about HTGR fuel performance and fuel fission
16 product release.

17 And as Dave Petti likes to say, this is
18 the sine qua non of the design. Without fuel and good
19 fuel performance, you really don't have a good design.

20 Okay. With regard to the objectives for
21 the presentation, there's really two major areas. The
22 first was at the request of the subcommittee, you
23 wanted to hear about an overview of the DOE's advanced
24 gas reactor fuel development qualification program.
25 And I'll be covering that at a fairly high level.

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1 The second part, I'll be talking about the
2 NRC'S HTGR fuels R&D that we're conducting to support
3 the NGNP licensing review.

4 And in this area, there are a number of
5 topics I'd like to cover. One of which is how the DOE
6 fuels program is supporting our work, our R&D work in
7 the fuels and accident modeling arena how we are
8 developing a code that was developed by INL called
9 PARFUME, it's a fuel performance code, and how we plan
10 to continue development and use it in regulatory
11 applications.

12 I'd like to go over in a little different
13 perspective, the fuels modeling that we are putting
14 into or have put into MELCOR for predicting fission
15 product release during normal operation accidents.

16 Also, activities that we are conducting to
17 increase the level of knowledge and know-how within
18 the staff in the fuels arena.

19 And, additionally, we have a small
20 cooperative research project that's intended to
21 develop additional information on the transport of
22 cesium through silicon carbide.

23 And finally, and we talked a little bit
24 about this, a guidance document that we developed
25 which will allow NRC inspectors to inspect fuel

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1 fabrication at a fuel fabrication facility for the
2 NGNP.

3 Now, for those who may not be totally
4 aware, there's obviously two kinds of fuel for HTGRs.
5 There's spherical fuel elements and prismatic fuel
6 elements as shown here.

7 The fabrication of either fuel type begins
8 the same with the fabrication of a very tiny spherical
9 fuel kernel which can be either uranium dioxide or
10 uranium oxycarbide fuel kernels.

11 The kernels then from a fabrication point
12 of view, are overcoated first with a porous puffer
13 layer made of pyrolytic carbon. Then there's a dense
14 pyrolytic carbon layer over that. A dense silicon
15 carbide layer. And then a dense pyrolytic carbon
16 layer overall.

17 And then in the manufacture of the
18 prismatic box, you take those finished particles. You
19 overcoat them with a graphite powder. And then you
20 press them into cylindrical compacts which are about
21 a half-inch long and two inches - excuse me. Half
22 inch in diameter and about two inches long.

23 And then the compacts are stacked and
24 inserted into fuel holes as was described earlier,
25 within the prismatic fuel block.

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1 For the pebble fuel, again the fuel
2 particles, typically UO2 particle kernels, are
3 overcoated again and then pressed isostatically into
4 a spherical fuel pebble which is the size of a tennis
5 ball.

6 Now, moving to the advanced gas reactor
7 fuel development qualification program, there are a
8 number of important objectives to this program. First
9 and foremost, to develop and qualify fuel that
10 supports the NGNP safety case.

11 And what I mean by that is fuel that meets
12 the fuel performance requirements and the fission
13 product retention requirements of the NGNP reactor at
14 its design operating conditions or service conditions
15 and the NGNP accident conditions.

16 Second, the program is intended to
17 reestablish within the US a capability to make high-
18 quality UCO-coated fuel particles at an industrial
19 scale. And they're pretty close to that.

20 Third, to demonstrate by irradiation
21 testing and accident condition testing, that the fuel
22 that they've made in fact meets the specified fuel
23 operational performance requirements in terms of
24 particle failure rates. And it also meets the
25 accident condition performance requirements in terms

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1 of particle failure rates.

2 Fourth is to increase the science and the
3 basic technical knowledge of the phenomena of the
4 effect, fuel product behavior and fission product
5 release so that the models that are developed will be
6 improved.

7 And finally, a lot of what we're talking
8 about here is the last item, to develop experimental
9 data that will be needed to model and validate the
10 codes that will predict fuel failure and also predict
11 fission product release in the safety analysis.

12 Now, this diagram all in one place talks
13 about the major program elements in the AGR fuel
14 development qualification program.

15 The first element at the top is fuel
16 fabrication, as I mentioned, or fuel supply
17 development. And the objectives of this element is to
18 develop a fuel particle fabrication process that meets
19 the fuel quality and fuel performance requirements
20 demanded of the NGNP safety case.

21 And the strategy that's being implemented
22 by DOE for this element is to first come up with a
23 process that meets the design specs for the particle,
24 but simulates and follows the German particle coating
25 process to the extent possible to end up with the same

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1 properties, coating properties, and ultimately the
2 same performance that the Germans saw in their
3 particles, which was a very high level of performance
4 in the reactors in Germany.

5 Next element, again, is fuel irradiation.
6 That's going to be conducted at the design conditions.
7 And in some case, in margin testing beyond the design
8 conditions.

9 And the objectives of this element are
10 first to develop data on irradiation fuel performance
11 of the particles to support fabrication by feeding
12 back the experience of how the particles perform into
13 the fabrication process.

14 Also, obviously, they'll be part of the
15 fuel qualification program, and also developing the
16 fabrication process, and also to support the
17 development of data for developing models and
18 validating codes to use in the safety analysis.

19 Next element is post-irradiation
20 examination and accident condition testing. And here,
21 the objective is to again obtain data on fuel
22 performance at the NGNP's design operating conditions,
23 and also in the accident conditions, by actually
24 looking at the fuel and taking measurements of various
25 sorts which I'll get into.

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1 Next element is fuel behavior modeling or
2 fuel performance modeling. And what we're talking
3 about here is actual particle failure prediction
4 modeling.

5 And what it does is in its objective, is
6 to model the structural and thermal and physiochemical
7 behavior of the processes within the coated fuel
8 particle with the objective of being able to actually
9 predict when a particle will fail.

10 And the final element is the development
11 of data to support fission product transport modeling
12 for the safety analysis and the development of
13 accident source terms. This needs to be done for both
14 normal operations, as well as for accident conditions.

15 And I would mention that DOE and INL are
16 also partnering with Oak Ridge National Laboratory,
17 B&W Lynchburg and General Atomics as participants in
18 this program.

19 Now, what this slide represents all in one
20 place is an overview of the AGR fuel program
21 activities here in one slide. The program consists of
22 eight different fuel irradiations; AGR 1 through AGR
23 8, which is shown in the orange boxes.

24 Following each irradiation is fuel safety
25 testing which is conducted along with post-irradiation

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1 examinations. And these are shown in the red boxes.

2 Each of the eight irradiations has a
3 different purpose. And these are shown in the yellow
4 boxes. And I'd quickly like to go through each of
5 those.

6 AGR 1 involves fuel compacts with coated
7 fuel particles with UCO kernels. And the coating
8 layers were made in a laboratory scale using a German-
9 type coating process.

10 The fundamental purpose INL would say for
11 this irradiation was really to check out the
12 irradiation capsule and train design which is going to
13 be used in the later irradiations for fuel
14 qualification, but also they included particles with
15 slight variance on the coatings to try to see if there
16 were any differences in performance to optimize the
17 one they would pick for the actual production fuel.

18 Now, AGR 2 is what could be called a fuel
19 performance demonstration irradiation. It involves a
20 UCO kernel, as well as UO2 fuel particles made on the
21 industrial scale here in the US with industrial scale
22 coater. But it also involves particles - excuse me -
23 yes, UO2 fuel particles that were made by CEA in
24 France, as well as UO2 particles that were made by
25 PBMR in South Africa. So, those are actually being

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1 irradiated as we speak.

2 Now, the purpose of AGR 3 and 4 is to
3 obtain data to develop the fission product diffusion
4 coefficients in the various elements or constituents
5 of the fuel, the coatings, the kernel, the matrix, et
6 cetera.

7 And to do this, they - it's got to involve
8 compacts with fuel that is designed to fail. And
9 these particles will put off a well-defined, known
10 quantity of fission products so they can then use that
11 knowledge in analyzing what the diffusion coefficients
12 would need to be, let's say, in the matrix to - once
13 they see what the fission product concentrations are
14 at the end of the irradiation via PIE.

15 Now, AGR 5 and 6, these are the formal
16 fuel qualification tests. What these tests are, and
17 there are two trains, 5 and 6, simply because they
18 need enough particles to meet the confidence level on
19 the statistic on particle failure rates when the
20 irradiation is over.

21 And they will use production scale methods
22 for making the kernels, the coatings and the compacts
23 with the prototype fuel in it to the specifications.
24 And then they will run it at the design conditions of
25 the NGNP, the design service conditions in terms of,

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1 let's say, packing fraction, temperature burn-up, fast
2 fluence and the like.

3 And from that at the end of the test, they
4 will have a count on how many particles have failed
5 out of the three hundred to 400,000 that are going to
6 be irradiated.

7 And through statistics, they'll be able to
8 infer what the design level failure rate would have
9 been given a certain number.

10 Hopefully they'll have no failure rates,
11 but they'll be able to check it. And that will be the
12 basis for qualifying - saying that the fuel made to
13 this spec on an industrial scale with these processes,
14 give this level of fuel performance.

15 MEMBER ARMIJO: Now, that's under normal
16 operating conditions, right?

17 MR. RUBIN: This is fuel qualification.

18 But the second piece to that then is to
19 take those irradiated compacts and put them into an
20 autoclave and heat them up in an accident condition
21 simulation test. And then get data on particle
22 failure rates under the accident condition.

23 So, that's the second part of the fuel
24 qualification. And it's both the normal operation, as
25 well as the accident condition testing for fuel

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1 qualification.

2 Now, the purpose of 7 and 8 is to obtain
3 data to validate the fission product transport codes,
4 as well as the particle failure rate codes, by running
5 experiment to actually fail particles intentionally.

6 And so, you would have data to then see if
7 your codes would be able to predict the number of
8 particles that failed and when they failed.

9 And, also, to have data on the actual
10 fission product releases to actually validate the
11 codes that account for both failed and intact
12 particles in their analysis, as does the code they
13 developed, PARFUME.

14 Now, the last piece is something called
15 fission product transport and retention. These are
16 intended to be out of pile. They're designed to
17 obtain data for developing and validating the models
18 for fission product transport outside the fuel form
19 that is within the helium pressure boundary, things
20 like lift-off, plate-out, absorption and the like, and
21 also tests to develop data for fission product
22 transport in the reactor building. So, this is part
23 of the fuel program as well.

24 Now, where are we in terms of the status
25 of this testing, this work? This slide kind of gives

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1 you the status.

2 AGR 1 irradiation, that was completed in
3 November of 2009. None of the particles out of the
4 more than 300,000 that were irradiated were found to
5 have failed.

6 The peak time average fuel temperature for
7 this irradiation was at 1250 degrees C. Fast fluence
8 was four times ten to the 25th neutrons per meter
9 squared. And the burn-up was almost 20 percent of
10 FIMA. And about 35 percent actually achieved the
11 burn-up goal of 18 percent FIMA.

12 The PIEs, this fuel has been taken out of
13 the AGR reactor and is now undergoing PIE. And
14 they'll do things like measure fission product
15 releases by examining the fission product content of
16 the holders and of the matrix material.

17 Again, we're looking at the silicon
18 carbide condition analyzing fission product, the
19 inventories and taking a look at the micro structures
20 of kernel and the conditions of coatings and so forth.

21 MEMBER CORRADINI: There's one thing you
22 said there.

23 So, the 20 percent is 20 percent of the
24 fissile inventory?

25 MR. RUBIN: Fraction of initial metal atoms

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1 that were fissioned.

2 MEMBER CORRADINI: Okay.

3 MR. PETTI: A hundred percent U235
4 consumption.

5 MEMBER CORRADINI: Oh.

6 MR. PETTI: Yes.

7 MEMBER CORRADINI: So, you burned out -

8 MR. PETTI: You've burned it out. We're on
9 fumes, yes.

10 MEMBER CORRADINI: Okay. That's what I
11 didn't understand. Okay. Thank you.

12 MR. RUBIN: Okay. You know, later this
13 year they're getting ready for their accident heat-up
14 testing. They've kind of gone through a shakedown.
15 And they plan to actually start that heat-up testing
16 on the AGR 1 irradiated fuel by the end of the year,
17 as I understand it.

18 AGR 2, that's currently underway. And the
19 detailed planning is underway as well for the follow-
20 on PIE work and safety testing.

21 As far as AGR 3 and 4, that's really the
22 heart of the fission product transport data
23 acquisition work. The fabrication of that fuel is
24 underway and the design of the capsules and the trains
25 are almost complete. And the irradiations will begin

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1 as soon as AGR 2 is finished.

2 Turns out that because of the feedback
3 that they expect to get from these irradiations to
4 come up with a final design for the fuel qualification
5 tests for 5 and 6, they're not ready to really get
6 started with the fuel design work just yet until they
7 see what the current fuel performance looks like from
8 PIE, et cetera.

9 When you look at the schedule which is not
10 shown here, it's a very, very aggressive schedule.
11 And it needs to be so because it turns out that the
12 fuel is on a critical path of the entire NGNP R&D
13 program.

14 I'd like to talk a little bit in the way
15 of segue into our - NRC's program about a code, a fuel
16 performance code, a particle failure prediction code
17 that I know has been developing for probably ten years
18 by now. And it has been developed to support the AGR
19 program to help them with their design and development
20 and testing prediction activities.

21 They call the code PARFUME, and that
22 stands for particle fuel model. And one would
23 consider it really a state-of-the-art TRISO-coated
24 particle fuel performance analysis code.

25 What it does is it calculates the failure

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1 probability of coated particles within the fuel
2 element. And it also calculates the fission product
3 release from the fuel element for both normal
4 operation, as well as accident conditions, by
5 accounting for both failed particles, as well as
6 intact particles within the fuel form.

7 It models all the important phenomena, I
8 would say, that can lead to particle failure, and
9 these include phenomena such as internal pressure
10 within the coated particles, cracking or de-bonding of
11 the pyrolytic carbon layer away from the silicon
12 carbide layer which can cause stress risers in the
13 silicon carbide layer, migration of the fuel kernel
14 toward the particle coatings, increased local coating
15 stresses due to amount of roundness of the particle
16 and silicon carbide layer thinning caused by fission
17 product interactions.

18 It also handles the statistical variations
19 in particle coating properties, including geometrical
20 properties like silicon carbide layer of thickness, as
21 well as mechanical physical properties.

22 So, because particles are made with
23 variations from one to the next, the coat is able to
24 take that statistical distribution from manufacturing
25 spec and put it into code, and that's factored into

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1 the statistics of particle probability.

2 CHAIRMAN BLEY: Stu, I'm just wondering
3 what kind of documentation there is on this to look
4 at.

5 When I look at the photographs I see and
6 the micrographs blown up like the one you showed on
7 Page 3, these things seem extremely irregular the way
8 they're grown. And modeling this seems like it would
9 be pretty darn tough to do, and do well.

10 MR. RUBIN: And this is at a 30,000 foot
11 level. I had another slide to describe what
12 documentation exists.

13 There is a theory manual for PARFUME that
14 we have received. There is a users manual that we
15 have received.

16 We have the code. We have runs. We have
17 the reference documents that the code used in
18 developing its models and the data that was used and
19 currently in the models.

20 So, there is a lot of data really - or
21 reference material really in large part driven by our
22 interest in acquiring the code.

23 So, I have a slide that I can make
24 available to you that we have.

25 CHAIRMAN BLEY: Yes, I'd like that.

1 MR. RUBIN: We have it in-house.

2 CHAIRMAN BLEY: They may ask to see some of
3 those if you have them.

4 MR. RUBIN: And we also have, and I'll
5 mention this, we did receive training, a five-day
6 training course on PARFUME, which got into a lot of
7 detail on the coating and the numerical methods, et
8 cetera, that are used to solve the base of the
9 equations in there.

10 MEMBER CORRADINI: But to get to his
11 original question --

12 MR. RUBIN: Yes.

13 MEMBER CORRADINI: -- I'm not sure if it
14 falls under another part of INL than the salmon-
15 shirted gentlemen over there.

16 (Laughter.)

17 MEMBER CORRADINI: Peach. Salmon.

18 What I guess Dennis was asking, and I was
19 wondering about the answer, so there is a distribution
20 function to how these things are made, right? Because
21 there's a -- I would say there's a recipe.

22 You go make the recipe and then you
23 inspect on some sort of statistical basis, what comes
24 out.

25 So, this is essentially a deterministic

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1 model that then has what I'll call a distribution of
2 what could be the geometry?

3 I'm trying to understand the probability
4 part of this.

5 MR. PETTI: What the code does is based on
6 the QC data, you get a mean and a standard deviation
7 for the population -

8 MEMBER CORRADINI: Okay.

9 MR. PETTI: -- for 30, 40 attributes. We
10 measure all sorts of stuff. That's all in the code.
11 The code then does - can do three different things,
12 but it basically can do a Monte Carlo sampling, sort
13 of what it does.

14 MEMBER CORRADINI: But it's a deterministic
15 calculation with essentially a distribution function
16 of all the key attributes.

17 MR. PETTI: Yes.

18 MEMBER CORRADINI: Okay.

19 MR. RUBIN: And there's a finite element
20 model.

21 MR. PETTI: Yes, there's a finite element
22 model and -

23 MR. RUBIN: So, you could have, you know,
24 bends in the coatings, and the finite element will
25 model that and pick up the stress risers associated

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1 with those bends.

2 MEMBER CORRADINI: Okay. But to the extent
3 that I want to make sure I understand it is the reason
4 you say the probabilistic is since I had the
5 distribution function, that would affect how it ends
6 up the peak pressures, thinning, diffusion, dah-dah,
7 dah-dah.

8 MR. PETTI: Right. And then we use a
9 Weibull failure, and that's how you get a failure
10 probability.

11 MEMBER ARMIJO: Do you have a list of all
12 the important attributes that you actually would
13 measure in your fuel fabrication facility -

14 MR. RUBIN: Yes.

15 MEMBER ARMIJO: -- from the buffer
16 thickness to the silicon carbide thickness?

17 MR. RUBIN: There are 77 specifications
18 that were measured.

19 MEMBER ARMIJO: And then you'll have a
20 process for measuring those?

21 MR. RUBIN: Yes.

22 MEMBER ARMIJO: Some experimental quality
23 control process?

24 MR. RUBIN: Yes, yes. In fact, my very
25 last slide is -

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1 MEMBER ARMIJO: I'd really be interested in
2 that because I come from a, you know, from Light Water
3 Reactor fuel background. And, literally, our smallest
4 thing we have to worry about is a fuel pellet.

5 Okay. But your fuel pellet and your
6 cladding, you know, these tiny, tiny, little things in
7 the hundreds and hundreds of thousands -

8 MR. PETTI: We have the means to measure
9 all of that.

10 MEMBER ARMIJO: At some point in the
11 future, Mr. Chairman, I'd like to get a manufacturing
12 presentation on how this is done and -

13 CHAIRMAN BLEY: And I think there's a
14 technical report associated with that kind of thing.

15 MR. RUBIN: Yes, we have a number of
16 technical reports, but I'm sure we could make it
17 available.

18 MEMBER ARMIJO: To me, a big concern I have
19 is this obviously pretty forgiving process, but batch-
20 to-batch variability on -

21 MR. PETTI: It's actually not as large as
22 you think, but we're actually tackling some of those
23 issues right now.

24 MEMBER ARMIJO: Okay. At some point, you
25 know, we can get that in to the Committee.

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1 MR. RUBIN: Yes, one of the goals of the
2 manufacturing process is to basically meet the spec
3 every time so you don't have any kind of surprises
4 coming your way.

5 MR. PETTI: And Stu doesn't - I don't know
6 if he has any slides on this, but what we're doing
7 today in 2011 is just a hell of a lot better than what
8 was done historically in 1975.

9 Okay. It's night and day. For those that
10 are on the NEAC side, you'll hear about it in a few
11 weeks.

12 But basically measurement science and our
13 ability to control the process is just much better
14 than it was in 1975. It's a real success story, I
15 think.

16 CHAIRMAN BLEY: Yes, we would be very
17 interested in that.

18 MR. RUBIN: My last slide, the last line is
19 a good document for you to read on the area of your
20 interest.

21 This next slide really covers the
22 continuity equations in PARFUME. And you can see it
23 covers thermal analysis, the stress-strain analysis,
24 fission product transport analysis in the particles
25 themselves, as well as within the fuel form whether it

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1 be a compact or a pebble matrix. And it also handles
2 intact and failed particles within there as sources of
3 release within the fuel form. And then release from
4 the element itself.

5 The reason I put up this slide in two
6 colors is that MELCOR has these very same models as
7 the ones shown in black. Where MELCOR and PARFUME
8 differ is in what's shown in red.

9 PARFUME actually does the stress-strain
10 calculation and calculates the peak stresses, and then
11 compares it to a Weibull failure probability curve as
12 a function of stress to come up with a failure
13 probability for particles that are at that stress.

14 PARFUME doesn't do that. What we're doing
15 - excuse me. MELCOR doesn't do that. With MELCOR,
16 we're putting in an input-defined failure rate in the
17 form of a failure fraction curve or failure fraction
18 response service, or we could put in something
19 different.

20 The main reason is it's a very time-
21 consuming type process to do this and it's just not
22 suitable to have this kind of a failure predictive
23 model in MELCOR.

24 MEMBER REMPE: And the impact will be, I
25 mean, if you compare the two, what we'll get?

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1 MR. RUBIN: Yes, I'll talk about that -

2 MEMBER REMPE: I'm sorry. Okay.

3 MR. RUBIN: -- as we go.

4 This next slide is really how are we going
5 to continue to work really in parallel with INL on
6 future development of the code? And what this
7 involves, really, is summarized in this slide.

