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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
SUBCOMMITTEE ON FUTURE PLANT DESIGN
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MEETING
+ + + + +
THURSDAY,
JANUARY 15, 2009
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The Subcommittee was convened in Room T2B3 at the Nuclear Regulatory Commission, Two White Flint North, 11545 Rockville Pike, Rockville, Maryland, at 8:30 a.m., Dr. Michael Corradini, Chair, presiding.

SUBCOMMITTEE MEMBERS PRESENT:

MICHAEL L. CORRADINI, Chair
WILLIAM J. SHACK
DENNIS C. BLEY
J. SAM ARMIJO
SAID ABDEL-KHALIK
HAROLD B. RAY
GEORGE E. APOSTOLAKIS

CONSULTANT TO THE SUBCOMMITTEE PRESENT:

THOMAS S. KRESS

ALSO PRESENT:

MAITRI BANERJEE, Designated Federal Official
STUART RUBIN
SHAH MALIK
MAKUTESWARA SRINIVASAN
AMY HULL
TIM LUPOLD
JOHN JOLICOEUR
JIM KINSEY
HERMAN GRAVES
SYED ALI
JOYCELYN MITCHELL
PAUL REBSTOCK
ANTHONY ULSES
DON CARLSON
MOURAD AISSA
MARY DROUIN
JOHN MONNINGER
TOM KENYON

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

(8:29 a.m.)

CHAIR CORRADINI: Okay, why don't we get started? This is the second day of our two-day meeting on Advanced Reactor Research Plan and Program. My name is Mike Corradini, Chair of the Subcommittee.

Let me just remind everybody that if we have members of the public present, we will have approximately ten or fifteen minutes for any member of the public who may want to ask questions to do so at the end of the meeting.

And then also a transcript of the meeting is being kept. We request the participants in the meeting use the microphones located in the meeting room when addressing the subcommittee. And participants should first identify themselves and speak with sufficient clarity and volume so we can be heard.

Amy Hull will be our staring point for the staff's presentation today. Ms. Hull.

MS. HULL: Okay. I am Amy Hull. I represent the Corrosion and Metallurgy Branch of the Division of Engineering, which is directed by Tim Lupold, who is the in corner there. My colleague Dr. Malik is a senior materials engineer in the Component and Integrity Branch of the Division of Engineering Office of Research.

I am going to talk about first our R and D objectives. As was mentioned last night, it sometimes becomes challenging to ensure that sufficient technical basis are available when we have a changing ball game. The temperatures are changing. We didn't know yesterday if we are talking about 750 or 950. The type of the reactor, whether it is prismatic or whether its pebble bed, is changing. There are a lot of things that are changing.

So partly that you will that we are doing is a lot of iteration with industry, with codes, with universities, with national laboratories to ensure that first, the technical bases such as codes and standards, regulatory guides, review guidance are developed and appropriate for regulatory decisions involving critical structures and components for future high temperature gas reactors or very high temperature gas reactors and liquid metal reactors.

There is not so much work that is presented in the ARRP about metals issues associated with liquid metal reactors but having once worked in a related field at a national lab, I know it is still a concern and we are tracking it. And there are conferences going on nationally and internationally, looking at metals issues associated with liquid metal reactors as well.

MEMBER ABDEL-KHALIK: Why -- I missed it. Why did you raise the issue of liquid metal? You mean as a coolant.

DR. HULL: Yes, you know like the sodium reactor?

MEMBER ABDEL-KHALIK: Yes.

DR. HULL: And NTS speaks about that later this afternoon.

MEMBER ABDEL-KHALIK: That's not related with NGMP.

MR. RUBIN: Well the ARRP covers mostly high temperature gas but a little piece is sodium fast reactors, including metals issues.

CHAIR CORRADINI: And we hear about that at the end of the day. Yes, okay.

DR. HULL: Okay. As needed and as complimentary to what is done elsewhere, not duplicating work done by the licensees or by the universities or by DOE, we conduct research on metallic components to evaluate and quantify degradation processes, metallurgical aging and embrittlement, carburization, decarburization, and better understand nondestructive evaluation and in-service inspection needs.

Oak Ridge in August 2008 wrote quite a comprehensive document looking at materials issues associated with advanced reactors. And this was headed by Bill Corwin. We have been working with Bill Corwin when we did our PIRT and also we work with Bill Corwin and Sam Shem and others through our activities with ASME BPV codes. And we had been stressing in the past year the need for more emphasis on NDE and ISI because there had not been so much previously.

So, we noticed after this came out a few months ago that DOE is talking more now about NDE as well. So the work that we do will be supplementary and complimentary, not duplicative of what is being done elsewhere. In some cases, we will be doing confirmatory work but work not -- being very careful in our discussion of what research needs to be done, not to duplicate work.

There has been work done on carburization, decarburization, nice work done at Argonne in the early 2002-2004 time period that we funded, NRC funded. That is important for confirmatory work. We are interested in, I am personally interested in maybe being able to continue that. I gave a paper at the

HDR Conference in Washington in the fall of '08 and there was a colleague from CEA who was talking about her study that she was doing. This was mentioned yesterday also, the CEA facility, the helium loop. It was mentioned that that was only available internationally. It is also available in the United States. Argonne has a facility and Idaho has a facility. According to Bill Crowin, Oak Ridge is really not working in that area now but that is important from the standpoint of understanding the metallurgical aging, carburization, decarburization. And I will talk about that a little bit later in the context of the impurity levels possibly associated with helium.

The other thing that we are doing is reviewing the currently available national and international procedures for design against fatigue, creep, and creep-fatigue. Dr. Malik will talk a little bit about the work that he is doing with creep and creep-fatigue. We also have been very active since 2006 in participating in the update of the ASME Code procedures to incorporate correlations developed from more recent research. Particularly, I am involved with the Section III, Subsection NH. NH is classified components in elevated temperature service.

So I participate and I am a voting member of various ASME BPV committees, such as the Committee on Elevated Temperature Design, which is also focusing on Section III.

There is a subcommittee for Section XI for evaluating in-service inspection needs that is HTGR application. And they are working on reliability, integrity, management alternative to the current approach that we have for ISI that is more risk-informed. Let's see. So that is that.

I wanted to point out which you have been reviewing the Advanced Reactor Research Plant, Figure 1 of the Advanced Reactor Research Plant focused on the key research areas. And under materials analysis, it emphasized graphite, high temperature materials, chemical attack, aging, ISI, and materials qualification. When we did the purge on high temperature materials, high temperature metals, we dealt with aging ISI materials qualification, as well as some of the needs maybe to get better qualification of the nickel alloys. For example, the Incanel and the HANES, the 670 and 213 are not qualified yet really against the needs for ASME BPV Section III-NH, which was developed and associated with liquid metal reactors, with the Clinch River Breeder Reactor. That was the origin of that.

When we were doing the work associated with the purge in 2007 and 2008, as well as the work with ASME, there were recurring key safety and licensing issues that we have kept in mind throughout our ongoing work.

The development of material fabrication and design codes and standards. Some of the most active participants we have in the DOE ASME Gen IV Materials Project that we in the Division of Engineering are associated with as both being on the steering committee and technical advisors. Some of the most involved participants are those from Japan and Korea. So, this is an issue not only in the United States, last summer for another project, I had to visit the Doosan Heavy Industry Facility. And there they were talking about also what they were doing in the context of events reactors.

Development and inspection requirements. There is the desire to have a longer time of running. So our in-service inspection has to be more clever. It is relatively more important. This has been pointed out in the ARRP and has also been pointed out in documents developed by Oak Ridge and others.

MEMBER APOSTOLAKIS: Why is this different from --

DR. HULL: It has a longer time between leaches. They plan to run them for a very long time.