8 The slide indicates what kind of
9 parameters we target for updating or evaluating, what
10 the source of the data is, when it's available and
11 when it's going to - the effort's going to be
12 completed. And as you can see, the entire effort is
13 really tied to the AGR irradiation test PIE programs.

14 The first row in the AGR program, I didn't
15 mention this before, is to develop data on the
16 mechanical and physical and physiochemical properties
17 of the fuel constituents. The silicon carbide layer,
18 the kernel, et cetera.

19 And these properties will make the code
20 more specific to the actual materials and the
21 properties of materials of the particles that DOE is
22 making rather than taking data from, let's say, the
23 German coating process experience and so forth.

24 So, with those updates, the ability to
25 predict stresses and strains and failures in a code

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1 will be more precise and accurate to the actual fuel
2 that it's trying to calculate failures for.

3 And then beyond that there's a number of
4 benchmarks that we plan to do pre-test and post-test
5 predictions of the different fuel irradiations, AGR 1
6 and 2.

7 By the time you get to AGR 3 and 4, you're
8 actually developing data for modeling of the diffusion
9 coefficients for the fission product release
10 calculations.

11 And there, the post-test prediction or
12 benchmark would actually rerun the calculation for the
13 actual test conditions with the new diffusion
14 coefficients to see how close you get to predicting
15 the actual releases that were measured by the PIEs, et
16 cetera, in the post-irradiation, also post-accident
17 condition testing.

18 And then there is the AGR 5 and 6 which,
19 again, will be the - used to do qualification testing.
20 And then 7 and 8 is validation testing where they
21 actually go into failed particles and you'll be able
22 to see if you can predict those particle failure rates
23 with PARFUME.

24 Now, with regard to MELCOR, we're not
25 going to be able to predict those failure rates.

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1 We're going to have failure fraction curves or
2 response surfaces.

3 What this test will do, it will allow us
4 to see if those failure fraction prediction curves are
5 wildly conservative or pretty good for the purpose we
6 had set out to have an input database rather than a
7 model to actually predict the failure rate. So, we
8 use it for MELCOR as well.

9 MEMBER ARMIJO: Stu, before you go on, just
10 to make sure I understand what constitutes failure in
11 a particle, is it simply a through-wall crack through
12 the silicon carbide layer? Is that -

13 MR. RUBIN: It's the failure of all layers.
14 It's the failure of all layers. You start with a
15 particle that has all the layers, silicon carbide, the
16 two pyrolytic carbon layers perfectly intact, and then
17 a failure of a particle which is observed by a large
18 increase in gaseous releases. You know you failed all
19 the layers at that point.

20 Now, the layers don't disappear. There's
21 a crack that allows that gaseous release. And then of
22 course there is the metallic release that will come
23 through that crack as well.

24 The way that codes typically model that
25 failure is at that point of failure, the assumption is

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1 the layers just disappear and you now have a kernel.
2 And the kernel now, and the releases from the kernel
3 into the matrix are what you're now modeling in terms
4 of integrated release from that pebble or compact.

5 MEMBER ARMIJO: So, if you have a failed
6 silicon carbide layer, but the buffer and the
7 pyrolytic graphite layers over a particle are still
8 okay -

9 MR. RUBIN: Yes.

10 MEMBER ARMIJO: -- you won't have much
11 release, or you will?

12 MR. RUBIN: Well, then you have a variant
13 on - I wouldn't call it particle failure. It would be
14 a failure or a defect in the silicon carbide layer.

15 And there, the modeling is the kernel and
16 the two pyrolytic carbon layer, but no credit for the
17 silicon carbide layer.

18 In fact, if you look at the specs for
19 manufacture, there is a spec on defective silicon
20 carbide layer from manufacture.

21 So, that fraction of particles should be
22 built into your code for fission product, core-wide
23 fission product release.

24 MEMBER ARMIJO: Well, I had the
25 misconception that the silicon carbide layer was

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1 effectively the cladding.

2 And if you lose that -

3 MR. RUBIN: It's the most important layer.

4 MEMBER ARMIJO: It is the most important
5 one still.

6 MR. RUBIN: Yes.

7 MEMBER ARMIJO: And so, failure of that
8 silicon carbide layer would constitute near failure of
9 the whole particle -

10 MR. RUBIN: Well -

11 MEMBER ARMIJO: -- even if the others were
12 okay?

13 MR. RUBIN: If you look at the categories
14 of particles, you have intact particles where all the
15 layers are intact, you have particles that can be
16 defective for manufacture where the silicon carbide
17 layer is missing or cracked, and that has to be
18 modeled as defective from Day One -

19 MEMBER ARMIJO: Okay.

20 MR. RUBIN: -- and then you have particles
21 that fail under irradiation or accident conditions,
22 and those failures are essentially failures of all the
23 layers.

24 We don't have a model that says, oh, only
25 the silicon carbide layer failed at this point. It's

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1 all the layers fail at that point.

2 The reason is that it may happen, and I
3 don't know that I've seen it from PIEs, but we'd have
4 no real way of detecting that it happened.

5 MEMBER ARMIJO: You probably can't
6 distinguish, you know, something is coming -

7 MR. RUBIN: You can't distinguish because
8 there's no -

9 MEMBER ARMIJO: Fission products are coming
10 out.

11 MR. RUBIN: -- there's no fission gases
12 released to tell you that that happened.

13 MR. PETTI: That's why we check. That's
14 why we check in PIE. We check how much cesium is
15 outside of the silicon carbide.

16 We take these compacts and we de-
17 consolidate them. And we measure the cesium content
18 in the fuel matrix. And if you had defective
19 particles - defective silicon carbide, the cesium will
20 get through. The noble gases will not be measurable
21 online because pyrocarbon holds in the noble gases.

22 And so when you look, for instance, at the
23 entire German experience, there was no silicon carbide
24 failure under irradiation.

25 What was measured in the PIEs was

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1 completely consistent with what was measured in the QC
2 that you would expect a certain number of defects.
3 And they looked at it and statistically it all, you
4 know, made sense.

5 And, again, most of the - the silicon
6 carbide's in compression. So, as a ceramic, that's
7 the way it's designed. It's not supposed to be
8 intention if it's intention than you run the risk of
9 failure.

10 MR. RUBIN: But interestingly if you look
11 at the signature of, let's say, krypton release when
12 the whole particle fails, you don't get a signature
13 necessarily that is all the layers disappeared. You
14 get something less than that.

15 Okay. But the modeling for reason of
16 conservatism, just assumes that all the layers are
17 gone at that point.

18 Okay. What are we going to do with
19 PARFUME? We're not going to use PARFUME as part of
20 our evaluation model that Joe Kelly talked about.

21 It's a very powerful tool. But because of
22 the long run times, it's just impractical to use it
23 for the hundred or more nodes of PARFUME that MELCOR
24 would need to do a calculation of particle failure
25 rate at any given time.

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1 What we do plan to do with PARFUME is to
2 evaluate the applicant's failure prediction model that
3 they will be using in their safety analysis codes.

4 We also will use it as DOE, and INL use
5 it, to do sensitivity studies to assess the affects of
6 variations in the geometry and the properties, in the
7 irradiation conditions and its affect on failure
8 probability.

9 We also plan to use it to help benchmark
10 MELCOR. Because, as I said, both codes really have
11 the same fission product transport model in them, we
12 can use one code to benchmark against the other in a
13 code-to-code type benchmark not only of kernels, but
14 also of actual particles in compacts by modeling the
15 actual experiment. And I'll talk a little more about
16 that later.

17 It's also a very good tool for training
18 the staff on the underlying principles of particle
19 behavior, failure and fission product release. And
20 we'll be using it for that.

21 And we can use it to assess the effects of
22 perhaps some testing, startup and safety testing that
23 may be envisioned for NGNP to satisfy ourselves that
24 there's no harm to be done in doing these tests in
25 terms of greater performance of the fuel in the core

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1 during operations.

2 And as a tool to get insights into what
3 potential administrative limits or - on the fuel
4 temperature or on the burn-up that may have on the
5 source term.

6 As compensatory measures, there's some
7 thought that we might need to have compensatory
8 measures to have some limits on the conditions of the
9 core, temperature burn-up, et cetera, to assure that
10 we're well within the safety analysis. And PARFUME
11 will give us some insight as to what those benefits
12 could be.

13 Just a quick slide that talks a little bit
14 about the differences in fission product transport
15 modeling between prismatic fuel elements and pebble
16 fuel elements. For the most part, they are identical.

17 I would point out the asterisked item
18 where I speak about diffusion through each of the
19 layer of coatings. The asterisk item would say if you
20 have failed particle, you don't actually model or give
21 credit for the diffusion or holdup of fission product
22 transport in those failed particles through the
23 layers.

24 Some of the differences that come up is
25 there's a gap between the outside of the compact and

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1 the inside of the graphite block in the fuel hole.
2 And that little gap provides some additional
3 resistance. And there is a solid-to-gas and gas-to-
4 solid transport process. And that needs to be
5 modeled.

6 And of course there's the whole graphite
7 block in a prismatic block that needs to be modeled in
8 terms of fission product transport in a prismatic fuel
9 element that doesn't get modeled in a pebble fuel
10 element. For the most part, they're really the same
11 modeling needs.

12 Okay. What this slide does is it takes
13 the earlier slide with PARFUME and it really talks
14 about, well, what can we use out of the AGR tests in
15 terms of actual experimental data to help us benchmark
16 not only PARFUME, but MELCOR in terms of fission
17 product transport. This would be Code 2 data-type
18 benchmarks.

19 And really, all of the AGR experiments can
20 be used for that purpose. Because at the end of the
21 day, we will have a well-defined geometry, well-
22 defined fuel, well-defined irradiation conditions and
23 very good data on fission product release during the
24 irradiation not only in terms of gaseous release
25 online measurements, but also in terms of PIEs of

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1 actual fission product inventories outside the fuel
2 particles, outside the fuel compacts.

3 And we can take that data to then see if
4 we could predict that with not only PARFUME, but also
5 with MELCOR.

6 So, the thought here is that we will use
7 all of these irradiations to actually do code-to-data
8 benchmarks from MELCOR.

9 The difference lies in the actual code or
10 fuel particle performance aspect of these tests where
11 particles fail.

12 Because MELCOR doesn't have a fuel failure
13 reduction model other than that response service, we
14 will use that aspect of these tests where particles do
15 fail, in some cases, by design in 7 and 8, to
16 benchmark PARFUME to see if its prediction abilities
17 for predicting particle failure rates is good or
18 otherwise.

19 And for MELCOR, we can use to see if
20 whether or not that response service is doing a good
21 job for how many particles have failed under the
22 conditions that the test was run at.

23 So, it's a very simple geometry, but it is
24 what I would call a unit cell. It is a stack of
25 compacts with particles in it. You have coolant flow

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1 around it and ability to monitor fission product
2 releases and distributions very well.

3 Okay. A question came up by the
4 subcommittee, well, how are the lessons learned and
5 results from the AGR program providing insights or
6 help to the NRC's activities?

7 And this slide is intended to list a
8 number of areas where DOE's AGR program has given us
9 benefit.

10 For example, that first item we had a
11 number of questions in the early going on what was
12 important to consider in modeling fission product
13 release from, let's say, prismatic fuel design and
14 what was not so important.

15 Things that came up like do you need to
16 model thermal diffusion as a separate kind of
17 diffusion category in addition to Fickian diffusion
18 which is simply concentration-based?

19 And there's evidence that there are some
20 conditions where you could have a separate thermal
21 diffusion affect.

22 And in discussing it with INL, we kind of
23 were agreed that it may not be considered that it will
24 be effectively part of the effective diffusion
25 coefficient in a Fickian-type diffusion approach.

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1 How to model the gap between the outer
2 surface of the compact and the inner surface of the
3 fuel hole, how to model that fission product barrier,
4 if you will, we got some ideas on that.

5 A number of questions came up on
6 temperature profiles in the particle, in the compact.
7 And it was their experience with PARFUME, our
8 experience with the way they - the data they got from
9 that test was very helpful. So, I would say that was
10 a very big success for us in obtaining help from them
11 on that.

12 Obviously, the AGR fuel irradiation
13 fission product release data that I talked about
14 before, that's starting to come to us now and will
15 continue to come to us and will benefit us in
16 benchmarking MELCOR.

17 We already got from them PARFUME's
18 prediction from the IAEA CRP-6 benchmarks. These were
19 code-to-code. In some cases, code-to-data. And so
20 it's - and I think that Hossein talked about his
21 initial prediction using the MELCOR model against the
22 PARFUME or INL results. They were very good results.

23 One could argue that perhaps neither is
24 accurate, but we have another code-to-code database
25 that they provided to us, and there are other things

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1 listed there.

2 So, I would say this is a big area of
3 success. I view it as kind of a unique opportunity
4 for research to probe and poke a quasi designer
5 organization on how they model important phenomena in
6 the absence of having a real design organization
7 that's made an application. So, this is good for us.

8 I'd like to turn now to a small project we
9 had with the University of Wisconsin and Todd Allen.
10 We had a cooperative agreement with them to improve
11 our understanding of fission product cesium transport
12 in silicon carbide.

13 The goal there was to get a better
14 understanding of what are the key properties or
15 characteristics of silicon carbide that have a
16 controlling influence on the rate of cesium transport
17 in silicon carbide simply because everyone is using
18 for now at least, the old German data on their
19 diffusion rates and claiming that while it applies
20 equally to us, we want to see if there's any basis for
21 saying that that would be a good bet other than just
22 kind of looking at the micro structure and looking at
23 how the grain size and orientation of grains look and
24 say, yes, I guess you could reference that data.

25 So, this was intended to give us some

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1 deeper understanding of the processes of cesium
2 transport in silicon carbide.

3 Basically, the scope involved bulk
4 diffusion and grain boundary diffusion. We want to
5 look at the effects of micro structure, as well as
6 temperature.

7 And the investigation involved both
8 molecular modeling methods, multi-scale methods,
9 atomic at the grain level, and then at the entire -
10 level of the entire composite.

11 And it also involved measurements of
12 actual cesium diffusion on irradiated silicon carbide-
13 wide diffusion couples.

14 Now, in terms of what came out of this
15 work, that's shown on this slide, basically. In
16 fitting the diffusion couple data to analytical
17 models, it yielded a bulk diffusion coefficient of
18 about ten to the minus 18 atoms per meter squared per
19 second at 1200, which is really in a good range for
20 what is typically measured.

21 The atomic level calculations indicated a
22 bulk diffusion involving what they would call, and I
23 don't totally understand this, charged defect clusters
24 having an energy, activation energy of 5.5 eV. And
25 those are shown as Lines 2 and 3, that kind of

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1 cluster, on this slide.

2 What they found, though, that the
3 predicted solubility of cesium and silicon carbide
4 was, by their calculations, very low and was not
5 consistent with measured release data or their
6 diffusion couple experiments.

7 And they could not understand that, and so
8 they postulate or hypothesize that there were other
9 more complex mechanisms. And the proposal was that
10 there could be some impurities that were acting to
11 affect the solubility and diffusion.

12 Well, there could be some affect of a
13 neutron irradiation field in terms of creating
14 vacancies or defects in the lattice that would speed
15 up the process.

16 And so, they proposed a follow-on research
17 to look at those effects. And we have approved the
18 latter to investigate the affect of neutron
19 irradiation in enhancing the absorption of cesium and
20 the diffusion of cesium through the creation of
21 defects in the lattice.

22 It is a particularly important question
23 because it turns out that historically the data on
24 diffusion coefficients have been taken from post-
25 irradiation theta testing after irradiation is over.

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1 And so, the hypothesis would say if proven
2 true, that that might not be a conservative way to get
3 to diffusion coefficients.

4 MEMBER ARMIJO: You want to be generating
5 your -

6 MR. RUBIN: You want to be generating -

7 MEMBER ARMIJO: -- at the same time.

8 MR. RUBIN: At the same time. So, that's
9 why we're interested in seeing how that may turn out.
10 We're not sure.

11 Okay. The last item is basically this
12 question of oversight and inspection of fuel
13 fabrication facilities.

14 We all would agree that how you make the
15 fuel and making it consistently to spec is the key to
16 fuel performance in the reactor.

17 And so, the idea was let's ask the people
18 who have all this experience in developing these
19 methods for DOE and that program, to write up a -
20 what's important and how you would go about examining
21 whether or not those important characteristics and
22 processes are being conducted within - in the right
23 way.

24 So, they turned around and took everything
25 that they had learned, and this is Oak Ridge in the

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1 lab scale work to develop kernels and coatings and
2 compacts, and asked them could you please put together
3 this document that describes what's everything that's
4 important and how would you go about inspecting for
5 and sampling of key important areas?

6 And they did that, an exceptionally good
7 job. It's a tutorial on the one hand, but it's also
8 very insightful on the details of how to go about
9 doing this.

10 And it was captured in the documents shown
11 at the bottom. If you have an interest in really
12 understanding how they do quality control and what are
13 the key parameters, as Dave mentioned, this document
14 covers it all.

15 Now, it would be accurate to say it does
16 represent a picture of a lab scale operation, but many
17 of the processes are scaled up for industrial scale.
18 But most of, I would like to think, of what's
19 important is still going to be retained even at the
20 scale-up level.

21 Okay. And that kind of covers everything
22 I wanted to cover.

23 MEMBER ARMIJO: I'd like to get a copy of
24 that report.

25 MR. RUBIN: Yes, it's very good.

1 CONSULTANT KRESS: Stu, do you envision NRC
2 actually showing any oversight over the fabrication
3 facility at all?

4 MR. RUBIN: Well, I -

5 CONSULTANT KRESS: You don't know.

6 MR. RUBIN: We have people go out to Light
7 Water Reactor inspection facilities. And the areas of
8 interest are contamination control, criticality
9 control and things of that sort.

10 Here, the interest is in are they actually
11 manufacturing it to the specs in a consistent way?
12 It's a little different, and it's a very important
13 difference.

14 CONSULTANT KRESS: I was assuming you would
15 have a way to when a batch of fuel is made --

16 MR. RUBIN: Yes.

17 CONSULTANT KRESS: -- and you're getting
18 ready to load it somewhere, you would take samples of
19 that.

20 MR. RUBIN: Well, they're doing that in
21 realtime as part of the manufacturing process. And we
22 would just be there as observers to see how they're
23 doing it.

24 CONSULTANT KRESS: Oh, you could make use
25 of their sampling -

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1 MR. RUBIN: Yes.

2 CONSULTANT KRESS: -- and testing?

3 MR. RUBIN: Absolutely.

4 CONSULTANT KRESS: But doesn't it have to
5 be tested in pile?

6 MR. RUBIN: Oh, well, the concept of fuel
7 qualification is that you develop and fix a
8 manufacturing methodology.

9 You say I now have a method that
10 consistently meets my specs and this is how I do it in
11 terms of equipment and procedures and specifications
12 and characterization and QA statistics and so forth,
13 and this is the entire package of how I did it. It's
14 the cookbook.

15 And now I'm going to test the fuel and in
16 the irradiation accident condition simulation to see
17 if the performance is what it needs to be.

18 And then if it turns out to be okay, I
19 have qualified my fuel that I made this way, and it
20 will perform under normal operation at the design
21 level of service conditions and at the accident
22 conditions and that's fundamentally my qualification.

23 Now, I got to start making fuel for the
24 plant that needs to go into operation. And the
25 presumption is that the fabrication facility will then

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1 follow that cookbook in exactly the same way and end
2 up with the same quality of fuel and will perform in
3 the same way, but there is no argument today that says
4 I still need to routinely irradiation test the fuel
5 that comes out.

6 CONSULTANT KRESS: I was assuming -

7 MR. RUBIN: However, there is one
8 distinction. The qualification that Dave's program is
9 talking about is an industrial scale, but it's not a
10 fuel fabrication facility yet.

11 I think Dave would say I need to turn this
12 all over to my fabrication plant and they need to have
13 a run of production fuel, and they need to go through
14 it, and then they need to have some small sampling
15 that goes into an irradiation accident condition
16 testing to show that they themselves have had the same
17 result with their fuel fabrication facility as Dave
18 and his people got at the end of his fuel
19 qualification program.

20 MR. PETTI: And that's in the plan, but
21 it's never talked about in this plan. It's talked
22 about in our acquisition strategy that you need a
23 proof test, but you do not need it routinely.

24 You would think at that point -

25 CONSULTANT KRESS: There are some

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1 interesting statistical questions about how can you do
2 this? How many samples do you take? Why would you
3 irradiate them, and where do you irradiate them?

4 There are some interesting issues there.

5 MR. PETTI: But by then, you know, we'll be
6 a heck of a lot smarter, you know, by the time we
7 figure out what's the right thing to do.

8 CHAIRMAN BLEY: Maitri, did you -

9 MS. BANERJEE: Yes, I did. That's the ORNL
10 documents.

11 CHAIRMAN BLEY: The ORNL, yes.

12 CONSULTANT KRESS: Okay. Thanks.

13 MS. BANERJEE: Thank you.

14 CHAIRMAN BLEY: Anything else for Stu?

15 Okay. Stu, thank you very much.

16 MR. RUBIN: Thank you.

17 CHAIRMAN BLEY: I guess we're ready for
18 Srini.

19 MR. BASU: Srini.

20 CHAIRMAN BLEY: Yes, right? So, we're
21 about a half hour behind.

22 MR. BASU: Srini is going to help us.

23 CHAIRMAN BLEY: I'm not so sure. I think
24 carbons and others is the issue, but maybe after that
25 we can begin to catch up.

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1 (Off-record discussion.)

2 CHAIRMAN BLEY: Okay.

3 MR. SRINIVASAN: Good afternoon. I am Dr.
4 Makuteswara Srinivasan. I am a senior materials
5 engineer specializing in nuclear graphite in the
6 Office of Nuclear Regulatory Research. I will present
7 an overview of the current status of NRC's research in
8 nuclear graphite.