MR. RUBIN: Continuous online fuel. You don't have to shut down for refueling exhaustion and even the prismatic block reactors inspected. So you have to wait a longer time before you can get in there again and do an inspection.

MEMBER ARMIJO: What is the order of magnitude of the cycle lengths for the prismatic and the, I know the pebble bed could last as long as you could want but what are they talking about? Just order of magnitude, are they talking four-year cycles or --

MR. RUBIN: Well, I am more familiar with pebble bed. I think it is about five years.

MEMBER ARMIJO: Five-year cycle.

MR. RUBIN: Something along that order.

CHAIR CORRADINI: Before they would --

MR. RUBIN: Between shutting it, you know, from starting it up to shutting it down to do some maintenance. To have access to these components. I am not that familiar.

MEMBER ARMIJO: But prismatic has to be refueled on some frequency.

MR. RUBIN: Some frequency, yes.

DR. HULL: Another recurring safety and licensing theme is that of quantification of the material performance and variability. And then again, and again, and again the assessment of aging-related degradation mechanisms.

As mentioned, we have been working on this at NRC for a number of years. And the advanced reactor research plan written in 2003 identified major metallic issues as well and in response during about the same time, some fundamental work was completed by Argonne in contract to NRC to review and evaluate codes and standards for metallic components in HTGRs. And the focus there was on NH and also comparing what is done in the United States with ASME BPV Code with elsewhere. That has been a very useful reference since then and that is something that should be continued and updated because we have been working on it on ASME quotes for a couple of years. I have been on the ASME code committees since the end of 2006 in this ongoing process and we recommend more focus. We are working with ASME right now to identify areas to more strategically target that are not done elsewhere.

The other thing that is important and has been begun and we think, I think, should be continued is more work evaluating the effects of the HTGR environment on degradation of metallic components and conducting confirmatory testing. This is a creep test program. So, here there are four different facilities. The impurities can be injected here. You can control the helium, the carbon dioxide, carbon monoxide. You can also, by passing hydrogen through a reducing environment, CO2 reducing environment have a CH_4. So you can control the moisture, the methane, carbon monoxide, carbon dioxide, hydrogen, in your helium stream. There is mass spec monitoring, gas chromatography monitoring on this and you can also do separate evaluation and monitoring of different gas streams. So, this is online already and is still available for use.

Okay. You probably read a recent document from Oak Ridge that was called the gap analysis. This is another way of doing a gap analysis. The gap analysis looked at all of the different PIRTs and emphasized where there was the highest priority. You see here we have a total of 58 different phenomena identified and of those phenomena 16 were identified of being high importance and low knowledge. So these are the most important for future research, in terms of prioritization of research. So I am looking at these again.

One of the problems that we had following the PIRT, because there were so many that were identified of being really critically important, they have to be sort of differentiated and discriminated to determine which are really, really key. If there are two or three out of these that were really important, it would be easier.

So anyway, I went back in to what we had done in 2007, completed in 2008 and looked again at what we had in terms of how we defined knowledge. We defined high knowledge as being that where experimental simulation and analytical modeling was available with a high degree of accuracy. And with the figure of merit, the highest figure of merit, in other words, the highest importance were those that would be a controlling influence on the primary evaluation criteria.

And one of the things you will notice when you go through this, the way it was done in this group for the high temperature materials, it was really more component oriented. So for example, you would have the phenomena especially targeted for an analysis of the reactor pressure vessel, as well as intermediate heat exchanger. So you would have two times when this would be determined of being of high importance and low knowledge. So this totals 14 different cases. And when you analyze these 14 different cases, they really break down into five different areas. One of the ones that I mentioned before that we want more focus on, we are having a short study being done through ASME to prioritize is that of inspection and NDE. Another one that comes up for both the metallic internals and the reactor pressure vessel is the compromise of surface emissivity. And I will talk about that a little bit further in the context of work that we have at the University of Wisconsin Institute of Nuclear Systems on Emissivity.

Crack initiation and subcritical crack growth. That is being done ongoing. Creep and creep fatigue, this is a project that we have funded at Oak Ridge that Dr. Malik will talk about.

MEMBER APOSTOLAKIS: Who is participating in these projects?

CHAIR CORRADINI: I can help you there. This was two years ago. If you remember, it was done about two years ago and published around April. We reviewed it at the time.

DR. HULL: Yes, on the committee, the chair was Bill Corwin. There was also Saurin Majumdar from Argonne. There was from MIT --

CHAIR CORRADINI: Ballinger.

DR. HULL: -- Ballinger, okay.

MEMBER APOSTOLAKIS: The usual suspects.

CHAIR CORRADINI: That is approximately right. Gary Watts.

DR. HULL: Yes.

MEMBER APOSTOLAKIS: The usual suspects.

DR. HULL: So, these end up being the really key areas based on the work of the PIRT and they also come out on the work that we have been doing on the ASME DOE Gen IV Materials Project.

Okay. So I will talk about some of the ongoing metals R and D work that we are doing now.

As mentioned before, we have a three-year project at Wisconsin Institute of Nuclear Systems.

MEMBER APOSTOLAKIS: Is that yours, Michael?

CHAIR CORRADINI: Is that this workman or is it Professor Allen's?

DR. HULL: Yes, Todd Allen's work.

MEMBER APOSTOLAKIS: So why did you say, yes? Wisconsin is yours?

CHAIR CORRADINI: Well, I do -- yes, I am there. Yes.

MEMBER APOSTOLAKIS: Are you conflicted now?

CHAIR CORRADINI: I'm trying to be quiet. You are not letting me.

DR. HULL: And that is one aspect. This is one topic of the multi-topic project that they have. They have relatively small funding, seed funding and they are being very active on this. I do not manage this project. It is managed by Lauren Gibson and Sud Basu is the technical monitor but I was one of the people who reviewed the original work and decided it was very important. So, I have a little bit of --

MEMBER APOSTOLAKIS: When you say the emissivity of materials for process safety, what exactly are they doing? Are they developing, for example, a probability distribution?

DR. HULL: They are doing experimental work also. They are looking at codings. They are looking at the stability and possible degradation.

MEMBER APOSTOLAKIS: So it is more of a mechanistic kind of behavior.

MR. RUBIN: Maybe I can help out. In the heat transfer model, during the access, radial heat transfer and, of course, the radiation cooling is a very, very important one and it is very sensitive to emissivity. And so it came up that through aging, the surface can change, the emissivity can change. During an event, there could be fine dust particles that can, you know, settle on to that surface, changing emissivity. And so we want to get our arms around all those effects and we felt it was a materials need to kind of manage that kind of a thing.

MEMBER APOSTOLAKIS: But that would be uncertain. You can't know a safety value for all these phenomena using, they are incredibly unsafe.

MR. RUBIN: Sure.

MEMBER APOSTOLAKIS: So is the objective of this project to develop a probability distribution for the possible values of emissivity?

DR. HULL: The next slide shows some of the objectives. Do you want me to go on to the next slide?

MEMBER APOSTOLAKIS: If it helps answer the question, sure.

DR. HULL: My focus was more in the experimental work. So, they were focusing on the reactor cavity, cooling system, reactor pressure vessel, the core barrel, and looking at the material parameters governing the extent of radiated heat.

Looking at emissivity --

MEMBER APOSTOLAKIS: But there will be point values for all this stuff because these are deterministic guides. Right?

CHAIR CORRADINI: Yes, God help them.

MEMBER APOSTOLAKIS: So, God help us because they are ignoring uncertainty. Tell me that it is five, it doesn't help me very much. So, who worries about that? Are you guys going to worry about that?

DR. HULL: I am a deterministic guy.