9 I will present the technical progress made
10 since my last presentation to you on January 15, 2009.
11 Based on such progress, we have also modified our
12 graphite research plan. I will address all these
13 areas listed here sequentially.

14 The outcome of our research will inform
15 technical assessment and independently confirm
16 applicant's technical basis for regulatory and safety
17 decisions on graphite core components used in gas-
18 cooled reactor.

19 Our research will also address data and
20 model uncertainties in graphite behavior in HTGR
21 environment.

22 We will use the results to confirm
23 material specifications, conformance to codes and
24 standards, and provide information and data for NRC
25 evaluation model.

1 Our results will also inform staff
2 evaluation of HTGR applicant's probabilistic risk
3 assessment due to graphite component degradation.

4 Our research contributes to the
5 development of technical staff expertise to conduct
6 safety evaluation of HTGR core component design and
7 ensure the presence of adequate design margin for safe
8 reactor operation.

9 We have previous licensing experience with
10 Peach Bottom and Fort St. Vrain graphite reactors.
11 Our most recent involvement in graphite research dates
12 back to 2002, when Exelon approached the Commission
13 with a potential design certification application for
14 a pebble-bed modular reactor.

15 At that time, we developed a document
16 outlining needed research in nuclear graphite to
17 provide technical safety information to adequately
18 review a gas-cooled reactor design.

19 We terminated our graphite research when
20 Exelon abandoned their plans. We re-started our
21 graphite research in 2006, in response to The Energy
22 Policy Act, enacted by the Congress in 2005.

23 I have listed the major technical issues
24 in this slide, particularly important for staff
25 technical review.

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1 Good progress has been made by worldwide
2 research in these areas during the past five years.
3 Specifically, the ASTM has published nuclear graphite
4 specifications and the publication of the ASME Code
5 Case for the design of graphite core components in a
6 high-temperature -- and the publication of their Code
7 Case is expected to be published later this calendar
8 year.

9 Material and component inspection codes
10 are yet to be developed by ASME. When they become
11 available, we will review and then begin an effort to
12 provide guidelines for the staff to evaluate the
13 inspection and evaluation methods provided by the
14 reactor applicant.

15 Methods are being developed by leading
16 nuclear graphite experts to predict irradiated
17 properties from fundamental material building block.
18 This is a challenging effort.

19 However, when accomplished, this will
20 hopefully eliminate the need to irradiate and
21 determine properties every time newer graphite is
22 introduced for the reactor core component.

23 Since the draft research plan was issued
24 in 2006, world-wide research organizations have been
25 addressing most of these issues in their research.

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1 Thus, we expect to use these research results in the
2 development of staff positions and guidance documents.

3 I have listed here significant items in
4 our graphite research strategy. Our main position is
5 that the applicant is responsible for providing us
6 with full data and technical bases in developing their
7 design of graphite core components ensuring adequate
8 operational safety.

9 The staff will use these and other data,
10 including the lessons learned from the operational
11 experience, for example, from the Japanese HTTR and
12 the Chinese HTR-10 reactors in safety evaluation.

13 We will continue to interact with the DOE,
14 Idaho National Laboratory and Oak Ridge National
15 Laboratory research staff as per guidelines
16 established by the NRC-DOE memorandum of
17 understanding, to efficiently and effectively promote
18 and gather technical information needed for safety
19 assessment of graphite components.

20 We will continue to cooperate with codes
21 and standards organizations providing input on
22 regulatory expectations for addressing uncertainties
23 in the data, and ensuring these are addressed in
24 developing conservative design safety factor.

25 We will continue to participate in

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1 international meetings, such as the International
2 Nuclear Graphite Specialist Meeting, the NEA/OECD
3 International Cooperative Research Program on Graphite
4 Creep, IAEA activities with respect to irradiated
5 graphite properties knowledge base, and the Generation
6 IV International Forum Graphite Working Group to
7 develop materials handbook.

8 Such international collaboration has
9 provided the staff valuable exchange of technical
10 information and knowledge on materials and inspection
11 challenges.

12 Through this international cooperation, we
13 are able to maintain and advance our technical
14 awareness and competency in assessing graphite
15 performance.

16 Periodically, the staff may identify
17 specific areas where independent confirmatory research
18 may be needed. Subject to resources available, we
19 expect to continue such confirmatory research.

20 In order to effectively and efficiently
21 review HTGR design, we need to develop the
22 infrastructure and the technical know-how to conduct
23 safety assessment of the applicant's core component
24 design.

25 Thus, the current challenge for us who

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1 have predominantly light water reactor safety
2 assessment experience, is to develop our expertise to
3 understand and apply material performance codes,
4 component integrity evaluation codes, graphite
5 surveillance requirements and inspection codes, and
6 the tools to evaluate the applicant-proposed graphite
7 component degradation management program.

8 We do not need to have our own independent
9 codes in all of these areas. However, the staff
10 should have adequate technical expertise to evaluate
11 the applicant's use of codes, and ensure the applicant
12 has provided sufficient factor of safety for designing
13 graphite components commensurate with data and model
14 uncertainties.

15 Based on the accumulation of such
16 knowledge, the staff intends to embark on efforts to
17 develop regulatory guides which address the evaluation
18 of the structural integrity of graphite components and
19 in-service inspection plans and surveillance
20 techniques which may be proposed by the applicant.

21 Let me now talk about current status.
22 First, let me address the consensus codes and
23 standards. During 2003, we awarded a contract to Oak
24 Ridge National Laboratory to re-start the ASME
25 graphite code case which had been dormant since 1993.

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1 We also asked Dr. Tim Burchell, the
2 Principal Investigator, to initiate and coordinate new
3 ASTM activities for standardization of nuclear
4 graphite specification and review and update standards
5 for determining graphite properties particularly for
6 nuclear graphite.

7 Thanks to the dedicated efforts of
8 international participants from industry, including
9 reactor core designers and graphite manufacturers,
10 academia, national laboratories and regulators, we now
11 have the ASME Division 5 Boiler and Pressure Vessel
12 Draft Code Case for the design of graphite core
13 components, and ASTM specification for components
14 subjected to severe irradiation dose, and another ASTM
15 specification for those components which are subjected
16 to limited dose, but nevertheless play a critical role
17 such as supporting the core.

18 MEMBER REMPE: Excuse me for just a second.

19 MR. SRINIVASAN: Yes.

20 MEMBER REMPE: The H-451 supply graphite is
21 no longer available. And so when I hear this
22 discussion, I'm wondering how you're accommodating
23 candidate graphites that may be used to replace that
24 451, because is there just one set of properties or
25 with the various types of graphite, how are you going

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1 to deal with that issue?

2 MR. SRINIVASAN: Right. You are correct.
3 451 grade is no longer available. It is not
4 replacement, but what the graphite community did was
5 to issue two ASTM specifications.

6 And what it is, is that there is a
7 graphite class. This is known as graphite class. if
8 class of material having such and such properties,
9 such and such limits for the impurities and things
10 that all participate in this.

11 So, any graphite manufacturer that
12 conforms to these ASTM specifications, basically will
13 have - but it's not qualified or something. That's a
14 different thing.

15 But they have - this is the minimum
16 requirements for room temperature, things that people
17 can do.

18 Day is gone. Experience gain in the Fort
19 St. Vrain and Peach Bottom reactor experience, as well
20 as the - largely based on AGR experience in the
21 British reactors somewhat, a little bit, but it's GTR
22 and HTR.

23 Did I answer your question?

24 MEMBER REMPE: Yes, you did.

25 MR. SRINIVASAN: Thank you.

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1 MEMBER RAY: Thank you for mentioning Peach
2 Bottom. I forgot to do that.

3 MR. SRINIVASAN: You're welcome.

4 MEMBER RAY: I didn't know anything about
5 Peach Bottom personally, but -

6 MR. SRINIVASAN: Basically, after the Peach
7 Bottom in 1993, there was a court case that was laying
8 dormant with respect to graphite specification itself.

9 That was a ten-page document in 1993.
10 That's where we were. And here is the latest ASTM one
11 that has gone through the Committee - I mean ASME.
12 Excuse me. ASME design code.

13 A lot of people put in a lot of effort,
14 and still we are still going through and dotting Is
15 and crossing their Ts.

16 And I'm sure that based upon the AGC
17 experiments that are going on in INL and other
18 facilities, we will probably revise this. But at
19 least there is a basic document that many people have
20 converged that this is a working document.

21 But the Peach Bottom and Fort St. Vrain
22 experience are definitely informed writing this
23 document.

24 All right. Okay. I want to mention that
25 there are also other properties, graphite properties

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1 that are important. Therefore, there are also ongoing
2 efforts to devise and update existing property
3 standards and initiation of new efforts in the area of
4 nondestructive evaluation of graphite.

5 The NRC staff has actively participated in
6 these codes and standards development activities. We
7 have provided input on potential technical safety
8 issues for graphite, and our expectations on defining
9 and establishing the minimum requirements in
10 properties and stress and temperature limits,
11 considering the uncertainties in data, material
12 models, component analysis models and inspection
13 models.

14 The objective is to better understand the
15 risk contribution for mitigation and proactively
16 establish requirements for compensatory measures if
17 needed.

18 During 2007, the staff in cooperation with
19 DOE, conducted a phenomena identification and ranking
20 table exercise known as PIRT, and identified several
21 significant safety phenomena pertaining to graphite
22 core performance.

23 Thankfully, many of the high-importance
24 phenomena with low knowledge are being addressed by
25 DOE and other international research.

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1 These include, for example, the
2 dimensional stability that you asked about, the
3 irradiation creep, thermal conductivity and the
4 Coefficient of Thermal Expansion as a function of
5 irradiation dose and temperature.

6 Other research being conducted worldwide
7 is expected to provide information on phenomena which
8 were ranked high for safety importance, and for which
9 experts agreed we needed improved knowledge.

10 We intend to actively provide technical
11 input and suggestions to include potential effects of
12 data and model uncertainties and how these will be
13 addressed in the design of graphite components.

14 Currently, we have a research contract at
15 Oak Ridge National Laboratory to determine the
16 magnitude of energy stored on previously high-
17 temperature irradiated graphite specimens, and
18 evaluate the characteristics of this energy release
19 during subsequent heating.

20 From safety perspective under certain
21 conditions, the release of stored energy can start a
22 self-sustaining reaction.

23 The stored energy is not considered to be
24 a significant safety issue for reactors operating at
25 temperatures greater than approximately 300 degrees

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1 Celsius, which would be the case for NGNP HTGR. This
2 research will provide technical data to confirm this
3 position.

4 To conduct independent confirmatory
5 analysis of applicant's stress safety margins for
6 graphite core components, we are also developing a
7 finite element stress analysis tool at Argonne
8 National Laboratory.

9 The code will incorporate ASME design
10 procedures. The code will determine the spatial
11 stresses for reflectors and moderators containing
12 keyways and holes or channels for fuel rods, control
13 rods and coolant flow paths and graphite core
14 supports.

15 This code will incorporate the inherent
16 nonlinear elastic stress-strain behavior of graphite,
17 spatial variation in temperature and flux, and the
18 contribution and role played by irradiation creep to
19 changes in graphite properties.

20 The time or dose-integrated stress will
21 use the time or dose-dependent coefficient of thermal
22 expansion, thermal conductivity, nonlinear elastic
23 modulus, Poisson's ratio, and material loss factor due
24 to oxidation or other potential corrosion mechanisms
25 from coolant chemistry changes and dimensional changes

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1 as input for stress calculations.

2 Reactor applicant and DOE research will
3 provide the data. The model and the procedures will
4 be validated and verified using ASME code and DOE and
5 other vendor data and benchmark calculations on
6 idealized core component shapes.

7 This finite element analysis tool is
8 expected to be available by 2013. We intend to use
9 this tool to confirm applicant's designed deformation
10 limits for graphite core components.

11 As we move along the NGNP path, we intend
12 to engage DOE research staff and provide technical
13 input as appropriate, by monitoring worldwide nuclear
14 graphite research.

15 We will complete research at Oak Ridge
16 National Laboratory and Argonne National Laboratory
17 and publish research information in the form of NUREG
18 or other publicly available documents.

19 We will continue to actively participate
20 in ASME and ASTM codes and standards activities,
21 providing regulatory perspective to information needs
22 and maintaining adequate conservatism in stress and
23 temperature limits for graphite components
24 commensurate with the estimated uncertainty in
25 irradiated properties data and material models.

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1 We will assess the accumulated knowledge
2 with respect to providing adequate information for the
3 structural integrity assessment and inspection
4 requirements for graphite core components.

5 Based on such information, we will develop
6 and publish regulatory guides incorporating public
7 comment on graphite core structural integrity
8 assessment and guidance on graphite core inspection.

9 I conclude my presentation.

10 MEMBER ARMIJO: I just want to make sure I
11 understood.

12 On, I think, your Slide 6, you said many
13 of the high-importance, low-knowledge things are now
14 being addressed.

15 Does that mean that some high-importance,
16 low-knowledge things aren't being addressed or was it
17 just the wording?

18 MR. SRINIVASAN: I think I misspoke.

19 MEMBER ARMIJO: Everything that you're
20 concerned about in that category -

21 MR. SRINIVASAN: I'll say a couple of
22 instances where the research is not being done. One
23 of the things that was identified was spalling of
24 graphite.

25 MEMBER ARMIJO: Spalling?

1 MR. SRINIVASAN: Spalling. Spalling in the
2 sense if you are thinking of a channel, for example,
3 and there are two cracks that come together in a
4 triangular fashion, let's say, and then graphite falls
5 off or spalls off.

6 So, in the refractories industries,
7 spalling is a big issue and they do work. Even in the
8 graphite electrode industry they do that.

9 So, that's a concern that's not being
10 addressed, but the fracture is being addressed in a
11 different format, really. So, that's one aspect.

12 Other one is with respect to the typology
13 of graphite in terms of the material loss itself.
14 That's not also addressed very well.

15 Third item perhaps that is important is
16 really that's the post-accident kind of a scenario in
17 the sense that they're comparable to water ingress and
18 air ingress scenarios, really.

19 The material loss due to air ingress,
20 severe air ingress and water ingress is not being
21 addressed in a formal fashion as yet in the programs,
22 but they are starting to be addressed. Let me put it
23 that way. So, that's my caveat with respect to that.

24 MEMBER ARMIJO: Okay. Thank you. That's
25 what I wanted to hear.

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1 CHAIRMAN BLEY: I'm just thumbing through
2 your backup slides, and I appreciate you bringing
3 those. We have talked about those issues. I think
4 you covered the stored energy.

5 Nobody here has pushed on the burning of
6 graphite issue, but I think at the full Committee you
7 need to be prepared to address that. And if anybody
8 here wants to hear what you've got, I looked through
9 it and it's really consistent with things I've seen
10 and - but I think that's something that will come up
11 in the full Committee for sure.

12 MR. SRINIVASAN: Thank you for -

13 CHAIRMAN BLEY: I won't push you to go
14 through it now.

15 MR. SRINIVASAN: I just want to mention,
16 yes, I think just very quickly a couple of slides.

17 CHAIRMAN BLEY: Okay. Good.

18 MR. SRINIVASAN: Basically, the burning in
19 place is self-sustaining reaction. For all practical
20 purposes by this definition, graphite does not burn.

21 MEMBER CORRADINI: So, what occurred at
22 Chernobyl then?

23 MR. SRINIVASAN: Okay. Good. Thank you.

24 In the Chernobyl accident, basically it
25 was uranium - sorry. Not uranium. It was cladding

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1 that burned.

2 Material loss is - because in order for
3 the oxidation to occur, you have to have continuous
4 flow of oxygen.

5 In the real cases, in the HTGR case that
6 we are talking about, the fuel is different and
7 things. In the case of scale, it is the uranium fire
8 basically.

9 MEMBER CORRADINI: But doesn't that, just
10 so I'm clear, so you're saying that you've got to have
11 another substance that is essentially isothermically
12 adding heat to the system.

13 MR. SRINIVASAN: Right. And also you're to
14 be replenishing oxygen continuously.

15 The other thing is that it is also in the
16 press and everywhere, graphite glow and things - the
17 glow of graphite, per se, does not mean burning.

18 And the so-called A squared on heating
19 business is based on resistance heating. Basically,
20 you supply the current and its resistance with the
21 graphite keeps the graphite.

22 So, basically on Figure 1 here on the
23 left-hand, far left, we are looking at the graphite
24 coming out of the furnace after being heated to 2800
25 degrees centigrade. Okay. So, that's being cooled

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1 and we see the glow up there.

2 In the middle one, you are seeing graphite
3 electrode glow in the arc furnace. In the far right-
4 hand corner, basically you have three graphite
5 electrodes.

6 On the top, you can see, what do you call,
7 greenish color. And then of course the white color
8 and things, really.

9 The last, you know, so, you can take these
10 things and then they are graphite pristine, so to
11 speak.

12 So glowing, per se, is really you can
13 think about our gas, you know, what do you call in the
14 home? Washing machine, dryer. No plug is there for
15 ignition thing. That will glow. Glow, per se, does
16 not constitute burning.

17 Okay. Moving along. Right along.
18 There's also anecdotal things in the Windscale fire,
19 which is called Windscale fire, but it's really the
20 uranium metal fire. And basically they looked at the
21 graphite before and after on things. Really, there's
22 not a -

23 MEMBER CORRADINI: There were some really
24 extensive reports on that.

25 MR. SRINIVASAN: Right. So, I wanted to

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1 include that.

2 And there was also - I'm sorry. You guys
3 didn't ask about dust explosion. So, I'll stop with
4 that.

5 MEMBER CORRADINI: So since we didn't,
6 let's talk about it.

7 MR. SRINIVASAN: Oh, sorry. There's also
8 the question about graphite dust explosion. Is it
9 possible, and so forth, really?

10 Lot of work has been done in the recent
11 past, that is within the last ten years, because of
12 the British. They have decommissioned the reactors
13 and then there's a lot of dust going to be created
14 because the irradiated graphite and what it is and so
15 forth.

16 So, they did a lot of work in Italy,
17 France, as well as in the UK. And this information is
18 available in an EPRI report. And I think in the last
19 meeting if I remember, I also showed the - I showed at
20 the ACRS meeting a movie of the combustion experiments
21 and so forth.

22 The bottom line is that it is termed as -
23 it doesn't explode out. It's weakly explosible in the
24 sense you have to have a lot of ignition energy, you
25 have to have closed atmosphere and so forth.

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1 And even then it's "poof" kind of a thing.
2 It is not like a flower or, you know, with green
3 things doing and so forth, that kind of a thing.

4 The other thing is that again in the
5 Windscale, there are thermal lances used to cut the
6 restraints and so forth. There was no explosion. And
7 dust is invariably produced, for example, in shops
8 like this, typical fabrication shop and so forth where
9 there are opportunities for dust entrapment in
10 isolated areas and things.

11 MEMBER CORRADINI: But in terms of burning,
12 though, since the length scale is so small, you would
13 get burning, right?

14 MR. SRINIVASAN: The burning - you would
15 get oxidation. Oxidation. Yes, indeed. Oxidation.
16 If there is oxygen and things, you will get oxidation.

17 MEMBER CORRADINI: So, the concern about
18 explosion is simply because it's explosive because of
19 the dynamic pressures or the fact because you would
20 get in any sort of a closed environment, you would
21 still get a combustion event of some sort, a burning
22 event?

23 MR. SRINIVASAN: Burning. And the thing to
24 differentiate is really, for example, in the - I think
25 it was Don Carlson, our colleague, pointed out just

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1 after this Japan incident and things, there was
2 somewhere in the press saying that graphite will burn
3 like coal and so forth. That kind of data is a
4 mistaken impression also.

5 So, if you look at the things, really, the
6 chemical composition of coal is basically will have a
7 fuel component in it in terms of hydrogen and so
8 forth.

9 For graphite or even graphite dust, it's
10 purely carbon material. So, there is the
11 differentiation that one has to be aware of.

12 I think I included these things except for
13 these two pictures. One, you probably don't have the
14 glow. This picture is not -

15 CHAIRMAN BLEY: Yes, that's not in there.

16 MR. SRINIVASAN: It's not there in your
17 package. I'm sorry about that. Later on - because,
18 again, I saw somewhere that glow is fire and things.
19 So, I thought I better put that in. I apologize for
20 not having included that.

21 And I also have not included this in the
22 previous one, I guess. Because this is again I wanted
23 you to be aware of graphite, machining is there and so
24 forth. I will be glad to give this to you.

25 CHAIRMAN BLEY: Good. Anything else?

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1 MR. BASU: That is for the full Committee
2 presentation, would you like us to include this
3 discussion as main part of the presentation or keep
4 them as backup slides and -

5 CHAIRMAN BLEY: I think the burning one as
6 at least one slide on it in the main presentation, and
7 have the backups in case. Because I know there are
8 some member - the last time we talked about this,
9 there were some members who wouldn't quite buy into
10 what we see here.

11 So, yes, one slide, and the rest is
12 backup. Yes.

13 MR. SRINIVASAN: Appreciate that. Thank
14 you.

15 CHAIRMAN BLEY: Thank you.

16 MR. BASU: Hopefully, we saved some time.

17 CHAIRMAN BLEY: Yes, we did. Let's do the
18 last presentation in this package, and then we'll take
19 the break.

20 MR. BASU: Good. Shah is next.

21 (Off-record discussion.)

22 CHAIRMAN BLEY: I know you don't have a
23 name tag, but we were introduced that you'd be here.

24 MR. BASU: Yes, I will introduce her.

25 CHAIRMAN BLEY: Okay. Good.

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1 (Off-record discussion.)

2 MR. MALIK: Good afternoon. My name is
3 Shah Malik. I will be making a presentation on creep
4 and creep-fatigue flaw assessment capability
5 development in high-temperature reactor materials.