MEMBER APOSTOLAKIS: You are a deterministic person.

DR. HULL: I am a bench chemist.

MEMBER APOSTOLAKIS: So you will defend it.

MR. RUBIN: You raise a good point. I mean, we will want to do some sort of sensitivity studies of some sort. And so that would be important to have.

MEMBER APOSTOLAKIS: Stu, what is wrong with a probability distribution? I mean, doing some sensitivity studies is a first.

MR. RUBIN: I'm not sure that we have asked for that.

MEMBER APOSTOLAKIS: But it seems to me somebody should worry about it. Because when the time comes to run the codes, you will need that, I mean, to propagate the uncertainty. That is the problem with all these codes.

MR. RUBIN: Correct.

MEMBER ABDEL-KHALIK: Is the concern here that there are some aging mechanisms that would actually decrease emissivity?

DR. HULL: Yes, it can. The concern is that it might be -- you want it to be stable is an important function here.

MEMBER ABDEL-KHALIK: I mean, if it were to increase, wouldn't that be conservative?

MR. RUBIN: Increase is good. Decrease is bad.

MEMBER ABDEL-KHALIK: So what aging mechanisms can actually decrease emissivity?

DR. HULL: Maybe if you have something that affects the surface roughness. That is something that is under consideration. The oxide layers, you know, the stability of the oxide layers are a concern. And so they are being studied in terms of correlating their stability and thickness and continuity with the value of emissivity.

MEMBER APOSTOLAKIS: So you are talking about the high marks.

MR. RUBIN: Well eventually, the heat has to get there but it has to go through these various ports.

MEMBER APOSTOLAKIS: Yes but the emissivity is important.

MR. RUBIN: Emissivity is the dominant parameter that gets you out there.

MEMBER ARMIJO: You don't have any problems with the emissivity of the graphites changing?

MR. RUBIN: I think we are doing some experiments on that. I think they expanded their scope to include that as well.

MR. KRESS: The shape factor probably overwhelms -- the shape factor, the impact probably overwhelms the event.

MEMBER APOSTOLAKIS: As a general comment, I think, you know, I don't know whether it's premature to worry about it, but we recognize there was some destruction on several distributions. And if you think about them now, you may get some insight as to what experiments. In other words, if you have in mind the optimum goal, then you can work backwards and say

I need to do this, and this, and that. I am sure most of it is there already. But you know, you never know.

MR. KRESS: Do they plan on aging these materials some way and then measure the emissivity in the function of time?

MR. RUBIN: I do believe we are putting in different kinds of specimens that reflect the aging process in terms of the rate.

MR. KRESS: Yes, I understand that.

MR. RUBIN: Right. You are putting in different specimens to account for the different aging points.

CHAIR CORRADINI: Are you allowed to say in open session what the initial point designs are as to the expected surface condition for the NGNP?

MR. RUBIN: It must be a specification.

CHAIR CORRADINI: I mean I am curious because I assume it is not going to be bare metal.

MEMBER ABDEL-KHALIK: I mean, that was the reason for my question.

CHAIR CORRADINI: That's where I think he was going. That is where he is going, I think.

MEMBER ARMIJO: No. I mean, you haven't got a design yet.

MR. RUBIN: That's part of the problem.

MEMBER ARMIJO: That is a big problem.

MR. RUBIN: We'll make a mental note of tracking that.

MEMBER ARMIJO: But the designers haven't specified the initial problems. And these guys have to confirm that it is going to stay that way.

DR. HULL: Okay, moving on. Another project that we have that is a little bit closer to home, we started this in November, is to helping to support some work on the ASME Roadmap development. There is work being done on HTRGs both in ANS through Standards 53.1, which has more of a systems approach. This is led by Jim August and Spellman of Oak Ridge.

And then a components approach is more that of ASME. So, we are doing work to determine where we need to do in developing the appropriate codes and standards for the kind of plant we might ultimately have is being developed with the Section XI HTGR working group. That is more dominated towards the PBMR. And so there are a lot of people there from South Africa and they are more, that is more risk-informed and there are risk specialists very active on that committee.

I have been involved, the third thing is the Gen IV/NGNP Materials Project. This is something that was developed by Trevor Cooke and we have been involved with that since 2006. There are 12 different materials tasks that have been undertaken. The first six are done. They range from a verification of allowable stresses in Section III, Subsection NH, with the focus then on alloy 800H and Grade 91 steel, which is nine chrome molybdenum, regulatory safety issues and structural design criteria of ASME Section III, Subsection NH improvement of the NH rules for Grade 91 steel.

The fourth is updating the ASME code case N201. Fifth is collecting creep-fatigue data for Grade 91 steel and Hastelloy XR. So we had an enormous international contribution there.

There is issues of what is going to be able to be publicly available and when it is only available to the committees. But an enormous database of material parameters and degradation values have been compiled through this activity.

MEMBER APOSTOLAKIS: When you say international, is it mainly the French?

DR. HULL: The French, Korea, Japan.

MEMBER APOSTOLAKIS: Oh, Korea?

DR. HULL: Yes.

MEMBER APOSTOLAKIS: Because the French

are looking both at the sodium-cooled and gas-cooled reactors.

DR. HULL: Okay. More recently in the past few months, we have started the last six tasks, focusing on operating condition, allowable stress values, co-considerations for the IHX associated with the work that was done on the PIRT, the work that has been done by Oak Ridge, very many different places. IHX is an area of concern because of the conditions associated with it, thin walls, etcetera. So we have a task number seven focusing on that.

Creep and creep-fatigue crack growth at structural discontinuities and welds. And Shah will talk about some, Dr. Malik, will talk about some related work.

International elevated temperature design codes, to update and improve Subsection NH, that is nine. Ten is alternative simplified pre-fatigue design methods. Eleven, new materials for NH and twelve, and the reason why I mentioned we went through this, twelve, is improved NDE methods from metals. And that is something that we at NRC are helping to support.

MEMBER APOSTOLAKIS: I am a little confused. Yes, all of these projects and so on, I mean, do you expect definitive answers to these issues, if I were five years from now? I mean, you mentioned earlier that there was another one in 2003, which presumably ended last year.

MR. RUBIN: That one was the first version of the ARRP --

MEMBER APOSTOLAKIS: Right.

MR. RUBIN: -- that I talked about yesterday. You weren't here. Now, we update it and now we have the 2008 version.

MEMBER APOSTOLAKIS: But you did have some good results from that one.

MR. RUBIN: The issues were identified as to point. In terms of actually work done, we didn't do that much.

DR. HULL: Yes, it was started --

MEMBER APOSTOLAKIS: Five years?

MR. RUBIN: We shut it down after PBMR.

MEMBER APOSTOLAKIS: Oh.

MR. RUBIN: Remember?

MEMBER APOSTOLAKIS: Oh, okay. So it was beyond your control.

MR. RUBIN: Right.

CHAIR CORRADINI: Just a question, a specific clarification question on your last -- I think you went between your third and your fourth bullet. I just want to make sure I get it right.

For the IHX, do you have all possibilities covered in terms of the materials-fluids compatibility that you are considering? That is, there are some of these designs that I have seen that are considered molten salt as the carrier fluid between the reactor and the process plant and others with helium. So, are you looking at those fluid-materials combinations as part of that work?

DR. HULL: This work on the IHX is not being funded by NRC. It is being funded --

CHAIR CORRADINI: Oh.

DR. HULL: It is being funded by DOE and ASME.

CHAIR CORRADINI: Okay.

DR. HULL: And I mention it because what we are doing, the little bit we are doing is complimentary and supportive and not duplicative of the work that --

CHAIR CORRADINI: It is more observing and collaborating.

DR. HULL: Yes and getting information.

CHAIR CORRADINI: Okay.

DR. HULL: And seeing where there are

holes so we can see --

CHAIR CORRADINI: Okay, thank you.

DR. HULL: -- where we at NRC need to do funding. You know, work best not done elsewhere.

MEMBER ABDEL-KHALIK: What are the materials used for the IHX?

DR. HULL: We have the, they're nickel alloys.

DR. MALIK: Yes, Alloy 617, Haynes 230.

DR. HULL: Okay, we will go to slide 17.

MR. LUPOLD: Yes, that -- this is Tim Lupold. Actually materials have not been specified yet. Everything is all up in the air.

MEMBER ARMIJO: To try and do a research program on an undefined produce where there are no design specs, there is no material selected, you know, it is, you are doing the best you can and you are learning as much as you can but I wouldn't do an experiment yet until I knew what the thing is going to look like.

MR. LUPOLD: We are monitoring what DOE is working on an INL. And these are two materials that they are looking at as a possible material for the IHX.

MEMBER SHACK: But these are these

microchannel designs, too. Right?

MR. LUPOLD: That is one possibility for the IHX. There are several configurations out there. You know, that is not the one we want.

CHAIR CORRADINI: Well I think a lot of this is evolving. But I guess I think I would echo Sam's point, which is I appreciate where you guys, what you need to do. But in some sense, I assume the conversation back to the DOE is the sooner the better to settle on some sort of point design so that you can deal with base technology, uncertainties on parameters of it. Otherwise, I can't imagine how you are going to meet the schedule that you are committed to.

Now, you can say that is DOE's problem but it seems like the money and the time is just clicking away.

MR. LUPOLD: A lot of the things that we are doing right now are be able to get our test systems up and running, make sure that we had the ability to run goods tests and that we can get good results. And then once these items are specified, then we can actually get it and do more research in earnest on the actual materials that will be used.

CHAIR CORRADINI: Okay.

DR. HULL: Okay, I'm going to go back

then.

CHAIR CORRADINI: Just keep on going. After we say our peace, you can go back to what you want. We feel better now.

DR. HULL: Okay, so we are monitoring what is happening with the Gen IV NGNP Materials Project, one of which is to compile -- there are a number of people with very little money with a lot of hard compiling information necessary for IHX.

The best project that was started in July, which also focuses on IHX is modeling creep and creep-fatigue crack growth processes in the HTGR and very high temperature gas reactor materials. And Dr. Malik will talk about that shortly.

Okay. We mentioned the work on emissivity. And in your handouts there is a sketch of the experimental facilities at Wisconsin. And we now have the modeling of creep and creep-fatigue crack growth processes.

DR. MALIK: Well, one of our topics, which has been found in the phenomena identification and ranking table to be of high importance and low knowledge is the subcritical crack growth. In particular, for high temperature, you are looking for creep and creep-fatigue crack growth process. And that this could happen either in reactor vessel or in IHX and that could develop pathway for the fission product release.

And so in that regard, we are trying to make into creep and creep-fatigue --

MEMBER ABDEL-KHALIK: If I may just go back to the previous chart.

DR. HULL: On 17?

MEMBER ABDEL-KHALIK: Right.

DR. HULL: Okay.

MEMBER ABDEL-KHALIK: On ten. Are there any directional variations of emissivity or are these all assumed to be gray bodies?

DR. HULL: Well, you are dealing with -- I don't know. Stu, do you know?

MR. RUBIN: No, I don't.

MEMBER ABDEL-KHALIK: I mean, if there are directional effects, wouldn't that impact the performance of these systems? So why hasn't that question sort of been addressed and put to rest?

DR. HULL: This, to the best of my knowledge, and from what I have heard from talking with others, this is the only project relatively small also that is being conducted in the United States on this topic. So, --

CHAIR CORRADINI: I think your third bullet helps.

MEMBER APOSTOLAKIS: Yes, isn't that angular dependence there?

DR. HULL: That's what I just mentioned.

MEMBER APOSTOLAKIS: That doesn't answer the question?

DR. HULL: Well, I thought maybe it did.

MR. JOLICOEUR: This is John Jolicoeur. They are planning to do angular measurements at Wisconsin for emissivity. It is not just going to be --

MR. KRESS: A lot depends on how porous the surface is or whether it has scales, dockside scales over here. That affects the angular. If it is clean material, you don't have any angular dependents.

MEMBER ABDEL-KHALIK: Okay, thank you.

DR. MALIK: Okay, this project had been started about five months ago at Oak Ridge National Lab with Dr. Sam Shem as the principle investigator to investigate the creep and creep-fatigue crack in materials of importance to intermediately extend it and will ask, to some extent, the crack vessel and the temperature was in the creep range.

MR. KRESS: When you are talking about

fatigue, are you talking about thermal stresses?

DR. MALIK: Yes. And in direction of higher temperature plus whole time effect and the cyclic loading.

MR. KRESS: So how do you get to cyclic loading? Does that involve the streaming of --

DR. MALIK: Well, it will involve heat up and cool down of transients.

MR. KRESS: Well of course you could get that. I was worried about the possibilities of extremely hot fluid because of this --

MEMBER SHACK: Thermal strife.

MEMBER ARMIJO: Is that high cycle versus low cycle? Is that your issue? Is there any way to get a high cycle?

MR. KRESS: Yes, that would be a high cycle effect and that generally is worse than low cycle effects. And that is why I was -- and you could get pretty big temperature swings that way. I was wondering if that was part of the fatigue study.

DR. MALIK: Not yet but we will be looking to more what kind of temperature and the fluid we would be using. And based on that, we can see that as well.

MR. RUBIN: I believe that the AVR had

some failures of metallic components above the core and they were traced to that issue.

MEMBER SHACK: By and large, that has to be a design issue.

MR. RUBIN: Yes.

MEMBER SHACK: You are not going to --

MR. RUBIN: Exactly.

MEMBER SHACK: There ain't no fatigue, you know, impermium.

MR. KRESS: Yes, you can get rid of the streaming. You are not going to -- you know a fatigue you can't design out of the system. You know, that is a materials problem that has to be solved, a thermal sort of striping sort of problem.

MEMBER SHACK: You figure out how to design out of it.

MR. KRESS: You had better get rid of that.

MEMBER SHACK: Yes, I agree.

MR. KRESS: So it is the same question here again. I mean, creep and creep-fatigue is so material dependent and yet you guys have, you know, no real idea --

DR. MALIK: Just reading the literature so at this point, I am going to follow what the DOE council of material selection and the temperature selection. So we are not going to start testing until we get all this cleared up.

Okay? Well, the scope of work involved. First of all, you have a document on investigate what is the current state of knowledge in that area and with emphasis on ASME Section III, Subsection NH, and potential VHTR materials such as nickel-base alloys.

MEMBER SHACK: What is the operating temperature of the pressure vessel?

DR. MALIK: Pressure vessel would be probably 500, 600 degrees something like that. But there was -- yes, centigrade. And IHX would be between 750 to 950.

MEMBER SHACK: You hope not, but okay. It will make it interesting.

CHAIR CORRADINI: Let me ask -- I guess I would like a comment from DOE. When will there be a decision in terms of the exit gas temperature level that will set all these other things and give you some semblance of certainty on some of this? Do you have a -- can you speak for them or can we get them to speak for themselves about this? Because it has been going up and down.

Oh, I recognize this face.

MR. KINSEY: This is Jim Kinsey from INL. Just to provide some update on where we are with our work with DOE on the NGNP project, I know we had some dialogue yesterday also around parameters.

The report to Congress and the licensing strategy describes some schedule results that are based on some assumptions of what the design may look and what its outlook temperatures may be.