6 After my presentation, there will be a
7 follow-up presentation by Dr. Amy Hull on a related
8 topic of monitoring for management of materials
9 degradation that concerns flaw monitoring, flaw
10 detection in high-temperature reactors.

11 The objective of this work is to develop
12 an independent confirmatory capability for creep and
13 creep-fatigue crack growth elimination process in
14 high-temperature reactor material that are operating
15 when the creep strain becomes significant at high-
16 temperature range.

17 This will assist NRC in developing
18 regulatory technical basis, as well as assessment of
19 licensee submittals on integrity of structural
20 component operating in creep range.

21 Just I would like to remind that creep is
22 not a deformation that is operating for LWR
23 components, because their temperature is much lower.

24 Breach to secondary system due to creep or
25 creep factor crack growth may occur in intermediate

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1 heat-exchanger/steam generator, cross vessel. Or if
2 the temperature are high enough in reactor pressure
3 vessel, that could lead to develop pathway for fission
4 product release, as well as air, steam and water
5 ingress.

6 NRC PIRT, the NUREG that was conducted in
7 2007, 2008, NUREG/CR-6944, determined a creep factor
8 flaw growth phenomena to be of high importance and low
9 knowledge.

10 In particular, creep and creep fatigue can
11 occur in structural discontinuities, as well as in
12 weldment operating in creep range of temperature.

13 The flaws can be preexisting or they
14 initiate early in life. If those flaws are not
15 detected or repaired after, they can grow sub-
16 critically under creep fatigue deformation.

17 And they can grow to critical size that
18 can trigger a structural failure mode as shown by the
19 middle bubble there, leading to component failure and
20 breach of primary or secondary system, and finally a
21 fission product release.

22 Current creep fatigue crack growth
23 modeling which is currently available, we can see
24 there's secondary creep.

25 On the left-hand side, I have shown a

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1 schematic for creep strain versus time for a given
2 temperature and given the stress.

3 Initially, you have a primary transient
4 creep followed by a steady state secondary creep
5 regime. And, eventually, a tertiary creep when the
6 creep rate become much more higher leading to creep
7 rupture.

8 Current classical creep or fatigue crack
9 growth model only consider the secondary part of the -
10 which is the steady state part of the creep curve.

11 The second graph shows there an actual
12 data for chrome-moly vanadium steel at 550 degrees.
13 As you can see, there is a significant secondary creep
14 that is straight line creep slope followed by quite a
15 significant tertiary creep also.

16 Now, there is a British R5 methodology,
17 French RCC-MR, as well as American Petroleum Institute
18 methodology for this creep crack growth under a steady
19 state secondary creep.

20 And that is applicable to chrome-moly
21 vanadium, as well as the stainless steel 3/4th, 3/16
22 steel. Applicable to fossil power plant, as well as
23 previous UK AGR programs.

24 So, the current time-independent creep
25 procedure will not be applicable to high-temperature

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1 metallic material that exhibit time-dependent creep
2 response. So, secondary creep is very - is non-
3 portion of the creep curve.

4 Here you have shown two different
5 material; Alloy 800H, which is one of the candidate
6 material for current NGNP project, as well as Alloy
7 617 for a little bit higher temperature range. And
8 both of them do not show -- for example, the Alloy
9 800H shows creep strain rate. We do not see a
10 significant part of the secondary or steady state
11 uniform creep rate.

12 Similarly for the Alloy 617, there is a
13 small portion of secondary creep followed by a
14 significant tertiary creep region. This was developed
15 - Alloy 617 was developed under the NGNP program. so,
16 it's the current data. Whereas Alloy 800H is some
17 earlier data.

18 So, this is for us to develop - there's a
19 need to develop a time-independent creep fatigue crack
20 growth modeling procedure that can be applied to creep
21 deformation when there is significant time-dependent
22 response of creep.

23 Time-dependent creep in nickel-based
24 alloys such as 800H and 617, and some higher-
25 temperature alloys such as Haynes 230 and additional

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1 alloy hastelloy X and XR, have a schematic similar
2 kind of behavior.

3 They start out as a creep strain rate with
4 this time plot. You have primary creep. It is
5 decreasing with time. Creep rate is decreasing with
6 time.

7 Then there is a creep softening region
8 where it is slowly increasing creep rate. Followed by
9 tertiary creep.

10 Now, this is assuming there is a crack
11 present in front of the material. Then after
12 application of load, initially there will be elastic
13 stress field.

14 As the time is progressing, there will be
15 a primary creep zone head of the crack tier forming.
16 And within that creep zone as time increase, a
17 secondary creep zone will form. And with increase in
18 time, you can have tertiary creep.

19 We have tried to come up with a roadmap
20 for developing high-temperature time-dependent creep-
21 fatigue flaw evaluation computer code. There are
22 three different modules in this computer code,
23 hopefully.

24 Methods of Development module which is
25 shown on the left-hand side, it has three components.

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1 The first basic component is time-dependent fracture
2 mechanics methodology development in which we are
3 developing crack tip parameters and crack tip
4 constraint effects for creep when all the three
5 components of creep are present. There is primary,
6 secondary, as well as tertiary creep.

7 And that will be applied to develop crack
8 growth correlation for proof of concept, which is Step
9 B of the same module.

10 And then apply it to more representative
11 geometry such as slender with cracks to develop crack
12 growth correlations.

13 And develop implementation strategy, the
14 final step in the method development module, so that
15 extrapolating this to longer service time.

16 For NGNP-specific application, there will
17 be a crack growth data development phase. That will
18 develop crack growth data.

19 Now, I'd like to mention very specifically
20 the data originated essentially with DOE and
21 applicant. We are using those data in our application
22 to develop correlations.

23 So, the left upper side, top portion,
24 Section D, we are using those data to develop
25 correlations in the air, as well as in pure helium.

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1 Finally, implementation module. First,
2 we'll develop a deterministic flaw evaluation
3 procedure. And using data uncertainty and other
4 probabilistic information for the material, as well as
5 modeling and incorporate it into an NRC modular
6 probabilistic fracture mechanics code.

7 I think you may have heard about currently
8 it's called XLPR code, extremely low probability of
9 rupture code, that is being used for dissimilar metal
10 weld evaluation in primary cracking in PWR components.

11 So, there will be further development on
12 that in the next three, four years. And that's with
13 this code we are going.

14 Now, the main work, which is the time-
15 dependent fracture mechanics methodology development,
16 that is being done at Oak Ridge under Program N6654.

17 It uses what is called concept of
18 similitude between lab specimen and the actual stress
19 component.

20 So, the equal stress and deformation
21 states in lab specimen will imply there will be growth
22 stress and deformation state and crack tip of actual
23 component.

24 That will then transfer crack growth data
25 from specimen to structural application subject to

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1 applying appropriate crack tip constraint when we're
2 going from specimens to a structural component.

3 Data generation, as I briefly mentioned
4 before, will be the responsibility of DOE, as well as
5 applicant.

6 There are three sets of data that go into
7 - initially it will be scoping data. And then finally
8 design data. When they are assembled completeness,
9 they will have both the creep crack growth data - when
10 I say "creep," I mean both creep and fatigue crack
11 growth data. And there is mechanical creep strain
12 data in air to develop time-dependent fly release
13 methodology.

14 And to determine an effective environment
15 such as impure helium, as well as effective steam.
16 There will be scoping data again developed at INL,
17 DOE, as well as at applicant.

18 And to find the affect of thermal aging on
19 crack growth initial scoping data, and then final data
20 set combined together for multiple heats to develop
21 design data by the applicant, as well as DOE labs for
22 both base metal, as well as weldments.

23 MEMBER ARMIJO: Is that data being
24 developed for, let's say, the 800H, the -

25 MR. MALIK: The data is being developed for

1 800H, but INL is also developing for 617 as well.

2 MEMBER ARMIJO: And the other, the Haynes
3 230 and the Hastelloy?

4 MR. MALIK: They are not being considered
5 at the moment.

6 MEMBER ARMIJO: Okay.

7 MR. MALIK: But they are the same class of
8 material if they were to - applicant were to use for
9 any component, they will end up developing some on top
10 of that as well.

11 This slide shows the major milestones. We
12 are working on the top row. Time-dependent fracture
13 methodology development. Soon, this fall, I think
14 we'll have the methodology completed.

15 We are also performing the peer review
16 independently by external reviewer to peer review to
17 use it finally into the next step of the process.

18 The second two rows shows developing crack
19 growth correlation starting in last quarter of '11,
20 going to '12, as we go up to fiscal '13 year.

21 And then in parallel, there will be NGNP-
22 specific crack growth generation at INL, as well as
23 the Office of Contract at Argonne National Lab for
24 creep crack data generation between '12 and '14.

25 And hopefully implementation of crack

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1 growth as the data start becoming available between
2 quarter '12 to quarter '14.

3 Now, here we have - I'm going to pass it
4 on to my colleague, Dr. Amy Hull.

5 (Off-record discussion.)

6 MS. HULL: Good afternoon. In January
7 2009, we presented you some of the highlights from the
8 2007 PIRT analysis in elevated temperature materials,
9 and identified improved in-service inspection to
10 monitor for management of materials degradation as
11 being of high importance and low knowledge.

12 Traditional ISI methods used for LWRs may
13 be insufficient to monitor development of cracks and
14 materials degradation in the NGNPs because
15 significantly longer periods between outages and the
16 potential for high-operating temperature-induced
17 materials degradation may require more than can be
18 provided by - and those techniques we'll talk about.

19 We've been looking at these issues since
20 that time, but the activity has been resource limited.
21 Consequently, I will make this presentation brief.
22 There are only three short slides.

23 The impetus is derived from work within
24 the RES Division of Engineering dating from the NDE
25 Workshop for events reactors held in September 2006,

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1 hosted by INL.

2 The NRC staff that participated came away
3 with the message that some of the key issues were ASME
4 code and new NDE inspection concepts, applications and
5 challenges.

6 It was at that time, also, that we became
7 more aware of the RIM, the Reliability and Integrity
8 Management approach, that was being considered for
9 rules for inspection and testing of components of gas-
10 cooled plants.

11 As a result of this, since late 2006 I
12 have actively participated in ASME boiler and pressure
13 vessel subcommittees and working groups that have
14 focused on events reactors.

15 The Gen-4 NGNP materials project had a
16 number of tasks. One of the tasks, 12, in-service
17 inspection technology for HTGRs, resulted in WCAP-
18 17084-NP. That further highlighted the value of
19 online monitoring such as acoustic emission.

20 Since then, we've continued our assessment
21 of AE monitoring of structural integrity looking at
22 fatigue, stress corrosion cracking, creep and leak
23 detection for high-temperature gas HTGR materials.

24 PNNL has experience with crack monitoring
25 in a reactor environment. So, because we were working

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1 with them on activities related to the proactive
2 management of materials degradation known as PMMD, and
3 we published a paper collectively at ICON 2009
4 Analysis of Emerging NDE Techniques, Methods for
5 Evaluating and Implementing Continuous Online
6 Monitoring, we went to PNNL for a new contract.

7 A sister report, PNNL 19401, Methodology
8 For The Analysis Of Emerging NDE Techniques, provides
9 more detail. As well, it discusses the AE validation
10 on an operating reactor. PNNL was involved with
11 monitoring SEC in the Limerick Unit 1 BWR Mark 2.

12 Next slide. For the 22-month project,
13 Effectiveness and Reliability of Acoustic Emission For
14 NDE in Advanced Reactors, PNNL personnel work with the
15 ASME code committees to update AE standards for online
16 use in either leak detection in DE technology or flaw
17 detection in monitoring.

18 Working with the NRC group, they review
19 the standards currently being generated by the Section
20 11 SWG HTGR, the special working group for HTGRs.

21 Together, we're identifying potential
22 issues with these standards and identifying where
23 additional information may be needed.

24 Based on extensive previous experience,
25 the PNNL group is determining the type and extent of

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1 evaluations working with us that we would need in
2 order to review licensee-proposed ISI programs.

3 And then finally as part of this work
4 N6907, within 22 months they'll provide us a basis
5 document for a draft regulatory guide for the ASME
6 Section 11 inspection programs for HTGRs.

7 Task 1, reviewing the ASME proposal for
8 RIM, is important. This group was led by members of
9 PBMR such as John Fletcher and Neil Broom, and
10 Technology Insights such as Carl Fleming, Steve
11 Gosland and Ron Campbell.

12 In developing the RIM methodology, they
13 started with some of our reg guides such as 1.178, an
14 approach for plant-specific risk-informed decision
15 making ISI of piping, but they're working with the May
16 '98 draft.

17 When I joined this committee in 2007, they
18 had a rough draft done of this. Now, it's at the
19 point where it can be reviewed by the special working
20 group. And we are reviewing it and making
21 recommendations first.

22 The second task listed there is to analyze
23 the existing ASME code for application to advanced
24 reactors and make recommendations regarding the use or
25 modification of existing AE provisions for use as leak

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1 detection, crack detection and crack monitoring
2 techniques.

3 The use of online or continuous monitoring
4 methods can be an effective way to ensure public
5 safety and component integrity.

6 AE is a prime example of a good option in
7 this context. It can monitor the region of piping or
8 pressure vessel. It can passively listen for
9 ultrasonic signals of a hundred to 400 kilohertz
10 emitted by cracks as they grow. And further, is
11 sensitive to cracking, but not to corrosion.

12 Next. As mentioned in the previous slide,
13 we are participating in the special working group
14 developing the Div II rules for inspection and testing
15 of components of gas-cooled plants, which complements
16 the Section 11 Div I parallel rules for inspection and
17 testing of components of light water-cooled plants.

18 The Div III as it's developed, will be for
19 liquid metal-cooled plants. And I'm NRC's rep for the
20 Div II and the Div III.

21 In the 2010 code that was recently
22 published, the wording for Div II still takes only one
23 and a quarter pages. The forward consists of
24 historical background and in-service inspection
25 philosophy and another subcaption, reactor system

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1 considered in co-drills.

2 So, in other words, developing Div II was
3 absolutely wide open for whoever was involved on the
4 consensual committees.

5 And in this case, as I mentioned before,
6 the people who were invested in this were the
7 representatives from PBMR and Technology Insights.

8 So, when they developed the IGA, this is
9 the draft IGA, general requirements for gas-cooled
10 NPPs, there was a focus on sort of a risk-informed
11 approach.

12 This 118-page IGA general requirements has
13 been drafted and is out for pre-special working group
14 review. It's not out yet for balloting or pre-
15 balloting review.

16 The activity has slowed down with the loss
17 of the former PBMR participants. So, we have more
18 time to revise the document as needed.

19 Participants of the ASME special working
20 group propose that the RIM program inspection roles
21 and requirements of this division will apply to all
22 passive metallic pressure-retaining components and
23 their supports, including pressure vessels, piping,
24 pump casing, casings for turbines and compressors,
25 supports and valves.

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1 Acoustic emission is specifically
2 encouraged in the proposed IGA general requirements,
3 the IGA-2934 acoustic emission monitoring and
4 examination.

5 The use of RIM, reliability and integrity
6 management, and the general requirements for the rules
7 for inspection and testing of components of gas-cooled
8 plants, seems to be a new approach.

9 The first sentence of IWA-110 scope for
10 light water-cooled plants states - this is the
11 Division 1 - this division provides requirements for
12 in-service inspection and testing of light water-
13 cooled nuclear power plants.

14 On the other hand, the proposed IGA-1100
15 scope begins, this division provides the rules and
16 requirements for the creation of the reliability and
17 integrity management, RIM, to select and implement a
18 combination of design, fabrication, inspection,
19 surveillance, operation and maintenance requirements
20 that meets the plant-level risk and reliability goals
21 that are selected for the RIM process.

22 So, my short overview is to sort of
23 indicate that I think a careful review by our NDE and
24 ASME code specialist is well-warranted since this
25 seems to be a significant change.

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1 We in DE, are also consulting with PRA
2 specialists. The team at PNNL working on this include
3 subject matter experts who have focused for a number
4 of years at the interface of NDE materials degradation
5 and PRA. And that's what I have.

6 CHAIRMAN BLEY: Thank you.

7 Do you have more?

8 MR. MALIK: One last slide.

9 CHAIRMAN BLEY: Sure.

10 MR. MALIK: Going forward, we will continue
11 with our research effort as per our planned roadmap
12 and interact with DOE/INL and other labs through the
13 NGNP project, as well as participate in codes and
14 standards activity.

15 CHAIRMAN BLEY: Thank you.

16 Anything from the committee?

17 Thanks very much for your presentations.
18 I think we'll take our break now. We will start
19 promptly at 3:30. So, get back a minute or so early,
20 and we'll go ahead.

21 Thanks very much. We're recessing for 15
22 minutes.

23 (Whereupon, the proceedings went off the
24 record at 3:15 p.m. and went back on the record at
25 3:30 p.m.)

1 CHAIRMAN BLEY: Excuse me. We're about to
2 start. The meeting will come back to order. Jose
3 Pires will take us through the structural discussion -
4 oh, and seismic.

5 MR. PIRES: Yes, structural and seismic.

6 CHAIRMAN BLEY: Excellent.

7 MR. PIRES: Good afternoon. I'm Jose Pires
8 from the Structural Engineering Branch. I am a senior
9 structural engineer.

10 This presentation was prepared by several
11 people. We have been involved as program managers for
12 some of these projects. We will be talking about
13 structural and seismic research.

14 The objective of this research is to
15 develop data and information, as well as to ensure
16 analytical capability for review and for independent
17 confirmatory assessments of safety-related structures
18 and equipment of future nuclear power plant designs.

19 The scope of the presentation, what we
20 will be addressing, is mostly the effect of high
21 temperature and radiation on concrete, especially high
22 temperature on concrete as a material, and as a
23 structural component.

24 And then we will be discussing various
25 seismic response issues related to structures and the

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1 calculation of loads on components.

2 And we'll also be talking about the
3 reactor vessel, especially core graphite components
4 and core support structures, and their response to
5 seismic loads, dynamic loads.

6 On the first topic of concrete subjected
7 to high-temperature demands, we have completed one
8 part of the research. We did a review of effects of
9 high temperature on concrete as a material during heat
10 and cooling. This report is being completed and has
11 been published.

12 One part of the study was to review what
13 are provisions on current US codes and standards, as
14 well as international codes and standards like what
15 was used to call the European Concrete Code, and now
16 is called the core published by the International
17 Federation of Concrete.

18 We have a project starting on soil-
19 structure interaction of deeply embedded or buried
20 structures. That project is going to continue.

21 Other projects that have already been
22 done, this is full competition procurement. The
23 proposals are currently being reviewed for awarding a
24 contract.

25 We also have another contract with a

1 national laboratory for multi-module response. That
2 is a condition in which you will have a common
3 foundation and various modules on that foundation, so
4 that you can - the number of modules can vary to the
5 life of the structure that look at these aspects.

6 What we have not yet started is the
7 evaluate assumptions and assess limitations of
8 existing codes for how can they be used to assess the
9 seismic response of reactor vessel graphite components
10 and core support structures.

11 These research interacts with the previous
12 work that was presented by - before that relates to
13 the evaluation of mechanical properties of the
14 graphite elements.

15 Now, this slide here is just to illustrate
16 that for some of the designs it is anticipated that at
17 least the reactor building and other - sometimes even
18 steam generator or other components would be
19 underground. Would be fully buried.

20 So, for that reason we needed to
21 investigate, and I put on the next slide, we need to
22 investigate what is the current provisions that exist
23 in the current regulatory guidance that are sufficient
24 to address issues that may arise for the seismic
25 response of deeply buried or embedded structures.

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1 The one concern here is to calculate what
2 are the ground motions of some of those components on
3 the vibrations of the ground are amplified because of
4 the structure and what loads they are going to compose
5 on the components. So, we need to assess that for
6 when the structures are deeply buried or fully
7 embedded.

8 We'll also be looking at the expressions
9 on the walls of these structures. Because as they
10 move and they push against the soil, the soil resists
11 this movement and induces forces, large forces on the
12 walls of the embedded structure.

13 Other aspects, for instance, if you scroll
14 down below, you'll see the multiple modules on common
15 foundations. And the number of modules may vary
16 during the life of the facility.

17 This of course is going to change the
18 natural frequency of the combined structure. May
19 affect the interaction, may affect the load on the
20 treatment, what we call the in-structure response
21 factor.

22 So, we want to look at the provisions that
23 currently exist, how adequate they are in terms of
24 broadening this. We have provisions to broaden the
25 flow response spectra, how this effusion to the - how

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1 can these things be accounted for?

2 Going back here to the concrete and the
3 high temperature, so that report that we just
4 published looked at the physical property assessment
5 methods and -

6 MEMBER RAY: Wait a second.

7 Could you go back to the slide where you-

8 MR. PIRES: Sure.

9 MEMBER RAY: Either I wasn't following you
10 word for word - on the last bullet, nonlinear dynamic
11 response of graphite reactor internals.

12 MR. PIRES: Yes. What the - we have not
13 started that. What the issue is there is that some of
14 these internals, as we understand, they have graphite
15 blocks that are attached to each of the dowels, simply
16 with dowels and with some keys to the ones on the side
17 vertically with dowels.

18 So, this is not a continuous structure.
19 So, this is just an example. The others will be a
20 part of pebble-beds in which you can have
21 densification off of the bed during a seismic event.

22 MEMBER RAY: Right.

23 MR. PIRES: And this blocks the -

24 MEMBER RAY: I understand, but I'm just
25 questioning that that's the only issue related to

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1 these structures. In other words, their nonlinear
2 dynamic response.

3 How about their behavior over time, the
4 ins-service inspection, basically? How do you verify
5 what their characteristics are over time?

6 Is that an issue?

7 MR. PIRES: It is an issue, and it is an
8 issue that is being also investigated again by the
9 other project that was referred. It looks at
10 mechanical properties of the materials, but we have
11 not been looking at that aspect in this project.

12 MEMBER RAY: It's being investigated by the
13 other project?

14 MR. PIRES: I think that if I understood
15 well on the previous presentations, I saw that they
16 had programs on assessing what are the mechanical
17 properties of the graphite components and -

18 MEMBER RAY: Yes, that's pretty traditional
19 at least in the 30 years I've been involved in it, but
20 there's always a problem of how do you determine what
21 the condition of those structures are over time? And
22 that's what I'm asking about.

23 MR. PIRES: Yes, it is I - we have not
24 looked at that, at that aspect yet.

25 MEMBER RAY: Well, you know, I can't do

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1 anything more than to say I think it should be an
2 issue for somebody, unless somebody's got a response
3 or an answer to it, because I've never -

4 MR. BASU: Harold, if I can just make an
5 attempt to answer your question, the materials program
6 and the graphite program that you heard in the last
7 couple of presentations, they will be looking at the
8 material degradation from the environmental factors,
9 as well as the aging issues that you are bringing up.

10 MEMBER RAY: Well, I did hear them say they
11 were looking at corrosion, but I guess I'm - it's
12 fine. If that's going to be the place where the
13 concern I have is addressed, that's sufficient, but
14 it's a little different than just either corrosion or
15 aging. It's actually verifying the integrity of a
16 critical structure periodically during its life.

17 And all I heard them talk about in that
18 regard is the pressure boundary. And so, that's why
19 I bring it up here thinking it was going to be talked
20 about in this context, but it's not.

21 It doesn't matter to me, but the point is
22 there's always been as long as I've been involved, an
23 unresolved issue which is do these things ever need to
24 be inspected? If so, how are you going to do it? To
25 what criteria?

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1 Or are you just going to assume you know
2 how they're going to behave over the life of the
3 plant, and that's the end of it? And that's what I'm
4 asking about.

5 MR. BASU: And, you know, we do appreciate
6 your question. There is the issue of in-service
7 inspection.

8 MEMBER RAY: Right.

9 MR. BASU: And you only got a very brief
10 presentation on that through the reliability and
11 integrated management program that Amy talked about in
12 the context of materials.

13 MEMBER RAY: Well, just make sure it's on
14 your list explicitly, okay?

15 MR. BASU: Good.

16 MEMBER RAY: Because it's been a dilemma
17 for a long time. And if somebody has solved it, I
18 would be pleased with that, but I have never heard
19 that anybody has.

20 MR. BASU: I made a note of that and will-

21 MEMBER ARMIJO: I'd just like to follow up
22 on something Dr. Pires mentioned, that is the response
23 of, let's say, a pebble-bed core to a seismic event as
24 far as densification of the core, some reactivity
25 insertion.

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1 Has that already been addressed or is it
2 being addressed in another part of your research?

3 MR. PIRES: We have not started that
4 specific study in this research. It's one of the
5 plans of the research is to address that. We have not
6 started.

7 There are computer codes that have modeled
8 similar phenomena on densification of granular
9 materials. So, those exist, but -- and I think that
10 there have been studies done by some of the - either
11 national laboratories or some of the developers of
12 these technologies to look at these aspects as well,
13 but we have not ourselves started looking at that yet.

14 MEMBER ARMIJO: It seemed like that
15 experimental technique that we were shown earlier
16 using these lasers to look at a two-dimensional slice
17 of a three-dimensional structure combined with some
18 seismic shaking would tell you -

19 MR. PIRES: Yes.

20 MEMBER ARMIJO: Could quantify a code and
21 say, yes, these things can densify and they will
22 change the -

23 MR. PIRES: I think that those techniques
24 can be useful to help validate codes, yes, those
25 techniques.

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1 MEMBER ARMIJO: But that's not necessarily
2 being addressed right now?

3 MR. PIRES: Not yet because we have not
4 started these.

5 MR. PETTI: We have done some.

6 MEMBER ARMIJO: You have? Okay.

7 MR. PETTI: And it's in the published
8 literature.

9 MR. BASU: Sam, those are addressing the
10 structural issues, but there are obviously other
11 issues, other facets of -

12 MEMBER ARMIJO: Yes. If you just shake a
13 bunch of balls together, they're going to compact.
14 They eventually get to -

15 MR. PIRES: Those techniques will be - when
16 I saw the presentation, I thought that those
17 techniques would be useful -

18 MEMBER ARMIJO: Yes.

19 MR. PIRES: -- to help validate the codes
20 determining actually initial conditions and to help
21 validations and verification. Probably also
22 inspection, depending how -

23 MEMBER ARMIJO: Yes, not too expensive.
24 Okay.

25 MR. PIRES: So, in this area here we have

1 published a review, a NUREG report under the contract
2 to Oak Ridge National Laboratory on the effects of
3 high-temperature on properties of concrete.

4 Typically, we have been looking at the
5 traditional properties of the concrete that tell the
6 compressive strength, elasticity, modules of
7 elasticity, bond strength.

8 And part of the work also will involve
9 lessons learned from concrete facilities subjected to
10 high temperatures.

11 And we are continuing the work to
12 understand how sufficient are the current code
13 provisions and guidance and what modifications those
14 are needed for those for review. So, it's still
15 necessary to continue the activity.

16 This is just a picture that gives you an
17 idea. It is not present data, but the compressive
18 strength of the concrete is very stable at to about
19 400 degrees Fahrenheit, about 200 degrees Centigrade.

20 Same thing for the modules of elasticity,
21 but it does degrade quickly after that. So, you can
22 at about 700, 800 degrees Centigrade get to about 20
23 percent or 40 percent of the values.

24 This is just a picture just to illustrate
25 that a phenomena - this is a phenomena in which

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1 traditional concrete - I mean concrete with an
2 ordinary cement paste was given to very high
3 temperatures and it dehydrates, and then it re-
4 hydrates again. It's spall, as shown on the right
5 picture.

6 So, it's just to see that other
7 phenomenology may also be important. Because if you
8 spall the concrete, you then have easier access of the
9 moisture and the temperature to the reinforcement.

10 We have been looking at various phenomena,
11 but these also can be prepared by using different
12 cement pastes.

13 The seismic soil-structure interaction
14 issues, as I said, we have several proposals in the
15 review for a project on deeply embedded structures.

16 The goal is to collect and summarize
17 experimental data. It will build and continuing on
18 previous work that has been reported on two NUREGs.

19 The first one there, the 6957, already in
20 a comparison in a benchmarking against some
21 experimental data from Japan from JNES with a small
22 scale. A 1/10th scale.

23 We will be doing a parametric study. The
24 parametric study is going to be looking at things like
25 the ground motion intensity including beyond design

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1 basis, advantage and disadvantage of linear versus
2 nonlinear analogies for review, what are the limits of
3 publication of each one, effects like gaps that may
4 develop between the soil and the structure, friction
5 at the interface between the soil and the walls and
6 some other three-dimensional impacts.

7 Some of the data in Japan is for
8 rectangular cross-sections. And while here, some of
9 the buildings may be more of cylindrical shape. So,
10 those also have some effects on the BA here.

11 In the entire research that we have been
12 doing, there are some assumptions that some data will
13 be available from the current DOE research work.

14 For instance, in the case of the elevated
15 temperatures, not only you are looking at the effect
16 of the temperature on the concrete as a material, but
17 we also need to start looking at how the temperature
18 from the reactor - or what will be the temperature on
19 the actual walls and what will be the cyclic soil flow
20 in high temperature, because these have an effect on
21 the behavior to see how much through the concrete wall
22 the temperature will go. So, we need some information
23 on that.

24 We have been looking at international
25 codes. As I mentioned, European codes for concrete,

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1 as well as the American Concrete Institute codes, ASME
2 codes.

3 We already have programs to obtain data
4 from the 2007 earthquake known as the Kashiwazaki-
5 Kariwa earthquake. And most likely we will try to
6 analyze data from more recent earthquake.

7 And I did make this summary of what we
8 did. So, we have completed the first phase of the
9 project on the high temperatures. We did a review.
10 We also made a comparison on those reports among
11 provisions and current codes.

12 We are now analyzing - have a project on
13 deeply embedded structures that builds on two previous
14 projects that is expected to start at the end of this
15 fiscal year.

16 We have already a project ongoing with
17 multiple models on a common foundation that started
18 already with a national laboratory.

19 The aspect of the graphite components and
20 reactor support structure, that is planned for a
21 future activity.

22 We have also worked with the code
23 committees; ACI 349 for concrete structures that are
24 safety related, the AISC N690 which we are developing
25 guidelines for steel plate-reinforced concrete

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1 structures, ASCE 43-05 which has information on
2 performance-based design or what constitutes an
3 adequate seismic design basis load. So, we continuing
4 working with the standard developing organizations and
5 committees.

6 Going forward, so we will continue with
7 the R&D plan that we currently have. We will adapt
8 the needs of that plan based on technology selection
9 if those - because adaptations are needed, you know,
10 particularly for some structural aspects may require
11 more knowledge of what the actual architectural
12 engineering aspect of these facilities would be.

13 And we will continue to brief the ACRS
14 periodically. And we will of course coordinate with
15 DOE and INL on what are the gaps that we will identify
16 for the reviews. And that pretty much concludes what
17 I have to say.

18 CHAIRMAN BLEY: Can I just take you back?

19 MR. PIRES: Sure.

20 CHAIRMAN BLEY: This isn't my field at all,
21 but to your Slides 8 and 9. I've been staring at them
22 and trying to make sense of the two.

23 MR. PIRES: Okay.

24 CHAIRMAN BLEY: I guess we struck a line
25 through these two sets of data that isn't quite the

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1 story. So, if you draw a vertical line at any
2 temperature looking at the one hour, four hour, 24
3 hours and seeing how far these things stretch apart is
4 more related to what we see on the next page that -

5 MR. PIRES: The next page is different
6 phenomena, but you are right. That line is not just -
7 there are other effects there like the time of heating
8 and - but - and this is supposed to - are the
9 properties at that temperature when it has been
10 heated.

11 The next page is a little bit different.
12 It's another phenomena that is, well, at these very
13 high temperatures, the concrete when heated with
14 ordinary cement paste, dehydrates, but also there are
15 chemical changes on the -

16 CHAIRMAN BLEY: That continue after it
17 dehydrates.

18 MR. PIRES: Yes, they continue after, but
19 then it hydrates. With additional water some of the
20 molecules expand, and that difference in what expands
21 and what does not expand causes the cracking.

22 CHAIRMAN BLEY: And this is just pure
23 concrete specimen.

24 MR. PIRES: It's just concrete. Is not
25 reinforced. Is cement and aggregate. Cement and

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1 aggregate. And these deformations mostly happen
2 within the cement and the bonds between the cement and
3 the aggregate.

4 But the other test we have done where if
5 you put, for instance, slag as part of the cement
6 paste, initially then this effect minimizes or almost
7 disappears. So, there are additives.

8 But the review, we just put that there to
9 illustrate that is not just the traditional properties
10 of strength and - of stiffness, but also these effects
11 that we need to be looking at.

12 Of course this is very high temperature.
13 So, maybe we will not get to those temperatures in the
14 concrete itself.

15 That's why I said that part of our
16 knowledge will be to try to look at how all the heat
17 from the reactor actually couples to the walls. And
18 then we will know if a more realistic assessment of
19 what are the temperature ranges we need to -

20 CHAIRMAN BLEY: Okay. Well, they are
21 different. But if you look at one of those curves,
22 like the first one with the compressive strength, and
23 you just pick a temperature like somewhere around 500
24 and look at the one hour, four hour and 24 hours, you
25 see it's losing its strength over that time period.

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1 MR. PIRES: Losing its strength.

2 CHAIRMAN BLEY: Yes.

3 MR. PIRES: Part of the work is how long
4 you stay in the sustained temperature and also the
5 cycles, how you go up and down.

6 CHAIRMAN BLEY: And this doesn't show you
7 the timer temperature. This is time after you were at
8 temperature.

9 MR. PIRES: I think this is the time at
10 temperature.

11 CHAIRMAN BLEY: I'm at temperature after
12 you guys got to that temperature.

13 MR. PIRES: Yes, this is at temperature.

14 CHAIRMAN BLEY: Okay.

15 MR. PIRES: And this data on these figures
16 is already old. There are more recent data points.

17 CHAIRMAN BLEY: So, this is just telling
18 you that you need to have concern. It's not telling
19 you what to do about it yet.

20 MEMBER ARMIJO: To stay at a low
21 temperature.

22 CHAIRMAN BLEY: Yes.

23 (Laughter.)

24 MR. PIRES: Preferably try to stay below
25 200 degrees Centigrade.

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1 (Off-record discussion.)

2 MR. BASU: Do you want me to repeat?

3 CHAIRMAN BLEY: If you want to.

4 MR. BASU: Well, I said as long as you stay
5 below 200 degree, you should be okay. So, that's the
6 message that -

7 MR. PIRES: There are specific provisions
8 in the codes at other temperatures that other
9 properties - tensile strength, you know, compressive
10 strength, all those vary in a different manner, but
11 just to give you a range of what happens.

12 CHAIRMAN BLEY: Okay. Thanks.

13 Anything else?

14 Thanks very much.

15 MR. PIRES: You are welcome.

16 MR. BASU: Okay. The next one is the PRA
17 on the list.

18 CHAIRMAN BLEY: Wonderful.

19 (Off-record discussion.)

20 MR. WOOD: I'm Jeffrey Wood. I'm going to
21 be presenting on the HTGR research plan for PRA. Mary
22 Drouin is also a support in this work.

23 MS. DROUIN: I'm here so you all don't beat
24 him up.

25 MR. WOOD: Thank you, Mary.

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1 Two PRA activities I'm going to mention
2 today. The first is a draft reg guide that was
3 completed by Research and transmitted to NRO for
4 internal review.

5 This draft guide discusses a risk-informed
6 approach to identifying licensing basis events. And
7 this draft guide is being considered with other
8 ongoing activities in developing a new risk-informed
9 regulatory structure for advance reactors.

10 Now, those activities are being led by NRO
11 and there's no more work in this research plan in that
12 area. So, I'm not going to discuss it further today.

13 CHAIRMAN BLEY: Okay. But that's what we
14 would have heard from when we talk to NRO about the
15 small modular reactors and the non-LWR small - SMRs,
16 is this plan.

17 MR. WOOD: Yes. Right.

18 CHAIRMAN BLEY: And that's actually under
19 development?

20 MR. WOOD: There's ongoing activities, yes.

21 CHAIRMAN BLEY: Okay. Go ahead.

22 MS. DROUIN: But the reg guide was to
23 support non-LWRs, not specifically SMRs. It was to
24 support the NGNP licensing approach. And a draft reg
25 guide was sent over to NRO for their review.

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1 So, right now it's in their hands until
2 they come back to us with comments, you know. We
3 don't know what will happen.

4 MS. BANERJEE: I guess what you may be
5 thinking is the White Paper, LBE White Paper that NGNP
6 developed that was provided.

7 CHAIRMAN BLEY: It's also the appendix to
8 the reg guide. It's the same thing.

9 Go ahead.

10 MR. WOOD: Okay. Thank you.

11 The activity I'm going to be focusing on
12 is a planning study that was undertaken to identify
13 potential PRA research needs to support the HTGR
14 licensing.

15 And I'll go through the background
16 approach, observations and insights and give the
17 current status of this study.

18 So, the background for this planning study
19 was motivated by the notion that risk insights will be
20 a part of licensing the NGNP plant. This is pointed
21 out in the NGNP licensing strategy report.

22 So, the purpose of our study is to
23 identify where there are gaps in the guidance methods
24 or data that's needed to support the development of a
25 PRA model for an HTGR.

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1 The scope of the study is to address all
2 hazards, all operating states, all risk levels and all
3 plant design life cycle phases.

4 CHAIRMAN BLEY: So, you're focused on what
5 would the PRA look like. And that first bullet up
6 there about how the PRA will get used in the licensing
7 isn't part of what you're reporting on.

8 MR. WOOD: That's correct.

9 CHAIRMAN BLEY: Okay.

10 MR. WOOD: And our concern is, is the PRA
11 technically acceptable?

12 CHAIRMAN BLEY: Okay.

13 MS. DROUIN: But how it will be used is an
14 important aspect you'll see later on, because how it's
15 used will depend what gaps you have.

16 CHAIRMAN BLEY: Absolutely.

17 MR. WOOD: Of course we have to consider
18 the application that the PRA is being used for.

19 CHAIRMAN BLEY: Okay.

20 MR. WOOD: So, the approach to our planning
21 study was to review available literature, to identify
22 unique design and safety issues associated with HTGR
23 that may impact the PRA model.

24 Also, to identify any gaps in guidance
25 data, methods, models, tools, that are needed to

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1 establish the PRA technical acceptability. And to
2 identify the assumptions that will be needed in order
3 to develop a PRA model.

4 It's particularly important when you're
5 talking about a plant that's in the design phase and
6 has limited applicable operating experience.

7 CHAIRMAN BLEY: We spent the day listening
8 to a lot of places there's technical gaps that are
9 being filled.

10 How integrated is what you've done in
11 looking at the PRA, how integrated is that with all
12 these other areas that people are actively working to
13 fill in the technical gaps?

14 MR. WOOD: Well, we keep in regular contact
15 with the other groups. But the planning study that
16 I'm talking about here is really a comprehensive
17 listing of the things that can affect the PRA.

18 CHAIRMAN BLEY: Okay.

19 MR. WOOD: Some of them do already have
20 ongoing research programs and other technical
21 disciplines that will influence what we need to do to
22 have the knowledge we need to review a PRA.

23 CHAIRMAN BLEY: All right.

24 MS. DROUIN: Those gaps we don't get into
25 because we already know that there's an ongoing

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1 program.

2 I mean, you know, there's a lot of
3 deterministic stuff that supports the PRA. So, where
4 those deterministic analyses are being done that would
5 support us, we don't get into that because we already
6 know they're being done in another program.

7 So, it's not a -

8 CHAIRMAN BLEY: You don't know how they're
9 going to finish though. You don't know if they'll be
10 resolved.

11 MR. WOOD: That's why they're on our list.

12 MS. DROUIN: That's why there's close
13 contact.

14 CHAIRMAN BLEY: Okay. But they are on your
15 list.

16 MR. WOOD: That's right.

17 CHAIRMAN BLEY: Okay. Go ahead.

18 MEMBER RAY: Well, let me say this: This
19 morning it was pointed out that the research program
20 was geared to the EPA description with respect to, for
21 example, siting. And, therefore, it assumed siting at
22 a DOE facility and so on.

23 Is that relevant to the scope of what
24 you're talking about here?

25 In other words, has the site location got

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1 any - are you looking for any site or are you just
2 talking about a PRA as it would apply in a particular
3 location such as Idaho?

4 MR. WOOD: Well, the site wasn't a major
5 driver in our review because most of the elements of
6 the Level 3 PRA or the consequence analysis, are
7 pretty much technology neutral. They don't really
8 depend on it being an HTGR or LWR.

9 MEMBER RAY: Well, what I'm thinking about
10 is how you would approach a PRA for a site that had a
11 very close-in footprint, for example. A small
12 exclusion area in an industrial location.

13 MS. DROUIN: Well, we -

14 MEMBER RAY: And I'm just wondering if that
15 would have any bearing on what you're thinking about
16 now.

17 MS. DROUIN: It depends at what part of the
18 process in the PRA you're looking at for the gap, you
19 know.

20 In the design stage where you don't have
21 a site, then the assumption is made for a generic
22 site.

23 As you move more into the operational,
24 then, yes, where that site is located becomes
25 important.

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1 MEMBER RAY: Well, yes, whether it's in a
2 remote location or in a -

3 MS. DROUIN: Exactly.

4 MEMBER RAY: -- area in which you can't
5 assume a large exclusion distance and that sort of
6 thing.

7 Okay. Well, fine. If it doesn't have any
8 bearing on what you're doing right now, that's enough
9 of an answer.

10 MS. DROUIN: Well, it's one of these - it
11 will be what we call a high-level finding, and Jeff
12 will be getting into that.

13 MEMBER RAY: Okay.

14 MR. WOOD: Okay. So, let me just quickly
15 go over some of the documents that we reviewed for our
16 planning study.

17 We looked at the technical documents on
18 the - discussing the HTGR design features, some NGNP
19 studies and also past information submitted to NRC for
20 previous HTGR design such as the MHTGR and the Fort
21 St. Vrain reactor.

22 We looked at standards documents related
23 to PRA. We reviewed the published ASME/ANS PRA
24 standard for operating reactors covering Level 1 PRA
25 and LERF.

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1 We also looked at several PRA standards
2 that are under development covering different aspects
3 of PRA for both LWRs and non-LWRs.

4 So, we have two types of observations
5 coming out of this study. We grouped them into high-
6 level issues dealing with the overall PRA technical
7 acceptability, and detailed issues related to each of
8 the technical elements that make up a PRA.

9 So, these are just examples here on this
10 slide. We have more examples documented in a report
11 for our planning study.

12 Examples of high-level issues are
13 observations related to the acceptable level of detail
14 for PRA, the risk metrics and the associated criteria
15 that are used to assess the results of PRA.

16 The spectrum of the operating states that
17 are analyzed, and also the hazards that are analyzed,
18 and any unique impacts of those hazards.

19 The example is given here of a seismic
20 event impacting the prismatic blocks that could clog
21 cooling channels. We heard more about that in the
22 last discussion.

23 So, some examples of the detailed issues.
24 And these are potential issues that may need
25 additional research to address.

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1 Examples include things like the analysis
2 of potential initiating events and derivation of
3 initiating event frequencies, defining PRA success
4 criteria. Also, considering that the PRA is intended
5 to be expanded to include sequences for anticipated
6 operational occurrences, design basis events and
7 beyond design basis events.