Currently at the INL, we are working with the reactor suppliers as subcontractors and a number of other entities to start some conceptual design work that is putting more emphasis on structure and working towards getting results to the kinds of questions that you are asking.

In addition to that, the DOE plans to go out with an offer of financial assistance in the near term to establish a public-private partnership to move the project forward. So, we are working with the industry at this point to engage in that process. We would like to not -- we are not planning to specify a specific outlet condition or specific reactor design conditions at this point but want to work through that through the response process and the ward of the public-private partnership arrangement.

CHAIR CORRADINI: But we do have

information from industry and from the folks who are involved in that process that would suggest there is, I guess I will call it a bell curve of industrial uses that are probably at a temperature that is lower than 950.

MR. KINSEY: You know, we expect it to be the range of 750 to 800. We are trying not to specify that at this point because we want that to play out through the responses to the request for assistance.

CHAIR CORRADINI: Okay.

MR. KINSEY: And you know, we are working to keep the staff informed as to what the flavor of that is looking like, so that we can try to focus our research efforts.

CHAIR CORRADINI: All right. That is helpful. Thank you so much.

MR. KINSEY: Sure.

DR. MALIK: Okay?

CHAIR CORRADINI: Go ahead, I am sorry.

DR. MALIK: Okay, so the current one is document the current state of knowledge of the creep and creep-fatigue crack growth processes. And then based on that, identify critical areas where there is a lack of knowledge and/or insufficient data. And again, it will depend on what material we choose. So that part is still kind of slow right now. And then make recommendations on approaches to addresses those gap areas and perform confirmatory research and conduct scoping tests in the critical areas.

Here we talk about a little bit the key aspects of creep and creep-fatigue crack growth processes. Here, the definition behavior and all the components. Cyclic plasticity, primary creep, secondary creep, and tertiary creep. Again, it will depend on what material we choose. Some parts may be more active and some may be less active.

Here in the middle, I show what happens when the elevated temperature creep resumes, and the monotonic loading condition, total strain versus time. You have initial elastic-plastic response, and then material such as chromium-molybdenum steel and chromium-molybdenum-vanadium steel, as well as stainless steel, exhibit three stages of creep stages process. The initial is called primary creep, again it is a transient form, and a sustained and steady secondary creep, and followed by tertiary creep, which is again, a transient form. So, you have several components on the formation behavior here. But at least no nickel-base alloy, high temperature alloys, do not show the secondary creeps or in that case, creep strain you will have only the primary creep and then the final tertiary creep. So we may have to consider all of these different, the formation behavior, depending upon the selected material, and to perform the fracture mechanics calculations.

Factors such as K stress indices factor, J integral extreme measure rate both for incremental formed delta for the case of fatigue, and K and J in the case of creep, that type of condition; and at the height of fatigue, you also have a CT integral, which is also like a J integral for creep review.

Next we can see and here is schematic case of the computation performed by Ashuk Saxena for the creep combined effect of cyclic creep, cyclic plasticity and creep is shown here. Ahead of the crack tip, you have a windshield cyclic plastic zone which is inside, which is surrounded by creep zone. And after that, that is also inside the plastic zone from that prime loading.

So the modeling material response and the modeling is much more complicated once you have both creep and fatigue as a cyclic loading.

The key aspects of the crack growth mechanism, you have like transgranular fatigue, which is cycle dependent. And here is an example shown for a Alloy 800H for fatigue crack growth. It has striations and transgranular fracture surface for fatigue loading condition.

And then we also have mechanism of intergranular, where the grain boundary cavitation takes place, which is a time dependent creep formula. And again, it was performed for Alloy 800H again in nickel-growth alloy. One can see here r-types are like round cavity formation, ahead of a crack, as ridge type of opening ahead of a crack tip.

So they explain it in loading condition both and fatigue as in a cyclic creep present loading.

And these additional considerations of what is the effect of the loading wave-form, how it will be cycling; what did R-ration, depending on what kind of mode we see over there, which is a ration of minimum stress to a maximum stress; and the cyclic modeling, what are the cracks of disclosures, what are the effects of that; and the effect of environment such as impurities, etcetera.

Now flaw evaluation procedures again, based on the crack growth correlations. The issues to be considered would be the transferability from specimen to the actual full-size component, as well as maybe the crack, sort of crack to constraint when you are doing the test on a single mini-axil test fracture specimen and applying it multi-axil real component.

And extrapolation also --

MEMBER SHACK: I mean, it just sort of boggles my mind though, I mean as I go from --

DR. MALIK: Elastic plastic to --

MEMBER SHACK: But I mean, if I have one of these microchannel type things, you know, the component dimensions and stuff are so different from different designs, it just -- well, I guess until you have some thing more settled, it is just very difficult to picture how things are going to go here. But it is good work.

DR. MALIK: This is just the plotting has changed, the economic. We stop further work until we know more about the materials and can complete a selection.

Okay, the extrapolation will involve again testing to be performed at short duration and high load; whereas in actual component, it would be long life, long load timing and new stresses. So, the effect of that extrapolation, at least as we can see here, means we are directing the crack growth correlations.

And additional degradation mechanisms,

such as due to impurities also those that you can see there.

Flaw evaluation procedures are similar to ASME Code Section XI for light water reactor could be formulated based on the tests we performed. And one can develop a correlation based on those.

The next step in the process would be how to use that into statistical and risk-informed computer code application, which we are trying to develop as well a modular probabilistic code. And that means for that validation and accounting for the uncertainty in the correlation needs to be doubled up for that.

I think this is a summary slide, the strategy for metals R and D. To maintain staff for awareness and expertise in the codes and standards area by following the possible technical meetings as the latest proximity in the international programs, such as the Gen IV/NGNP Materials Program and the ASME Section III high temperature gas reactor special working group, as well as ANS standard, safety standard for modular helium reactors.

And another topic we are looking into is the International Creep-Fatigue Round Robin Testing, even though this is not directly involved with NGNP

Materials that will still participate in that.

Existing R and D programs based on phenomena which are high in importance and low knowledge and based on the PIRT process we conducted during 2007. And the project we are particularly looking, as we discussed before, was emissivity for passive system safety as well as creep and creep-fatigue crack growth processes.

Further refinement in NGNP metals PIRT prioritization is being conducted in the form of monitoring what is happening in the international arena, as well as update following HTGR specifications at DOE, to do determine what additional confirmatory testing needs to be done.

And the scoping studies for NDE and ISI Technology for high temperature is also being pursued.

I think that is all. Last slide? Last slide.

CHAIR CORRADINI: Other questions by members? Well, you know, I am waiting for you to give us the send off, Sam.

MEMBER ARMIJO: Well you know, I think, to me the most important thing that the NRC staff is doing is developing their own expertise of literature, the phenomena, all materials. And until we have a design really to focus your research on, it is probably, as long as you are doing, if you are being very selective in what you choose to work on, for example, emissivity that might have broad applicability independent of design, that is probably all good stuff to do.

But it seems to me that the designers have the responsibility of defining the environments that eliminate a whole host of these challenges, carburization, decarburization. They certainly must know what levels of impurities in the helium lead to problems. Maybe they are not totally correct but at least they say I cured my starting point, if we are going to make very, very pure helium and then the regulator can say well, we don't think that is good enough because.

It just seems to me like they are asking you to answer questions that haven't been asked. But I think you are doing the best you can.

I like the research plan write-up. I thought it was very comprehensive but I thought it was just impossible to achieve because it is such a huge test matrix because you don't have a design. And I think it will correct itself once DOE focuses on a design and material and temperatures. But until then, you are just working in the area.

With that, I will cease.