8 Understanding of unique environments and
9 conditions for an HTGR that can impact the system
10 performance.

11 There are human performance considerations
12 such as controlling multiple units from a single
13 control room, and modeling of new phenomena in the
14 PRA. For example, air/water ingress. Also, aerosol
15 transport models for dry environments as opposed to
16 human environments.

17 And I think earlier in the day you heard
18 about the MELCOR development. That's addressing some
19 of those issues.

20 So, our observations led to insights for
21 follow-on work. The primary task that's proposed is
22 the development of a guidance to support the staff's
23 review of an HTGR PRA.

24 This guidance is intended to facilitate
25 the understanding of where assumptions are likely to

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1 be made, what constitutes an adequate assumption, the
2 relative importance of assumptions, the assessment of
3 parameter uncertainties and also appropriate use of
4 bounding analyses.

5 CHAIRMAN BLEY: You say the NUREG on
6 uncertainty and LWR PRAs is something you need to
7 expand?

8 Is that what these two bullets are
9 suggesting?

10 MR. WOOD: Not expand, but just take
11 consideration of the unique aspects of an HTGR design.

12 CHAIRMAN BLEY: When that came out, you
13 said it was for LWRs.

14 MS. DROUIN: Can you repeat your question?
15 I didn't quite follow it.

16 CHAIRMAN BLEY: You wrote a NUREG on
17 uncertainty in LWR -

18 MS. DROUIN: And we're revising it. We're
19 going to come see you in October.

20 CHAIRMAN BLEY: Oh. And that will now
21 extend it beyond LWRs?

22 MS. DROUIN: No.

23 CHAIRMAN BLEY: So, my question was, is
24 what's in there what you need to think about with
25 respect to uncertainties for the HTGR, or are you

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1 having to go beyond the kinds of issues that you
2 identified for LWRs?

3 MS. DROUIN: Well, you have to remember
4 that that guidance is to - guidance to the licensee of
5 how is he to assess these uncertainties in his PRA.

6 A lot of the process, and we said that
7 before to the ACRS, a lot of that process is if you
8 want to call it technology neutral, because it really
9 doesn't get into the type of reactor. It gets into
10 how do you treat the uncertainties in your basic
11 events?

12 When you're calculating your risk
13 measures, you know, how do you take those
14 uncertainties? You know, how do you deal with the
15 model uncertainties and how do you deal with all of
16 this?

17 CHAIRMAN BLEY: How do you identify them
18 all?

19 MS. DROUIN: I'm sorry?

20 CHAIRMAN BLEY: How do you identify them
21 all? There's a lot of work on that provided.

22 MS. DROUIN: How do you go about identify
23 them? That's in there, too.

24 So, a lot of that process would be
25 applicable because it's really separate from the

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1 actual design of the plant.

2 CHAIRMAN BLEY: Thanks. That's what I
3 wanted to hear.

4 MS. DROUIN: Oh, okay.

5 CHAIRMAN BLEY: Go ahead, Jeff.

6 MR. WOOD: Okay. Next slide. So, in
7 parallel to this guidance development, we're also
8 going to continue to prioritize activities to close
9 any existing technical gaps. And this includes
10 determining if there are any issues that require
11 additional technical guidance development. And, also,
12 to identify what the best vehicle is for that
13 development. It may be an NRC-led task or industry-
14 led or maybe some cooperation between the two.

15 And, also, we acknowledge that there are
16 some issues that have ongoing related research
17 activities that may be sufficient to address the needs
18 for reviewing an HTGR PRA.

19 So, our status of this planning study, we
20 completed the study. We completed our contract
21 support in February. We have this study documented in
22 a report.

23 Currently, we're coordinating with NRO to
24 pursue follow-on activities which will be the
25 development of the guidance that I discussed and also

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1 assessing any other activities that may be needed to
2 close the technical gaps. And that's all I have.

3 CHAIRMAN BLEY: Thank you.

4 Anything more from the Committee?

5 Thanks very much. Next.

6 MR. BASU: Next is the human factor.

7 (Off-record discussion.)

8 MR. FLEGER: Good afternoon. My name is
9 Steve Fleger. I'm a senior human factors analyst in
10 the Division of Risk Analysis.

11 The objectives of our research were just
12 to provide an overview of the plan for conducting
13 confirmatory human factors research to support DOE's
14 NGNP program.

15 That confirmatory research then that we're
16 in the process of doing, will serve as a technical
17 basis to support the update of the NRC's primary human
18 factors documents - or guidance documents, I should
19 say.

20 And there's three guidance documents;
21 Chapter 18 of the Standard Review Plan, NUREG-0711
22 which is the programmatic guidance that is utilized
23 for reviewing an applicant's implementation plan,
24 human factors implementation plan or management plan;
25 and then NUREG-0700 which provides a human factors

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1 guidance for reviewing the human system interfaces.

2 In terms of trying to scope this effort
3 out, we're looking at the differences between
4 essentially the existing Generation 2 plants, as well
5 as the new Gen-3 plants and the advanced Gen-4 nuclear
6 power plants.

7 These differences can be binned into two
8 primary areas; the reactor design and the control
9 room.

10 In terms of the reactor design, we're
11 talking primarily about non-light water reactors that
12 usually utilize passive safety systems and involve
13 multiple modules.

14 The control room differences that we're
15 going to see in the new and advanced plants are best
16 described as being a highly-integrated control room.

17 And by that I mean they have digital I&C,
18 increased use of automation, advance control
19 algorithms. Usually involves sit-down consoles with
20 soft controls and the use of computer-based
21 procedures.

22 CHAIRMAN BLEY: Stephen, I asked this, I
23 think, before you were here this morning, but we've
24 just put it off until now: We've been looking at the
25 new I&C and new control room designs for the plants

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1 that are coming in for design certification. As far
2 as I can tell, they're working at the edge of
3 technology right now.

4 Is there anything envisioned for the
5 plants you're looking at that in any way go beyond
6 what we're seeing in the new design cert plants?

7 MR. FLEGER: There is, and I'm going to get
8 to that.

9 CHAIRMAN BLEY: You got that. Okay.

10 MR. FLEGER: Yes, yes. I'll get to that in
11 a couple of slides.

12 The short answer is the SMRs. We're
13 seeing some unique differences with the SMRS. So,
14 I'll go over that briefly.

15 CHAIRMAN BLEY: Okay. Yes, we haven't seen
16 any of that yet. So, go ahead.

17 MR. FLEGER: So, as a result of those
18 changes in a highly-integrated control room, Research
19 about maybe five, six years ago performed a study
20 where we looked at emerging technology that is
21 anticipated in these new plants.

22 And that report was summarized in a NUREG,
23 NUREG/CR-6947, which I believe the same subcommittee
24 evaluated earlier this year.

25 That particular NUREG identified 64

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1 research issues as being new or different or that need
2 to be addressed.

3 So, those 64 research issues, we divided
4 them into about seven different human factors topic
5 areas. And then we applied a PIRT methodology to bin
6 those research areas into one of four priority areas
7 and about 20 different topics were identified as being
8 of the highest priority.

9 So, given the current state of knowledge,
10 the differences between the new and the advanced
11 nuclear power plants exist more with the design of the
12 reactors and less with the design of the control room.

13 Therefore, the research that's needed to
14 address human performance issues brought about by the
15 emerging technology, are equally applicable for both
16 new and advanced reactor designs.

17 So, most of the human factors research
18 that's being planned or that's currently underway is
19 applicable to both the new Gen-3 and advanced Gen-4
20 reactor designs with one exception. And that
21 exception has to do with the modular reactors.

22 So, recognizing the differences, we
23 sponsored a study about a year and a half ago to look
24 at the human factors aspects associated with the
25 concept of operations of modular designs.

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1 And that project consists of four tasks.
2 The first task was to develop a CONOPs model, and by
3 that I simply mean a characterization of SMRs in terms
4 of the concept of operations. How do the CONOPs for
5 the SMRs differ from the CONOPs for the existing fleet
6 of reactors, as well as for the new Gen-3 plants?

7 And so, that characterization I guess can
8 best be described in a couple -- summarized in a
9 couple of areas.

10 Typically, they involve small electrical
11 outputs, 350 megawatts electrical or less, they
12 involve multiple modules and have usually more than
13 one mission in addition to power generation or maybe
14 hydrogen production and process heat applications.

15 And probably the biggest area has to do
16 with the area of operations from the control room
17 operator's perspective. So, we're talking for the
18 CONOPs for these plants, generally talking about
19 operating -- a reduced crew operating from a single
20 control room, multiple reactors which may be in a
21 variety of states and running at different power
22 levels.

23 MEMBER CORRADINI: So, I guess I don't
24 understand the assumptions that you just said.

25 So, the thinking process is that there

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1 would be a control room for multiple modules? And
2 that links up with the current design concept from the
3 - I'm thinking only the light water group, the light
4 water reactor modules, or are you thinking beyond that
5 to like NGNP-related that also there would be multiple
6 modules in a single control room?

7 MR. FLEGER: No, so for the multiple
8 modules, the multiple reactors, from what we've seen,
9 it's looking like there will be just one control room.

10 And so for that one control room, they'll
11 have a crew. And the crew may be less. We may have,
12 you know, one operator for each reactor.

13 So, if you have a design consisting of 12
14 modules and 12 reactors, you'll have a significantly
15 reduced crew all operating from one control room.

16 And so, the concept in terms of how do you
17 lay out the I&C, how do you lay out the work stations
18 which are digital, sit-down work stations? Do you
19 have work stations for each reactor? Is that better?
20 Or should you have just one work station and then have
21 the operators all sharing that work station?

22 MEMBER CORRADINI: All there multiple
23 module fossil plants that one can look at and see how
24 they're designed now that would match up with that, or
25 is there something unique about this relative to the

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1 module area?

2 MR. FLEGER: No, there are. And I'm going
3 to talk just briefly about that next.

4 MEMBER CORRADINI: Okay. All right.

5 MR. FLEGER: So, given the CONOPs model
6 with admission in the middle, we identified five
7 supporting dimensions.

8 And so for each of those supporting
9 dimensions, we looked at the - we're interested, I
10 should say, in identifying the human performance
11 issues associated with those dimensions which support
12 the CONOPs model.

13 So, since there are currently no modular
14 operating reactors, we had to look at surrogate
15 systems.

16 So, through a combination of site visits,
17 as well as literature review, we looked at - we
18 examined offshore oil platforms, we looked at
19 refineries, we looked at tele-intensive care units,
20 naval vessels and -

21 CHAIRMAN BLEY: Did they share information
22 with you?

23 MR. FLEGER: Yes.

24 CHAIRMAN BLEY: They did?

25 MR. FLEGER: Yes, they did.

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1 (Off-record discussion.)

2 CHAIRMAN BLEY: Hey, you said you had this
3 project.

4 Is there a report out on this?

5 MR. FLEGER: There will be this year, yes.

6 CHAIRMAN BLEY: Okay.

7 MR. FLEGER: I think the project has been
8 going on for about 18 months now and it's currently
9 slated to - the period of performance as far as I
10 know, is supposed to end the end of next month.

11 CHAIRMAN BLEY: Okay.

12 MR. FLEGER: And then there's the review
13 process. So, by the end of the year we'll anticipate
14 having -

15 CHAIRMAN BLEY: Brookhaven again or
16 somebody else?

17 MR. FLEGER: Yes, this is Brookhaven.

18 CHAIRMAN BLEY: We'd be real interested in
19 following that when you get something.

20 Okay. Go ahead.

21 MR. FLEGER: Sean, I don't know. Are we
22 going to be mentioning that on Friday?

23 MR. PETERS: Is this thing on?

24 CHAIRMAN BLEY: Yes, you're on.

25 MR. PETERS: Sean Peters. I'm the branch

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1 chief for the human factors and reliability branch in
2 the Office of Research.

3 And, yes, we will have a very small
4 discussion on CONOPs, but we will have the author of
5 the project, John O'Hara, in house. So, if you have
6 any further questions, we can delve into that. At
7 least the current state of that project.

8 It wasn't on the initial agenda to go into
9 a detailed discussion of it, but we can expand upon
10 that as we're closer.

11 CHAIRMAN BLEY: Super.

12 MR. FLEGER: Okay. So, real quickly then,
13 the third task was to evaluate current NRC regulations
14 and guidance to look at the suitability of that
15 guidance for addressing human performance issues that
16 were identified in the SMRs.

17 And for each of the six dimensions of our
18 model that we developed, we did identify a number of
19 human performance issues that are new that we feel
20 need to be looked at.

21 The guidance review, NUREG - rather the
22 regulatory guidance review is finished now. There
23 were aspects of the existing regs that will require
24 modification. And I believe there are also some new
25 issues that we've identified, human performance issues

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1 that may require the issuance of new guidance or
2 regulations.

3 And finally the fourth area then is to
4 develop draft human factors guidance. And that will
5 be done following our NRC's guidance development
6 methodology.

7 In terms of our research to support new,
8 as well as advanced reactors, it's been categorized
9 into these six areas: The first has to do with
10 research addressing human performance aspects of
11 automation and human system interface complexity.

12 That study was completed last year.
13 There's a technical report out on that. There's also
14 another study underway that is following up on BNL's
15 research that's being conducted by MIT. And I believe
16 we're about halfway through the period of performance
17 on that effort.

18 In the area of computer-based procedures,
19 the NRC has been supporting IEEE's nuclear power
20 engineering committee, Subcommittee 5's effort to
21 develop new guidance on computerized operating
22 procedure systems.

23 And we also have a task underway with INL
24 to research some of the specific shortfalls we've
25 identified in supporting the computer-based procedures

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1 standard.

2 CHAIRMAN BLEY: You've been up to the - any
3 of the vendor facilities that are actually
4 implementing those and see what they're doing?

5 MR. FLEGER: I personally have not been.

6 CHAIRMAN BLEY: I know NRO has been up.

7 MR. FLEGER: NRO has been.

8 CHAIRMAN BLEY: It's worth it. You learn
9 a lot up there.

10 MR. FLEGER: Yes, I'd love to get up there.
11 We do have people, though, real quickly, on the
12 committee, IEEE committee, that's involved with the
13 design of all that.

14 So, I think the standard will do a pretty
15 good job at addressing some of the needed guidance for
16 computer-based procedures.

17 CHAIRMAN BLEY: Well, I hope the people
18 involved in the standards are actually getting to see
19 what's being done, because there's some, I think, real
20 surprises when you see what they're doing up there.

21 MR. FLEGER: Yes, there are a number of
22 folks in NRO that are on that committee that have made
23 those trips.

24 CHAIRMAN BLEY: Okay. Good.

25 MR. FLEGER: So, they are involved.

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1 Human performance impacts of degraded I&C
2 and HSIs, this study was also published last year.
3 It's a BNL initiative. And as a result of that, we
4 identified a lot of additional work that's needed.

5 So, in support of that, this year we'll be
6 launching a new study to follow up on that work. And
7 we can go into more detail on that, too. And, in
8 fact, I know we are on Friday.

9 Fourth area, workload, situational
10 awareness and teamwork. Got an SOW that's written and
11 that, as I understand it, task was just awarded last
12 month. So, that effort will be starting soon.

13 And then the considerations for staffing
14 development and validation, that SOW is in process.
15 And integrated system validation or the performance-
16 based test contract will be also this year. And
17 that's related to methods and tools development, which
18 is an ongoing contract.

19 Some of our assumptions or research needs
20 has to do with the lack of availability of the Gen-3
21 and Gen-3 plus designs in this country.

22 So, we're hoping to get some of the
23 information from the Japanese and the French with the
24 N4 and the ABWR. And I've just identified four
25 bullets, four areas that we do need additional

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1 guidance on and hopefully we will be able to get from
2 our colleagues overseas.

3 And the other area has to do with
4 simulation and simulators. And although the
5 applicants will submit research results needed to
6 support their designs, it may be necessary for us to
7 do some independent validation of that work. So, we
8 feel that a research simulator will be essential to do
9 that confirmatory analysis.

10 And then in moving forward, you know, we
11 plan to continue our research. I'd say most of the
12 research I just highlighted here in those six areas,
13 probably half of it's done and the other half is
14 underway with a couple of projects that will be
15 launched this year.

16 That research then will be used to support
17 the technical basis which will form the foundation for
18 our primary human factors guidance documents. The
19 first of which, Rev 3 of NUREG-0711, is slated to be
20 released this summer.

21 CHAIRMAN BLEY: Can I take you back to your
22 first bullet? The need for the simulator - I'm sorry.
23 The previous page.

24 Is that something you see NRC doing, one
25 of your contractors doing, something you do with

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1 Halden or what are you thinking about?

2 MR. FLEGER: Well, probably all of the
3 above.

4 We do have -- Research did procure a
5 simulator. It's on board.

6 CHAIRMAN BLEY: Oh.

7 MR. FLEGER: It's on board. We have it.

8 CHAIRMAN BLEY: Down in Chattanooga or is
9 it up here?

10 MR. FLEGER: No, it's up here. Church
11 Street.

12 So, the plan is through a combination of
13 those three, to do research in-house to utilize
14 Halden. In fact, right now we're working on a
15 bilateral agreement with Halden to support the
16 integrated safety validation research that I
17 mentioned.

18 CHAIRMAN BLEY: Okay. Good. Thanks.

19 MR. FLEGER: And that's all I have.

20 CHAIRMAN BLEY: Anything more from the
21 Committee?

22 Stephen, thanks very much.

23 Sud, next.

24 MR. BASU: Next is I&C presented by Russ.
25 We have two presenters also for this one.

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1 MS. BANERJEE: I have only one for Dr.
2 Yang.

3 MR. YANG: Yes, this presentation was
4 prepared by both Russell and me, but Russ asked me to
5 give the presentation so that I have some experience
6 here.

7 CHAIRMAN BLEY: Well, welcome.

8 MR. YANG: But if you have tough questions,
9 ask my boss.

10 (Laughter.)

11 MR. YANG: All right. So, I'm going to
12 talk about NGNP instrumentation and controls. This is
13 the scope of my presentation.

14 First, I'm going to talk about objectives
15 of NGNP I&C research. Then I'm going to talk about
16 unique I&C issues in NGNP and expected I&C design
17 features in NGNP.

18 After that, I'm going to talk about three
19 research projects in I&C, and what do we know from
20 this project and what we don't know yet. The last
21 part is our future plan.

22 First, our objectives is to provide
23 technical basis for regulatory decisions and to
24 develop regulatory infrastructure necessary to support
25 the review of NGNP license application.

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1 Next. In order to achieve our objectives,
2 we need to know what are the differences between I&C -
3 NGNP and I&C in light water reactor.

4 So, I'm going to spend a little time to
5 talk about unique I&C issues which may affect I&C
6 design.

7 The first thing is the harsh environment.
8 You may know that NGNP temperature will be as high as
9 like 570 degree, which is much higher than light water
10 reactor.

11 We also may have -

12 CHAIRMAN BLEY: five, seven?

13 MR. YANG: 570 - thank you. 750 degrees.

14 CHAIRMAN BLEY: That's better.

15 MR. YANG: The light water reactor is below
16 400 degrees C. So, it's much higher.

17 We also may have corrosive materials if we
18 use, say, SI processes in hydrogen generation where we
19 have all the chemical processes.

20 Also, co-generation makes the I&C design
21 different because now we are going to control not only
22 the generator, but also we need to control the key
23 processes, which makes the system more complicated.
24 Will have more systems.

25 CHAIRMAN BLEY: So, if we have an attached

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1 hydrogen generation system or process system using the
2 heat, NRC will be reviewing the I&C for that process
3 system; is that true?

4 MR. YANG: We don't know that yet, but I
5 think NRC is best to be prepared if we need to review
6 both side.

7 CHAIRMAN BLEY: Thanks.

8 MR. SYDNOR: There are certainly the safety
9 implications of that on the protection system.

10 MR. YANG: Because the - if hydrogen
11 generation has some upset, it may require the reactor
12 system to treat for the safety. That's why we need to
13 consider it.

14 CHAIRMAN BLEY: That's fine. Go ahead.
15 Thanks.

16 MR. YANG: Another issue is the advanced
17 reactor design concept may affect the I&C design. For
18 example, we now have clear cut capacity for graphite.

19 We also have reactivity design for fuel.
20 We have a big margin between the operation temperature
21 and the critical temperature because in normal
22 operation, the temperature is 750 degrees. But the
23 temperature to fill is 1,600 degrees. So, there is a
24 big margin.

25 All this advanced design concept makes the

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1 dynamics much slower, which it gives the control
2 system more time to respond if something is wrong.

3 And, also, selection of reactor design and
4 heat process also affect I&C design. One example is
5 like if we use pebble-bed reactor, then we need to
6 measure the knob. But if we use prismatic, we do only
7 this measurement. So, these are the main factors
8 which may affect our I&C design.

9 Next. Besides these unique issues, we
10 also expect I&C design has the following features.
11 First, we expect the NGNP design needs more sensors,
12 including unique sensors. By example, we may need
13 moisture detector.

14 We expect digital I&C system will be used
15 because it can efficiently handle the complex system.
16 The system is much more complex than the AWR because
17 we have an increased number of systems.

18 The digital I&C can effectively work with
19 digitized sensors, digital data communication systems,
20 computer supervisory control systems, FPGA devices, et
21 cetera.

22 So, it also can use signal processing
23 method to improve measurement accuracy and
24 reliability. It can facilitate post-accident analysis
25 because of the data log capacity. That's why we

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1 believe the systems will be used in the NGNP.

2 May not be used in protection systems, but
3 it definitely - not definitely, but it most likely
4 will be used in control systems.

5 We expect the digital control system will
6 be able to coordinate all the subsystems such as
7 reactor, steam generator, IHX, turbine, hydrogen
8 production process work together with few human
9 interactions.

10 We expect realtime monitoring and the
11 diagnostics will be used for important parameters to
12 improve system awareness.

13 Like this morning you may have heard that,
14 for example, the crack detection we may need to have
15 automatic monitoring systems to detect a possible
16 failure.

17 We expect advanced resilient control
18 including cyber-security, will be implemented to
19 mitigate the consequence of unpredicted disturbance,
20 sensor failures and malicious attack, et cetera.

21 Next slide.

22 CHAIRMAN BLEY: What do you mean by
23 "resilient control"?

24 MR. YANG: Resilient control means if
25 something goes wrong, the system can automatically

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1 reconfig so that the reconfigure system can still
2 work, at least will not go to the next level. I mean
3 the system will be safe. Will not go to the next
4 level of -

5 CHAIRMAN BLEY: Have you thought about how
6 we keep the operators knowledgeable about what their
7 plant really is at this point?

8 MR. YANG: Yes, which means that we may
9 need to educate the operators in a different way.

10 MR. SYDNOR: We don't know that these are
11 going to be used, but we know that Idaho is looking at
12 these features.

13 MR. YANG: Yes, Idaho had some report
14 released last year, 2010. At the end of last year,
15 had two reports suggest to use resilient control.

16 We have three research projects in I&C.
17 The first one is advanced reactor control. The
18 objective of this project is to review past and
19 existing HTGR control design, track NGNP control
20 design, provide technical information to NRC staff and
21 develop regulatory acceptance criteria for advanced
22 reactor controls.

23 The second project is advanced reactor
24 instrumentation. We had a similar goal, but we
25 emphasize our instrumentation instead of a control.

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1 The third project is advanced diagnostics
2 and prognostics. We have this project because we
3 expect the online monitoring and diagnostics were the
4 part of NGNP.

5 The objective of this project is to
6 investigate issues arising from the integration of
7 advanced diagnostics and prognostics system into
8 nuclear power plant, including the impact on
9 regulatory requirements.

10 What we know and what we don't know yet.
11 First, what we know has been described in that report.

12 MEMBER RAY: This is the Rumsfeld version.
13 (Laughter.)

14 MR. YANG: First, the United States and
15 other countries has accumulated a lot of experience on
16 HTGR I&C design.

17 We have three NGNP pre-conceptual design
18 released by DOE. So, this is pre-conceptual design by
19 PBMR, by General Atomic and by AREVA, which described
20 many different configurations.

21 Several hydrogen processes has emerged as
22 leading processes. We know that DOE recommended one
23 as the NGNP, but it hasn't been approved yet.

24 Several possible heat transportation
25 systems are considered. And a few potential heat

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1 process applications are proposed.

2 From this information, we may infer the
3 general requirements on I&C design, but we do not know
4 the details yet.

5 So, that's what we - next, what we do not
6 know. We will spend the rest of the time to
7 investigate what we do not know and we will try to
8 include those findings, you know, final NUREGs.

9 The first on the list of what we don't
10 know is DOE hasn't made final decision to down-select
11 reactor design. So, we do not know NGNP is a pebble-
12 bed reactor or prismatic reactor.

13 As we previously mentioned, different
14 reactor will have different requirement on I&C
15 systems.

16 Second, conceptual design has not finished
17 yet. So, we do not know what configuration will be
18 NGNP. And we do not know exact I&C requirement yet.

19 Finally, engineering design will be after
20 conceptual design if DOE decided to go ahead. So, we
21 do not know the NGNP I&C design details right now.

22 Looking forward, we are going to track -
23 continuously track NGNP development progress and
24 follow the development of I&C system design.

25 We will analyze the licensing implications

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1 of NGNP I&C system design if the design will be fixed.
2 We will update existing licensing guidance and develop
3 new licensing guidance for NGNP I&C design as needed.
4 That's it.

5 CHAIRMAN BLEY: You know, there's one thing
6 that bothers me about the presentation. And that is
7 it seems a lot like an advertisement for the
8 advantages of advanced resilient digital I&C, and less
9 a concern by a regulator about where this could get
10 you into trouble in the future. And that concerns me
11 a bit.

12 MR. YANG: We actually have reviewed all
13 the - not all. Many of the existing guidance related
14 to I&C systems.

15 And we found most guidance can be used for
16 high-temperature gas-cooled reactor. That's good
17 news. But there were a few ones, not many, to be
18 updated or maybe we need to give up some new guidance.

19 CHAIRMAN BLEY: There are some things you
20 had in the presentation about things you expect to see
21 in this system that's taking digital I&C a couple
22 steps beyond what we're seeing in the design cert
23 plants like all the way back to the sensors and that
24 sort of thing.

25 I mean, your colleagues in NRO are

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1 struggling with how you make sure on the safety side
2 there aren't any holes in these systems that can get
3 you into trouble.

4 And if it's being expanded, it seems - I'd
5 sure like to see more emphasis on that in this kind of
6 a presentation.

7 I have to go back and look at the research
8 plan. Maybe it's well done in there. I don't
9 remember the details.

10 MR. SYDNOR: All of this is focused on
11 impact of safety. And so, I think the presentation
12 probably gave you that impression because we're
13 stressing what might be, and a lot of this is yet to
14 be approved, right, or DOE hasn't made decisions on.

15 All of these things are being looked at,
16 may be considered, may be proposed. And so, I think
17 the presentation stressed the unique aspects that we
18 might be facing, because that's what we're focusing on
19 with this research.

20 We're not trying to redo the licensing
21 that's already been developed for digital applications
22 in current and new reactors, because that's currently
23 working.

24 So, this is focused on the things that
25 might be problematic and could impact safety. So, I

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1 think that's why it gave you that impression.

2 It's not our intent. All of our research
3 is focused on -

4 CHAIRMAN BLEY: When we get to the full
5 Committee if we have anything on this, I'm not sure
6 we'll have time to have this emphasize the other side.

7 And you've talked me into going back and
8 reading more carefully over what it says about I&C and
9 the research plan. Because the areas where it might
10 be really new things, I think the research ought to be
11 focused on just that issue of making sure you're not
12 getting into any safety binds by having all the
13 coolest things in the plant that you can have.

14 MR. SYDNOR: We're not proposing this.
15 We're, you know, making sure that if it is proposed or
16 if it is incorporated in a design that the staff is
17 ready to analyze the impact on safety.

18 MR. YANG: Yes, exactly.

19 MR. SYDNOR: That's a better focus, and
20 that is our focus. I think we gave you the wrong
21 impression because, like I said, we were stressing
22 what could be unique aspects.

23 CHAIRMAN BLEY: It all sounded like how
24 good all these new things were.

25 MR. SYDNOR: Do I expect all of those to be

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1 implemented in? No, I don't.

2 CHAIRMAN BLEY: Anything from the rest of
3 the Committee?

4 MR. BASU: As a regulator, we will not be
5 designing I&C for the vendors anyway.

6 CHAIRMAN BLEY: I don't want to see us
7 selling one either.

8 MR. BASU: Right.

9 MR. YANG: Yes, this expected aspects was
10 actually based on what we have seen from the DOE-
11 released materials from the pre-conceptual design
12 material.

13 So, we thought that maybe that would be
14 there. So, we better be prepared. It may happen or
15 it may not happen.

16 CHAIRMAN BLEY: That's good. Thank you.

17 Anything more?

18 Sud, you're back up.

19 MR. BASU: I'm back. All right.

20 (Off-record discussion.)

21 MR. BASU: Okay. Now, this one is going to
22 be a very short presentation for all the good reasons.

23 CHAIRMAN BLEY: Excellent.

24 MR. BASU: Not to mention that we all want
25 to go home or go back to your hotel, right?

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1 MEMBER CORRADINI: I'm trying to stay here
2 as long as possible.

3 (Laughter.)

4 MR. BASU: And of course the professor has
5 to be testifying tomorrow.

6 All right. No, but on a more serious
7 note, on this particular topic we are on a standby
8 mode. And you can understand why, because reactor
9 design is not complete, as you heard the previous
10 speaker, and process heat application demand has not
11 been defined.

12 So, what I'm going to present to you is
13 basically what I presented two years ago as the
14 research plan. That still stands.

15 Given the Energy Policy Act assumption,
16 which is hydrogen co-generation being the focus of the
17 process heat application -

18 CHAIRMAN BLEY: Let's not dwell on that
19 part much.

20 MR. BASU: Right. So, I'm not going to
21 dwell on that. All I'm going to show you is the scope
22 of research being if it was hydrogen co-generation,
23 that we would be interested in the blast loading
24 effect on reactor.

25 Of course for any process heat

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1 application, we will be interested in the coupled
2 thermal-fluid behavior providing the external loading
3 on the reactor side and again from the safety aspect,
4 component degradation issues again from the process
5 heat products, and then the toxic and corrosive gas
6 dispersion modeling.

7 One item that goes from the reactor side
8 to the process heat side is the tritium migration that
9 we will remain interested in.

10 As I said, we are in the standby mode. We
11 haven't initiated any research in this area. We do
12 have a wealth of data that have been accumulated
13 through other programs in the past. Blast loading for
14 one.

15 Then we go to the next slide. Decades of
16 LWR hydrogen combustion research, we have blast
17 models, combustion models. We also have decades of
18 R&D on atmospheric dispersion modeling that we can
19 make use of.

20 Material degradation and toxicology
21 databases are out there for practically any toxic
22 substance that you can think of from the process heat
23 application.

24 If there are new toxic substances having
25 an affect on the material degradation, we have to look

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1 into that.

2 We also have the benefit of some
3 national/international programs. EUROPAIRS I
4 mentioned. That is the end-use process heat that has
5 started a couple of years ago.

6 There was some Korean and Japan R&D
7 program on hydrogen. I'm not sure about their most
8 current status on the nuclear energy university
9 program funded by DOE and we should be able to benefit
10 from that.

11 The DOE-sponsored activities that are
12 listed here may be dated. They are from a couple of
13 years ago and I'm not up to date on where DOE is with
14 the down-selection of hydrogen production technology,
15 whether or not that is still the major focus.

16 So, we'll have to just monitor the DOE
17 program in that respect and see where that takes us in
18 terms of the process heat application.

19 And then we'll revisit our R&D plan. And
20 if there's any modification that we need to make,
21 we'll do so.

22 So, with that I'll just mention one other
23 thing. There are some administrative aspects that are
24 not in the R&D plan for the right reason.

25 These are who has the regulatory

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1 jurisdiction of the process heat plan? And I think
2 you can relate to that.

3 And so, we have to have some dialogue with
4 the other regulatory bodies ahead of time to make sure
5 that NRC is on the same page with the other regulatory
6 bodies insofar as the reactor safety is concerned.

7 So, if that means that we have to impose
8 some requirements on the other side of the planet,
9 we'll just initiate the dialogue with the right
10 parties.

11 So, that's in a kind of nutshell in two
12 minutes thing. I'm open for questions.

13 CHAIRMAN BLEY: From anybody?

14 Sub, thanks very much. And thanks,
15 everybody, for the presentations. At this time, we're
16 going to take a minute and go back over items we think
17 we raised for questions that we'd like to hear more
18 about.

19 And then we'll go around and hear from the
20 committee members --

21 MS. BANERJEE: And the public.

22 CHAIRMAN BLEY: -- and the public. I
23 would not forget them, but they come after the
24 Committee.

25 Maitri, can you go down the list and we'll

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1 just see if we -

2 MS. BANERJEE: Yes, I compounded a list,
3 but I may need a little help here.

4 CHAIRMAN BLEY: Yes.

5 MS. BANERJEE: The first one, I think
6 multiple members had questions on how the staff is
7 using the Fort St. Vrain experience and data and all
8 that.

9 So, you'd like to hear little bit about
10 that at the next presentation.

11 CHAIRMAN BLEY: Yes. I'm not sure we need
12 that at the full Committee, but maybe the next time we
13 talk.

14 MS. BANERJEE: Next time.

15 CHAIRMAN BLEY: Or feed something back to
16 Maitri for us on that.

17 MEMBER REMPE: I think what I heard was the
18 licensing experience was the way that they worded it.
19 Not just Fort St. Vrain experience, but -

20 CHAIRMAN BLEY: That's true. The Fort St.
21 Vrain licensing experience, yes, and how that's being
22 -

23 MR. BASU: Okay. What I would suggest we
24 do is we provide you with some information between now
25 and the full Committee meeting. And at that point if

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1 you see any further need, we will -

2 CHAIRMAN BLEY: Okay. And be prepared in
3 case it comes up at the full Committee.

4 MS. BANERJEE: And then your question on
5 digital I&C, I think, went away.

6 CHAIRMAN BLEY: It went away.

7 MS. BANERJEE: Okay.

8 CHAIRMAN BLEY: I got answers on that.

9 MS. BANERJEE: And then how uncertainties
10 are prescribed regarding the SCALE model development,
11 you had some question there?

12 CHAIRMAN BLEY: I'll just summarize the
13 idea. Uncertainty is clearly important in this area.
14 Everybody talks about it.

15 That one slide bothered me and I just -
16 we've recommended several times that the Agency have
17 a complete process for - a systematic agreed-on
18 process used everywhere for considering uncertainties
19 and presenting them and identifying them and dealing
20 with them, and that's the gist of my comment.

21 You're not going to answer that, but in
22 the future we'll be pushing on that more. And that
23 when uncertainty ideas are presented, they're
24 presented in a coherent fashion and not things that
25 aren't related to each other looking the same when

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1 they're presented.

2 So, the basic idea of what you're looking
3 for in dealing with uncertainties, and then every
4 analysis and presentation ought to be consistent with
5 that approach.

6 So, that's not something to address now,
7 but that's a long-term goal. And if we have - that
8 might come up in a letter out of the full Committee
9 meeting.

10 MS. BANERJEE: Like a generic kind of
11 comment.

12 CHAIRMAN BLEY: Yes.

13 MS. BANERJEE: And you had a question on
14 PARFUME. I think you wanted to see something, a
15 technical report. Wanted to see something in the
16 future.

17 MR. BASU: The user manual, the reference
18 manual, those you are -

19 CHAIRMAN BLEY: Well, you have those
20 manuals and we might want - I think we'd like to be
21 able to see them.

22 The other thing was that Petti mentioned
23 that there's technical reports and the possibility of
24 presentations on the manufacturing process,
25 measurement science and practice and process control,

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1 how that's all being done. And it sounded very useful
2 to us.

3 So, at some point in the future like
4 between now and the full Committee meeting, we would
5 like to have a session where that's discussed in some
6 detail and access to those documents.

7 MR. BASU: And my understanding is you will
8 be looking at Idaho National Lab to give that -

9 CHAIRMAN BLEY: I think that would be most
10 appropriate, yes.

11 MR. BASU: Right.

12 CHAIRMAN BLEY: Okay.

13 MS. BANERJEE: Okay. And then I'll get a
14 copy of the ORNL document -

15 CHAIRMAN BLEY: Okay.

16 MS. BANERJEE: -- TM-2009. And then
17 address graphite burning at the full Committee.

18 CHAIRMAN BLEY: Backup slides or maybe one
19 slide that addresses it just to make sure that it gets
20 on the table.

21 MEMBER CORRADINI: You might term it
22 "graphite oxidation" since we've discussed what
23 burning is.

24 CHAIRMAN BLEY: Well, there are - I think
25 both are important to mention. I think we might have

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1 some vigorous discussion about it at the full
2 Committee. I might be wrong.

3 I'd rather have it at the full Committee
4 than have it in a letter-writing session.

5 MEMBER CORRADINI: Right, right.

6 (Off-record discussion.)

7 MS. BANERJEE: The RIM program, the ISI for
8 graphite components, Harold had some questions and
9 would like to be -

10 MEMBER RAY: Yes, I think the easiest way
11 to express my concern is just show me that there is a
12 explicit acknowledgment, don't just say it's part of
13 some program, that long-term verification of the
14 integrity of graphite structural members is part of
15 the agenda.

16 I hesitate to use the word "in-service
17 inspection," but that's what I mean.

18 CHAIRMAN BLEY: And related to that, Harold
19 brought one up that I think everybody agreed with at
20 the time.

21 In the first presentation, Sud had
22 mentioned that there's nowhere in the current research
23 plan that it looks at several key issues that need to
24 be looked at eventually, including the fuel cycle
25 safeguards and security in an integrated way in

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1 siting.

2 So, you know, we'll probably have a
3 comment something related to that before we're done.

4 MEMBER RAY: The way I suggest, Dennis, or
5 might think about it is that what we've reviewed here
6 is basically the - I don't know what to call it - the
7 research program or the path for pursuing these things
8 that is defined in the six-year-old Energy Policy Act.
9 And that was very specific. The plant was to be sited
10 in Idaho. Period. Full stop.

11 And as long as that's a constraint, I
12 mean, I think all we need to do is acknowledge it and
13 say that that's what we reviewed here because it's
14 very hard for both the NRC and the DOE to say, oh,
15 well, we've decided to do something different. And
16 especially for the NRC to do that.

17 So, given that that's the constraint, I
18 guess you call it the roadmap or whatever it is that
19 closed out of that, that the research is to satisfy
20 the provisions in the 2005 Energy Policy Act for the
21 NGNP. And that is very specific.

22 MS. BANERJEE: Is that a letter item or is
23 that something you want to -

24 MEMBER RAY: Well, I would just -

25 CHAIRMAN BLEY: We'll talk about it.

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1 MEMBER RAY: Yes, yes, yes.

2 CHAIRMAN BLEY: We won't decide that here.

3 MEMBER RAY: Obviously, but I'm just saying
4 that that's the way I think about it. Rather than it
5 looking like it's on a mission or something like that,
6 it's just that the program is defined by the terms of
7 the NGNP as defined in the Energy Policy Act.

8 And when it comes to siting, that's siting
9 on a government facility as a demonstration plant in
10 Idaho. That's it.

11 And I think we would all agree we need to
12 acknowledge that, but not, like I say, indicate that
13 it's somehow an omission or a flaw or something like
14 that. It's just that's the boundary conditions for
15 the research program.

16 CHAIRMAN BLEY: Maitri, anymore?

17 MS. BANERJEE: I think Sam had a question
18 on densification of granular material.

19 MEMBER ARMIJO: No, it just was an
20 observation that they had some nice experimental
21 facilities. It might be able to be used to address
22 the compaction of the core, a pebble-bed core
23 quantitatively.

24 Shake those things and use that neat
25 technique to see what the porosity value is.

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1 MR. BASU: Yes, I mean, it got me thinking
2 that. All we have to do is put that thing on a -

3 MEMBER ARMIJO: And just do it with your
4 plastic things and see how your models are predicted.
5 It's pretty slick.

6 MS. BANERJEE: And the last one -

7 MR. BASU: Maybe that's something we could
8 suggest.

9 MEMBER ARMIJO: If I was back at school,
10 I'd do it.

11 MS. BANERJEE: And the last one was the BNL
12 project report on human performance CONOPs.

13 CHAIRMAN BLEY: We're going to hear more
14 about that on Friday. So, I don't think we need that.

15 MEMBER CORRADINI: Can I ask just a general
16 question?

17 So, from a standpoint of effort dose, 90
18 plus percent of all of NRC's effort is in the
19 evaluation model and all the associated aspects of it
20 in terms of where you call the R&D. And you're
21 relying on, for all intents and purposes, all the
22 preponderance, all the experimental data, et cetera,
23 is in DOE's camp; is that fair?

24 MR. BASU: Well -

25 MEMBER CORRADINI: From a standpoint of

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1 overall effort.

2 MR. BASU: Yes, you're right. Different
3 sources. DOE, primary source in this case, but also
4 applicant. The applicant's safety case.

5 MEMBER CORRADINI: But I'm talking about
6 mainly from the standpoint of your effort, it really
7 all centers around that picture that you or Joe,
8 somebody showed early on in terms of the evaluation
9 model.

10 MR. BASU: Correct.

11 MEMBER CORRADINI: Okay.

12 MR. BASU: Well, if you are just restricted
13 to that figure, I don't know - I'll quantify as 90
14 percent, because remember now there is a bunch of
15 research in the graphite high-temperature materials in
16 those areas that are not reflected in the evaluation
17 model.

18 MEMBER CORRADINI: But somehow it's going
19 to be folded into it.

20 MR. BASU: Yes, we could call it a truth
21 development for safety analysis performance
22 verification, et cetera. And if we do that, then,
23 yes, maybe 90 percent will be there, yes.

24 MEMBER CORRADINI: Thank you.

25 CHAIRMAN BLEY: Okay. At this time, I'm

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1 going to go around to the committee members. And
2 we've already hit some of this in the reprise with
3 Maitri, but anything more you want to add?

4 Harold.

5 MEMBER RAY: Well, Dennis, I guess I just
6 would say that looking ahead we need to - this is a
7 hard letter to write. And I appreciate that's not the
8 question you're asking me, but that's the way I'd like
9 to frame the comment I want to make, which is what can
10 we really say?

11 We've seen a lot, but it's at a very high
12 level. And it will be at an even higher level at the
13 full Committee.

14 So, I guess what we would be aiming at is,
15 is there any omissions or something left out? But
16 very hard for us to comment very much on the content
17 of these programs because there are so many of them
18 and we've only had, like I say, a high-level view of
19 them.

20 It's inevitably the case, I think, that
21 the NRC winds up doing work in parallel with the
22 development that makes you ask yourself are we
23 actually designing this or are we - we're not
24 designing it. That isn't the word I want to use.

25 Are we doing the work that will then make

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1 it difficult for us later to be critical of what we've
2 done looking at things like fuel performance and
3 radionuclide models and so on.