CHAIR CORRADINI: I was hoping for some sort of overall --

MEMBER ARMIJO: Well that is my overall.

CHAIR CORRADINI: Abdel?

MEMBER ABDEL-KHALIK: Are there any soft of data on radiation effects on the properties of these materials?

DR. HULL: This has been done in the fusion community as well. So one of the things -- fusion reactor materials. One of the things I didn't mention is we have always been monitoring what has been done in other communities looking at reactor materials. In fact, a number of the people who are working on metals for the high temperature reactors have also been actively involved in the fusion reactor materials community.

MEMBER ABDEL-KHALIK: But the spectrum is just totally different.

DR. HULL: Well, we have not, ourselves, been looking at radiation damage. Let me see what the Oak Ridge -- I think the labs have been doing, they have been compiling work that had been done earlier. For the work we are doing with ASME and DOE, we are not specifically looking at that so much. It was identified in the PIRT as being of concern, obviously, because at the beginning I mentioned, you know, creep-fatigue under as effected by radiation also.

MR. KRESS: Is there a pressurized thermal shock issue with these reactors?

DR. HULL: That wasn't identified by the PIRTs.

MR. KRESS: Because of low fluids, probably and the fact that they know how to weld those things together now without --

CHAIR CORRADINI: The only thing that I would say that I would expect would have come out in the PIRT, maybe it is buried somewhere in there, is if the IHX is going to have that be different fluids coming in and you have got these, as Bill was saying, these particular designs that have real issues about ceiling, you could see by some sort of continual oscillatory behavior, you could essentially then have some sort of de-bonding or issues such as that.

MR. RUBIN: But the other aspect is there are some transients where the pressures can increase and the concern we create with the IHX, some of the material is very thin, and that becomes the critical point of concern for failure of the pressure boundary.

CHAIR CORRADINI: Other questions? Thank you.

So, again, I am going to turn to you, Stu. I notice your next presentation is on graphite. It is supposed to go over an hour. So we can take a break now, we can take a break in the middle of the presentation or we can take a break after the graphite presentation.

MR. SRINIVASAN: I think a break now probably would be --

MR. RUBIN: Break now.

MR. SRINIVASAN: -- best. I expect you to ask more questions about graphite.

CHAIR CORRADINI: We will? Okay, I guess we will. All right, so 15 minutes. We will come back at 9:45.

(Whereupon, the foregoing matter went off the record at 9:26 a.m. and resumed at 9:45 a.m.)

CHAIR CORRADINI: Okay. Let's get back and we will be talking about graphite materials and Srini will take us through this. So, we chatted kind of at break. Some of the members had questions about graphite erosion, dust generation, etcetera. He is, Srini is willing to discuss that but I propose that we let him get through his prepared material and then in the question, the QA period at the end, we can bring up those questions to settle what the members have and what they have questions about.

So, go ahead.

MR. SRINIVASAN: Good morning. I am Srini Srinivasan. I am a senior materials engineer in Corrosion and Metallurgy Branch of the Division of Engineering in Office of Nuclear Regulatory Research.

My presentation today is on Nuclear Graphite Materials Research Plan related to high temperature gas-cooled reactors.

I will begin my presentation with the objectives of NRC's research related to graphites for high temperature gas-cooled reactors. The leading objective is to enable data on information acquisition for licensing decisions on HTGRs. I will provide a brief background on the outcome of our cost research on graphites. We have been actively participating in the national and international codes and standards activities over the last five years. I will provide you a status report, a snapshot on this.

We also conducted a graphite PIRT during 2007 which formed the basis of future NRC research in graphite area. I will provide an overview of the PIRT results. We have currently minimal activity in graphite research, primarily to elicit expert opinion, particularly information gaps that might be closed sooner or with improved quality with NRC's participation.

After providing a brief insight into the future plans for graphite research, I will conclude this presentation with a summary.

There is a general awareness and recognition that it is the responsibility of the applicant to provide NRC adequate technical data and information to support safety case for graphites in the HTGR design. The staff needs to be technically competent to evaluate and assess the licensee data and information, to provide adequate assurance of safe operation.

To accomplish this responsibility, the staff usually conducts confirmatory analysis of the applicants' data using independent analysis tools.

The overall objective of NRC graphite research is to independently generate technical bases needed for licensing HTGRs. Such research is expected to generate technical bases for developing one, staff regulatory positions on structural and functional liability of graphite, code and code support components, which will be stated in the regulatory guides.

Staff regulatory positions on inspections needed to ensure the existence of adequate, structural, and functional safety margins, during normal operations and anticipated operational occurrences, which would also be stated in regulatory guides and for input into accident analysis calculation tools.

A good understanding of graphite properties is needed for evaluating the integrity and failure modes of graphite components. The integrity of components should account for potential air, water, or steam ingress into the pressure boundary and the melting core geometry. The pressure boundary also acts as a barrier to release of radioactivity.

In conducting graphite research independently, we enabled a generation of technical data and information which will identify and quantify degradation process by analytical models. Graphite research is also intended to provide information and data for HTGR accident analysis evaluation model. For example, graphite dust and for evaluating PRAs.

The committee has been previously briefed on a materials research technical issue related to graphite components for HTGR which is a major issue that was identified, namely, the absence of consensus national and international design, construction, and inspection standards for graphite and other ceramic components for HTGR.

To address this major deficiency, we initiated a contract at Oak Ridge National Laboratory during 2002 and 2003. The objectives that initiate codes and standards to relevant activities at both ASME, American Society for Mechanical Engineers and ASTM, American Society of Testing Materials, that would involves active participation of national and international technical community interested in the development of high temperature graphite moderated helium-cooled high temperature reactors.

This slide gives you some technical considerations for development of codes specific to graphites for HTGRs. The current high temperature gas-cooled reactor is made of graphite bricks or blocks, which function as moderator and reflector of neutrons. The bricks are assembled with keyways and keys connecting the bricks in the designing the core. During reactor operation, irradiation changes the structure of graphite.

The most significant graphite property for reactor safety is a dimensional change during reactor operation. This change is not uniform and not linear as a function of neutron dose. During initial reactor operation, the overall dimensional change leads to shrinkage. However, during later stage of reactor operation the overall dimensional change leads to swelling.

The neutron dose change at which this turn around in dimensional change occurs is traditionally known as end of life for graphite components. The core functionality is ascertained by the ability of the unhindered movement of control rods and fuel elements. Also, continued adequate cooling of the fuel in the core and finally, the continued ability to charge and discharge the fuel.

Significant properties, such as thermal conductivity, thermal expansion and shrinkage, Young's modulus and creep vary as a function of dose or time. Interactively, these properties contribute to stressors that add to the normal service stress due to the coolant pressure.

Though the damage mechanisms are reasonably well-known, there is a continuing need to establish a better understanding or the interaction effects of several properties changes, which also depend on irradiation temperature. The challenge is to correlate the effects of graphic constituents and microstructure, graphite manufacturing method, and the fluctuations in the field variables on the interaction effects of significant properties.

So, these are the things that really are challenging for core development.

Currently, the ASME Division III Subgroup on Graphite Core Components, which will probably move to a new Division V, this subgroup's mandate is to develop rules for material selection, design, fabrication, installation, examination, inspection, and certification of graphite core components, reactor internals, and fuel blocks. Because of prior history and existing gas-cooled reactors, the majority of members of this subgroup are from offshore. Experienced technical experts from European Union nations, South Africa, Japan, and Korea are providing valuable help in the development of these cores.

In order to fully utilize their expertise and ease travel and other burden related to the continuous and rigorous participation in these core committee meetings, half of the core meetings are held outside of U.S.A.

Here I am providing an overview of the current status of ASME core development activities in this light. Several articles are being in development by the members presently. These have been drafted in the very preliminary stage. These include Article 1000, which defines the scope and boundaries of jurisdiction for components, so 2000 on materials, 4000 on machining and testing, 5000 on installation and examination, and 8000 on certification stamping.

In formulating these articles, the subgroup relied heavily on the existing cores for metallic components, modifying certain provisions as appropriate for graphite components. These drafts are still undergoing revision as they go through the initial stage of balloting by subgroup members.

The articles on general requirements, glossary and design are being worked on currently. Of these, Article 3000 on design will be the most extensive and will need a lot of additional work and data and information on several grades of graphites being irradiated currently at many parts of the world. It is expected that a very preliminary draft of this article may be ready in about two to three years or less, depending on how much funding is available.

To aid the development of several articles mentioned in the previous slide and to provide technical bases for the various cores, the subgroup is also developing many mandatory appendices.

These appendices are shown in this slide. The objective of these appendices is to provide those with considerable metallic materials design expertise, information on designing the graphite as a structural material. The appendices include information on nuclear graphite, ASTM material specification, material data sheet on the generation of design properties for graphite components, aspects related to probabilistic design with brittle materials, consideration of irradiation damage to graphite during reactor operation, chemical effects due to impurities in the coolant, creep and dimensional changes are some of the aspects that are expected to be included in design.

The most challenging task is to provide a recommendation of an accepted practice for stress analysis of an irradiated part, which includes imposed mechanical and thermal loads, loads related to design, such as keyway stressors, internal stresses due to irradiation, creep stress, and stresses due to changes in dimensions resulting from irradiation. It is expected that the first consideration of some significant portions may become available for subgroup members' initial review by about the end of this year.

MEMBER APOSTOLAKIS: Are these appendices

and appendices the same before? I don't understand why there is Appendix 1 in Arabic and one in
Roman. What is the difference?

MR. SRINIVASAN: The appendix in the Roman numerals are changeable. It has to do with a lot more rigorous qualification of graphite. So where as the appendices 1, 2, 3, in the sense it is a ASTM materials specification and properties of later appendices. The appendices Roman numerals I through IV is related to design. Why they chose to have Roman numerals, I don't know the reason.

MEMBER ARMIJO: That is an ASME --

MR. SRINIVASAN: I'm sorry?

MEMBER ARMIJO: That is an ASME practice.

MR. SRINIVASAN: Could be, yes.

CHAIR CORRADINI: They are engineers.

MR. SRINIVASAN: Thank you.

Now, similar to what I talked about the ASME challenges, the challenges exist also for technical specification -- I mean sorry not technical. Excuse me. -- testing specifications and mechanical specification for which ASTM is involved.

As a result of the ASTM efforts during the last five years, two material specification standards are currently available for nuclear graphite. Until this time, we didn't have any nuclear graphite material specification. It is expected that graphites used in HTGR will have a high level of isotropy with respect to the thermal expansion coefficient property.

One ASTM specification deals with graphite components subjected to high doses, such as moderators and reflectors in HTGR. The other provides material specification for those components, which are subjected to low neutron dose. These will include, for example, graphite core supports.

The specifications that deal with purity and chemistry ensure many, many activated impurities after use to enable safe disposal. The specifications also include many requirements for physical, thermal, mechanical and chemical properties. These specifications do not contain any information on irradiator properties because insufficient data or knowledge are currently available for graphites currently contemplated for application in HTGRs. This is an important issue, however.

MEMBER BLEY: When you say it that way, I guess I understand the graphite that was used years ago is no longer available. There is new graphite for which we don't have that experience.

MR. SRINIVASAN: That is correct. That is correct.

If I may follow-up on that, to the best of people's knowledge base and ability in offering these specifications, material specifications that was authored along with active participation by graphite manufacturers, it was back extrapolation based on previous experience that these are the minimal properties expected for isotropic materials that is expected to irradiate properties that could provide adequate safety modem, if you will.

MEMBER ARMIJO: Why as-fabricated graphite and isotropic? You talk about degree of anisotropy but is there a fundamental reason why it is that way?

MR. SRINIVASAN: Yes.

MEMBER ARMIJO: It is cubic material. Right?

MR. SRINIVASAN: I'm sorry?

MEMBER ARMIJO: It is -- well, graphite gets hexagonal?

MR. SRINIVASAN: Yes. It's a diagonal structure. The primary concept table for graphite manufacture is coke. And the coke inherently has the base of pane and the feed direction and it gives us an isotope.

Now, the bulk of the graphite that is used in the world is used for electrodes for steam melting furnaces. That is made by extrusion, not that it matters, but basically the extrusion itself gives you grain orientation with grain that is grain. So, you are going from the fundamental property of coke, which is inherently anisotropy to the manufacturing, Sam, that you asked about.

MEMBER ARMIJO: Right.

MR. SRINIVASAN: Now, in demanding applications, there is also the question about grain size and things. What you do is that you pulverize the coke to very fine particles really and then therefore, minimize the strengths of anisotropy, if you will, and then use manufacturing approaches that will produce minimum amount of anisotropy. For example, an isomolding.

CHAIR CORRADINI: So, they are almost like powder metals. You squish it --

MR. SRINIVASAN: Absolutely. It is a ceramic process. If you do extrusion, if you do anything with the directional involvement and things, just like your code working, grain orientation and metallic materials, you can expect that. But the inherent thing is that there is a basic thing you have to have -- not you have to. You will have a certain amount of anisotropy to begin with because the coke particles constitute, basically constitution itself is anisotropic and there is nothing you can do about it. Therefore, there is a minimum of those.

MR. KRESS: Is that not a property necessarily bad? You can make use of it sometimes.

CHAIR CORRADINI: But as long as -- it is not predictable, I think is the problem.

MR. SRINIVASAN: It is not bad or good in that sense, as long as you understand what you have. Buyer beware, kind of a thing. Technically we are aware of what you do.

MEMBER ARMIJO: That is addressed in the ASTM spec, --

MR. SRINIVASAN: Yes, it is.

MEMBER ARMIJO: -- what is an acceptable level of as-fabricated anisotropy.

MR. SRINIVASAN: Yes, what we have defined is there is a 1.10 ten percent ratio in CTE, coefficient of thermal expansion, that is how it is defined anisotropy.

CHAIR CORRADINI: Say it again. Excuse me.

MR. SRINIVASAN: The isotropy graphic is defined as one which is having less than 1.10 of the ratio of the coefficient of thermal expansion in one direction and the coefficient of thermal expansion in the other direction should be less than or equal to ten percent variation.

Nearly isotropic is defined from ten percent to fifteen percent. Okay, 1.15. More than that is anisotropic and is not recommended or is not yet accepted as a nuclear graphite material as per the ASTM standards.

MEMBER ARMIJO: Well the designer has got to take that into account when he puts these things together.

CHAIR CORRADINI: So then it has to be checked, in some sense, if you think of the prismatic design as you develop the blocks for the initial drilling and manufacturing. Each specimen has got to be checked to fit into this.

MR. SRINIVASAN: That is correct. Actually what we have done, when I say "we" have something, excuse me. I have been a part of this committee for about five years now and we are the ones, NRC were the ones who initiated both the ASTM and the ASME activities.

The graphite material specification also includes some, in the end, inspection requirements and assurance of some kind of a density, anisotropy, as well as to the extent possible the effects that might be there or might not be there. That has yet to be negotiated between the user and the manufacturer -- designer and the manufacturer.

MEMBER ABDEL-KHALIK: How are the prismatic blocks manufactured?

MR. SRINIVASAN: The prismatic blocks are manufactured both in an isomolded way, as well as extrusion way. Both processes are acceptable.