4 And there isn't any way to avoid it,
5 because we can't sit and do nothing. We have to do
6 what's being done, but I would like to feel more clear
7 in my mind about how we avoid becoming part of the
8 thing that we then try and step back and look at
9 objectively.

10 We talked about that a little bit somewhat
11 today. But nevertheless, it's still on my mind. So,
12 the upshot of it is I guess I would just want it to be
13 clear that what we can say is limited by the
14 information that's available and what visibility we
15 have into it and the lack of definition at this point
16 in time of what it is that will be used to evaluate.

17 So, there's a lot of qualifications to it,
18 but mainly we would be just saying we do or we don't
19 see that there's a gap somewhere, I would say,
20 probably.

21 CHAIRMAN BLEY: Thank you. Sam.

22 MEMBER ARMIJO: Yes, I thought the
23 presentations were very good. I learned a lot of this
24 stuff from this work.

25 I think given the fact this is a

1 government-sponsored project and no private sector
2 involvement to any significant extent, I just don't
3 see that you can do anything other than what you're
4 doing.

5 You've got to develop the tools and be
6 sure they're - at least they're independent from what
7 IO is doing. And I think you've outlined a very good
8 set of programs.

9 I'm a fuel guy and I was very interested
10 in what IO has been doing in the fuel area and some
11 very nice basic work at University of Wisconsin. I
12 have to admit that, Mike.

13 (Off-record discussion.)

14 MEMBER ARMIJO: So, I just think you're
15 doing - with the limitations of this program, you
16 know, DOE hadn't selected a plant design. DOE hadn't
17 selected a fuel design. DOE hasn't selected a process
18 - a heat - or how they're going to use the process
19 heat.

20 So, within all those constraints, I think
21 the NRC is doing the best they can and I think a very
22 good job. So, I'm complimentary. I think it's a
23 pretty good R&D program.

24 MEMBER RAY: Sam, could I just comment by
25 saying that the Energy Policy Act says this is a

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1 partnership, not a government program.

2 So far, it's a government program.

3 MEMBER ARMIJO: I was talking reality, not
4 the -

5 MEMBER RAY: But it's not meant to be
6 viewed as a government project at the end of the day.

7 MEMBER ARMIJO: Well, that might be, but
8 I'm sticking with it.

9 MEMBER RAY: All right.

10 CHAIRMAN BLEY: Mike, you came out of the
11 other meeting very late, but I -

12 MEMBER RYAN: Thank you for the chance to
13 join in late. Thank you.

14 CHAIRMAN BLEY: I know we have conflicts
15 and things. So, within the range of what you two can
16 say, Joy, is there anything you want to add or -

17 MEMBER REMPE: I just wanted to thank the
18 staff for their presentations. I found them
19 informative and appreciated them.

20 CHAIRMAN BLEY: Mike.

21 MEMBER CORRADINI: We're allowed to say
22 anything, aren't we?

23 CHAIRMAN BLEY: You can say anything you
24 want.

25 MEMBER CORRADINI: I guess the one thing I

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1 wanted to get back to is that I think in some sense
2 just to reflect on - Joy found it, but I think it's
3 important. In the revised draft program plan, there
4 is a table in terms of what NRC views as theirs to be
5 lead on and what things they're expecting from DOE.
6 And I think that's important for us to see.

7 Other than that, I guess I wanted to ask
8 Sud a question. Put him on the hot seat or Stu or
9 somebody.

10 How far can you continue in this generic
11 mode before you're presented with a design?

12 In other words, can you do this for
13 another month? Another six months? Another year?
14 Eventually all things are going to have to stop until
15 you see a design.

16 MR. BASU: Eventually, yes.

17 MEMBER CORRADINI: So, can you define
18 "eventually"?

19 MR. BASU: In terms of months, no. I'll be
20 very hard pressed.

21 MEMBER RAY: Two years. Tell him two
22 years.

23 MEMBER CORRADINI: Well, the only reason
24 I'm putting it in that regard is I really do think we
25 ended this - last time we had a briefing, I think

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1 Sam's the one that said don't come back until you see
2 a design.

3 And so, you're back.

4 (Simultaneous speaking.)

5 MEMBER CORRADINI: In some sense, I think
6 that's where a lot of us will get very - will get more
7 focused on asking questions.

8 MR. BASU: In fairness to Sam's remark, I
9 think at that time our expectation was that in about
10 a year, 18 months we will have - this comes down to a
11 point design.

12 That evidently hasn't happened for, you
13 know, a number of reasons. But the reality is we
14 don't have a point design today. And your question is
15 can I put my fingers on when we are going to have
16 that?

17 The best I can answer you on that is
18 whenever the Secretary is going to make a decision on
19 -

20 (Off record discussion.)

21 MR. BASU: But this is not - this is not
22 actually deterring us from carrying on our R&D at this
23 point. We are in the midst of developing tools. We
24 are in the midst of conducting experiments which are
25 going to provide data for model development, code

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1 assessment, et cetera.

2 So, we'll get to some point which is still
3 going to be somewhat generic in nature, but you're
4 right.

5 At that point, we have to then either say,
6 okay, stop the work because we don't have any further
7 to go until we have the design. Or hopefully at that
8 time we will have the design and then we can say,
9 okay, now that we have this design, let's see what
10 more we have to do.

11 CHAIRMAN BLEY: To me, the counterpoint to
12 Mike's question is I think you've done a lot even
13 designing a test facility now that you can address
14 alternative design issues.

15 All right. Tom Kress, haven't heard from
16 you.

17 CONSULTANT KRESS: Well, I have a number of
18 thoughts. I'm probably out of - putting them down in
19 a consultant's report, but I'll go over -

20 CHAIRMAN BLEY: I appreciate that, yes.

21 CONSULTANT KRESS: I'll go over a few of
22 them anyway.

23 Number one, I thought the research plan
24 was very thorough. I liked it. I think it covered
25 all the bases. I thought it was really ambitious. I

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1 think you ought to be prepared to not meet all your
2 milestones, and figure out what to do in case you
3 don't.

4 And some of that data takes a long time to
5 get. Particularly, I'm familiar with getting fission
6 product release data. That takes an awfully lot of
7 tests and an awful long time.

8 Some of my comments have to do with the
9 white papers which I read before I came here as
10 compared to the meeting.

11 I really liked the frequency consequence
12 acceptance criteria that, you know, I've been an
13 advocate for that for a long time. And I think for
14 licensing basis, they've got the right idea.

15 They did carry it on out to beyond design
16 basis. I had a little problem figuring out how their
17 curve addressed the prompt fatality safety goal, but
18 I'll work on that a little longer.

19 I could not convert - I didn't have Level
20 3, but I had ways to do it. So, I had a question
21 about that.

22 I really didn't see any plans for steam
23 graphite oxidation. I understand there are some, but
24 I didn't see any in the plan. I think you will need
25 that.

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1 I think you should be prepared to have to
2 provide some sort of technical justification for the
3 assumption that the fission product species will be
4 the same as we deal with in LWRs particularly because
5 they have to pass through high-temperature graphite
6 first where they have a chance to change.

7 For the fission product release models,
8 the Booth-like models, I hesitate to think you can get
9 effective diffusion coefficients for every fission
10 product species.

11 I think you'll have to figure out some way
12 to scale the other products from the cesium like they
13 do with the LWR. I don't know what the scaling
14 factors will be right now, but they may be the same as
15 the LWRs.

16 I don't know of any models that exist for
17 dust production through graphite. I would like to see
18 what sort of models you're going to use for that.

19 And I didn't see good plans for how you
20 were going to determine the amount of dust during
21 operation and the nature of it, what its size and
22 scale factors, shape factors might be.

23 MEMBER RAY: You think there should be a
24 limitation on the amount that could accumulate, for
25 example?

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1 CONSULTANT KRESS: Oh, gosh, yes. And I
2 think there will be a lot of it.

3 MEMBER CORRADINI: How are they going to
4 know what that is in -

5 MEMBER RAY: Well, that's what he said.

6 CONSULTANT KRESS: I think it will be the
7 driver for how much fission product release you get.

8 I don't think we know a lot about graphite
9 plate-out and resuspension either, but those are going
10 to be the drivers.

11 On the quality of fuel, I would like to
12 rely on the standards for the manufacturing process to
13 tell me my fuel quality meets the levels I want.

14 I would like to see for every batch that
15 goes into the core, some sort of sampling and
16 measurement of that core to that batch.

17 So, there's some issues about -
18 statistical issues about how many samples, how you go
19 about putting them in an in-pile and testing them and
20 determining natural quality. So, I think there's some
21 issues there that need to be thought about.

22 I have felt on pebble-bed reactors, I
23 think spears won't move very nicely down through a
24 pebble-bed. And there may be ways especially when
25 they get irradiated and hot and the graphite changes

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1 dimensions, that you will get stuck spears in there.

2 And that releases to real hot spots and I
3 think you'll need some sort of probabilistic model for
4 these.

5 And I don't know how you deal with it in
6 the MELCOR thermal models, but I think that needs to
7 be given more thought and I think we might need some
8 experiments.

9 I think I saw some where you look at the
10 movement of spears down through a pebble-bed core, but
11 I don't know if they were at the right temperatures.
12 And of course they won't have the irradiation
13 component to them.

14 I worry about the status of aerosol
15 behavior graphite dust, but I've already mentioned
16 that.

17 I, you know, one of the white papers said
18 they're going to rely completely on mechanistic
19 scenarios rather than design basis.

20 I really like the idea of design basis
21 accidents. And I wish we'd think a little more about
22 how we might develop those because, you know, you have
23 to deal with uncertainties and the fact that you may
24 be missing some scenarios.

25 You have to have defense in depth and I

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1 think you deal with those well with design basis, as
2 well as looking at the risk end of it.

3 And I'd be interested in this report that
4 talks about how you use a PRA to develop licensing
5 basis events that someone mentioned. I thought that
6 would be interesting.

7 I was very pleased when I read some of the
8 reports to see that site acceptance criteria, the SE
9 curves, will be for all the modules taken together,
10 not just an individual. I think that's necessary.

11 And because of that, I think when you talk
12 about a site if we ever get to that point, the site
13 has to be - you have to specify up front how many
14 total modules you're going to have on that site. I
15 think that's a policy issue that may have to be dealt
16 with.

17 I think you have to think about common-
18 mode failures with these. Particularly seismic and
19 floods.

20 I think you're going to impact the model
21 simultaneously with some things and I don't know how
22 to deal with that in the PRA.

23 And I don't know what all the co-
24 generation processes are, but I can't envision there
25 should be any reactions particularly in intermediate

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1 heat exchanger and blast, toxic materials, things of
2 that nature.

3 And the fact that the control room may
4 have controls for that, I don't -- I would hate to see
5 controls for the co-generation in the reactor control
6 room, but I don't know how you're going to deal with
7 that. I would rather see those separate.

8 Anyway, that's my initial thoughts on the
9 subjects.

10 CHAIRMAN BLEY: A goodly list, sir. Thank
11 you.

12 At this point, did you want to comment,
13 Sud?

14 MR. BASU: No, I'm waking up.

15 (Laughter.)

16 CHAIRMAN BLEY: We'll send you the list.

17 MR. BASU: I'm tempted to respond to some,
18 but I will, you know, when we get the list, we'll
19 certainly respond. That probably would be better.

20 CHAIRMAN BLEY: We're now going to ask if
21 there are any members of the public here in the
22 meeting who have a comment or would like to say
23 anything.

24 Is the phone line open now?

25 Please open the phone line.

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1 Is there anybody on the phone line who
2 would like to make a comment? I'll give you a second
3 to make sure you're there.

4 (No response.)

5 CHAIRMAN BLEY: Okay. Nobody is speaking
6 up. So, I guess there is not.

7 I would like to thank everybody for great
8 discussions and good presentations. And I guess I
9 ought to for the full Committee, I don't know for sure
10 the schedule, but we'll either have only an hour, an
11 hour-and-a-half probably at most. So -

12 MS. BANERJEE: I think they gave us almost
13 two hours.

14 CHAIRMAN BLEY: Did they? Okay. I didn't
15 see that. Okay. So, two hours. So, that's a small
16 piece of what we did today. And you can't go over as
17 many slides as fast because you certainly with the
18 full Committee, are going to need gaps for allowing
19 people to ask questions and dig into things.

20 So, you know, we can talk a little bit to
21 make sure we get a package that's of the appropriate
22 size. So, if we can see that a little early, it would
23 be helpful.

24 At this point, thank you, everyone, and
25 we'll call the meeting to a close. The meeting is now

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1 adjourned.

2 (Whereupon, the meeting was adjourned at

3 5:22 p.m.)

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U.S. NRC

UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

High Temperature Gas-Cooled Reactor (HTGR) NRC Research Plan An Overview

**Sudhamay Basu, RES
(sudhamay.basu@nrc.gov)**

**ACRS Future Plant Design Subcommittee
April 5, 2011**

Outline

- Objectives
- Role and Scope of Research
- Assumptions
- Implementation Status
- Going Forward

Objectives

- Provide an update of NRC's HTGR Research Plan and its implementation
- Solicit ACRS feedback
- Request a letter from ACRS after the full committee briefing

Role of NRC HTGR Research

- Develop analytical tools and capability to:
 - perform confirmatory safety analysis
 - support licensing review
 - provide technical basis for regulatory decisions
- Develop technical basis for:
 - identifying and resolving safety issues
 - regulations and guidance
- Develop staff technical expertise and review capabilities

Scope of HTGR Research

- **Confirmatory Safety Analysis Tools**
 - Codes, evaluation models, data, V&V
- **Major Technical Areas**
 - Thermal-fluids, nuclear analysis, accident analysis
 - Fuel and fission products
 - Graphite and high temperature metallic materials
 - Coupling of reactor and process heat utilization plants
 - Structural integrity of systems and components
- **Other Technical Areas**
 - Probabilistic Risk Assessment (PRA)
 - Human Factors (HF)
 - I&C technology

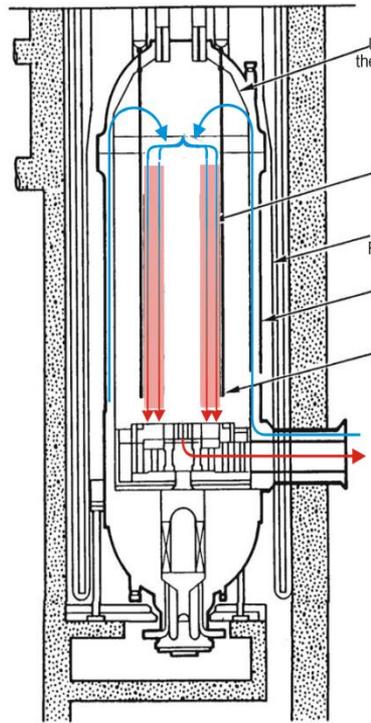
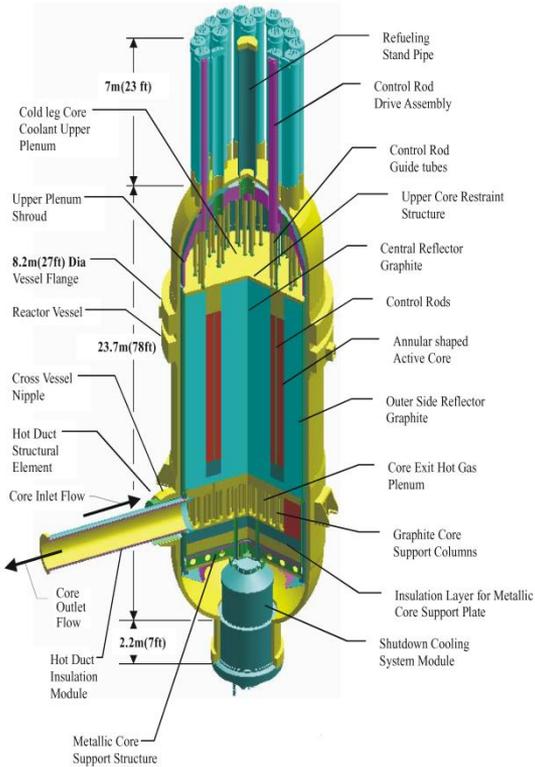
Assumptions

- Research scope in large part generic
- Availability of data from DOE-sponsored VHTR R&D
- Availability of applicant-furnished data for plant-specific licensing review
- Availability of complementary data from international HTGR R&D programs
- Reliance on national and international codes and standards
- Adequate resource allocation

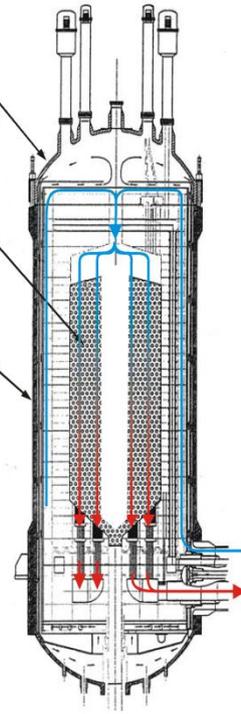
New Development since Last Briefing

- Development affecting NRC R&D program
 - Decrease of reactor outlet temperature
 - Re-consideration of steam cycle for power conversion
 - Broadening scope of process heat utilization
- Other development with potential R&D, design, or regulatory impact
 - Co-location at industrial sites
 - Multi-module design
 - Consideration of fuel form
 - Consideration of technology alternatives

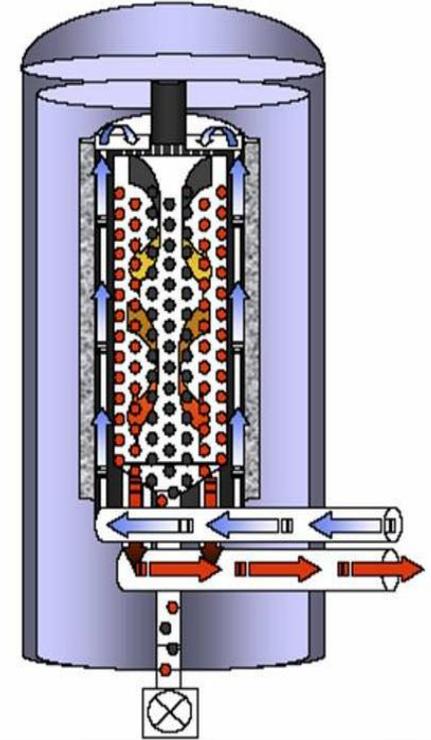
Prismatic and Pebble Bed Designs



a. Prismatic



b. Pebble-bed



Implementation Status

Thermal-fluids, Nuclear Analysis, Accident Analysis

- Thermal-fluid code and model development
 - MELCOR modifications for HTGR in progress at SNL
 - PARCS-AGREE development at U. Michigan
 - SCALE code suite modification and validation at ORNL
 - Developmental assessment using existing data
- Supporting experimental programs
 - High Temperature Test Facility at OSU
 - OECD-HTTR LOFC program (pending)
 - Core heat transfer and bypass flow studies at TAMU
 - Stratified counter-current flow experiments at PSU
 - Emissivity experiments at U. Wisconsin

Implementation Status

Fuel Performance and Fission Products

- Fuel fission product (FP) model development
 - MELCOR model for FP diffusion (coatings and matrix)
 - MELCOR model and code benchmarking
 - PARFUME code exercise and benchmarking
 - Metallic FP transport through SiC layer
- Fuel failure modeling
 - Mechanistic modeling of fuel particle failure in PARFUME
 - Empirical particle failure surface formulation for MELCOR
- Coordination with DOE/INL on AGR fuel program
- Regulatory guidance and oversight of fuel fabrication and quality assurance

Implementation Status

Graphite and High Temperature Materials

- Properties and performance of graphite components
 - Stored energy release experiments and analysis at ORNL
 - Core component stress analysis tools development at ANL
 - Codes and standards activities
 - Coordination with DOE/INL on AGC program
- High temperature metallic materials behavior
 - Creep and creep-fatigue evaluation of RPV, IHX, SG, etc.
 - Develop time-dependent fracture mechanics methodology
 - Codes and standards activities
 - Coordination with DOE/INL on Materials R&D program

Implementation Status

Structural Analysis

- Assessment of concrete behavior at high temperature
 - High temperature effect on concrete physical and structural properties evaluated (NUREG/CR-7031)
 - Concrete strength generally retained within temperature range
 - Research on radiation effect on concrete initiated
- Seismic and Soil-structure interaction of deeply embedded structure
 - Previous study (NUREG/CR-6957) under review for appropriate update
- Seismic loading consideration for multi-modular design

Implementation Status

Digital I&C and Human Factors

- Digital Instrumentation and Control
 - Research initiated on advanced reactor controls
 - Research on advanced reactor instrumentation
 - Investigate advanced diagnostics and prognostics (AD&P) system integration issues
- Human Factors (HF)
 - Developing technical basis to support update of HF guidance documents
 - Research focus
 - CONOPS for modular design
 - Automation and human system interface
 - Staffing consideration

Implementation Status

Probabilistic Risk Assessment (PRA)

- Planning study undertaken to identify PRA needs and scope for HTGR licensing
 - Gaps in guidance, methods, tools, or data to establish PRA acceptability
 - Assumptions for constructing a PRA model for HTGRs
 - Guidance development to support initial PRA review
- Other PRA related activities
 - Development of PRA Standards
 - Development of ANS 53.1 Standard
 - Research to close the technical gaps

Going Forward

- Continue focus on R&D that is generic to both reactor technologies
- Track DOE NGNP program and modify NRC R&D activities based on NGNP technology selection
- Continue coordination with DOE to resolve key technical issues and close R&D gaps
- Brief ACRS periodically on the progress

Thank You



NRC Evaluation Model Development for the Next Generation Nuclear Plant

J.M. Kelly

**USNRC Office of Nuclear Regulatory Research
Joseph.Kelly@nrc.gov**

ACRS Future Plant Designs Subcommittee

April 5, 2011