MEMBER ABDEL-KHALIK: The co-particles are anisotropic. And this process is totally random. The orientation of these particles within that macro structure is totally random. So, I mean, you would have to be incredibly unlucky if these particles are to be aligned in such a way so that this macro structure turns out to be anisotropic.

MR. SRINIVASAN: That is correct. It is a good observation. That is the why isomolding is better because you are minimizing the extent of anisotropy that might arise out of manufacturing.

Two things you do. One is to make sure that the beginning coke particles are isotropic as possible by keeping it as a very small particles. The second thing is that by isomolding you don't introduce any directionality in your fabrication process. So, yes, indeed, that is right. That is why we keep it as isotropic as possible in the finished product.

MEMBER ABDEL-KHALIK: So the inspection techniques that would have to be done would have to be done on an individual macro component basis.

MR. SRINIVASAN: Yes, right. There are methods available. Ultrasonic modulus measurements have been proven to be very good in terms of defining the extent of anisotropy or isotropy also, on a manufacturing basis.

CHAIR CORRADINI: Looking at directionally speed of sound and the direction.

MR. SRINIVASAN: That is correct.

CHAIR CORRADINI: Okay, that makes sense.

MR. SRINIVASAN: So that is industrially used as a quality control on a daily basis.

Any other questions? Okay.

MEMBER SHACK: Yes, why don't you use that to define the degree of anisotropy? That seems a lot more convenient measure than coefficient of thermal expansion.

MR. SRINIVASAN: Right. I am glad you asked this question. It is an interesting one. In the nuclear graphite, as far as irradiation properties are concerned and things, CTE plays a lot more active role than Young's modulus.

So that and then we debated this issue and then we wanted to be more rigorous because it is a nuclear graphite specification, rather than a general graphite specification.

CHAIR CORRADINI: So there is not a one-to-one correspondence. If you measure the bulk, essentially by doing the sonic thing, you are doing the bulk modulus. And you are saying the thermal, the differential thermal expansion or the directional thermal expansion is not a direct one-to-one.

MR. SRINIVASAN: Unfortunately, it is not. And also, it is also as I mentioned in an earlier slide, all these properties are -- as a function of irradiation, the change is not uniform as well as not linear. So, you have to consider all the properties in their isolation as well as in their interactive effects and things.

Okay, moving on. Quite recently, as you know, we did -- excuse me. Sorry. Go ahead, please.

MEMBER ABDEL-KHALIK: If I were to look at the flux gradient, radial flux distribution within one of these cores, how much variability across an individual hexagonal block would I expect? And would that result in property gradients within an individual block?

MR. SRINIVASAN: The answer is yes.

MEMBER ABDEL-KHALIK: So how do you accommodate that in the design?

MR. SRINIVASAN: There are two approaches. One approach is a Japanese approach in Japanese HTGR in which they very cleverly did density -- density is a good indication of the flux and how the temperature is going to vary and, therefore, the differences in temperature from within the one region to the next region and that type of a thing, which you are offering to.

The Japanese approach was to use a material that is very highly isotropic, as well as very highly homogeneous material, so that you keep, the material is, itself, constant.

Secondly, even if you have some density differences between block, block and things, they arranged it in such a way that the overall cumulative effect would be reasonably uniform flux and temperature radiation. It is important in the design. That is one thing.

Now, that is a very costly approach because the Japanese IG-110 is a very, very costly material. Now, you can go to the next level of activity, in which case you will do a rigorous analysis of the flux profile, as well as the temperature profile. That will give you, in an iterative fashion, the stressors and so forth. So, you move all of the stressors out and things. It is --

MEMBER ARMIJO: You are actually are putting gaps in and things like that to account for differential expansion or is all of this locked together?

MR. SRINIVASAN: They are locked together.

MEMBER ARMIJO: So you build up stress?

MR. SRINIVASAN: You build up stress.

MEMBER ARMIJO: But I thought what you were getting at was is that once you start with the design, then by the second method evolves so that if you are going to take the second approach, you are going to have to do a continual iterative mechanical thermal thing to watch these things grow and know where things are growing and things are shrinking.

MR. SRINIVASAN: Absolutely. That is what AGR, as well as MagNox and United Kingdom they do. And they have a channel core measurement and things you look at and so forth by a TV camera, as well as growth meter going all around it.

MEMBER ARMIJO: So at some point if these stresses get too big, you have to replace a graphite component. Is that correct?

MR. SRINIVASAN: Yes, the one I talked about the end of life as a dimensional change and things really. Well before that, you are supposed to replace the reflector blocks, really because you don't want to get into the end of life itself really.

So, you will have an in-service inspection. The necessary thing is that you should have fuel rod movement, fuel element movement, as well as a control rod movement unhindered, as well as the coolant channels going through unhindered. So, you watch the rod really. There is a definite technical specification as the time that is taken for dropping and releasing that type of a thing.

CHAIR CORRADINI: And an HTGR, just to repeat your first method, in HTGR they use a graphite with much tighter specifications that eliminates a lot of this.

MR. SRINIVASAN: That will, A, eliminate a lot of this, but two, you also, you don't believe in your own design, so you do inspection to ensure that you do have, you know, there is no non-modality if you go, you know, I mean the coolant channels and things really are not non-circularity. Modality, excuse me.

MEMBER ABDEL-KHALIK: But even if you start with that perfectly homogeneous material, --

MR. SRINIVASAN: Yes.

MEMBER ABDEL-KHALIK: -- the operation conditions are different at different points in the core. So how do you account for the effect of different dpa at different locations within the core on variation in swelling and, therefore, the resulting stresses?

MR. SRINIVASAN: Yes.

MEMBER ABDEL-KHALIK: Just not from the initial conditions but the actual operating conditions of different points within the core.

MR. SRINIVASAN: Yes. What you do is a typical thing is I will get into that in a minute or so, is that before you design, you have to have the properties as a function of those dpa. And that is what forms the basis really of your predictions of what the stresses would be, and what amount of deflections would be, and what the amount of channel destruction, if you will, will be in place.

Now, during plant shutdown, you go and measure the --

MEMBER ABDEL-KHALIK: Verify.

MR. SRINIVASAN: To verify. You know, you might have the control rod and the fuel rod channels going through properly and things but yet you have to actually measure the circularity and the modality in that and things really. You do measure that and you keep record of that. And then if there is any associated difficult surprises or unpleasant surprises and things, then you go back and check.

In the case of British AGRs, they do during shutdown procedures, they go and cut out samples, if you will, from the actual reactor and go and test it in the laboratory for properties. And then from the original MTR measurements, which form the basis of design, and now the actual reactor, what is the delta? And then go and, unfortunately, help improvise those exponents and subscripts and things like that in your original design, and then modify your thinking.

CHAIR CORRADINI: What you are saying is that you have to almost renormalize your prediction, based on in-service inspection data and then project out and renormalize and project them.

MR. SRINIVASAN: Exactly.

MEMBER ARMIJO: Or it confirms your

original form, maybe.

MR. SRINIVASAN: Correct. And there is really more to it than what I am talking about because there is a lot more complexity with respect to neutron. You know, graphite creep is an important issue because it is not the traditional thermal creep really. Because of creep of graphite, you have graphite reactor. If creep was not there, I mean, because of neutrons and things because that accommodates a certain amount of, you know, dimensional things.

MEMBER RAY: Well, I have listened to all the discussion here about dimensional changes but on your next slide, you are going to talk about what I am more interested in, which is changes in mechanical properties. And it is not clear to me how this surveillance that you are talking about performing addresses that issue.

In other words, the strength of the material in a design-basis event condition which, of course, you don't anticipate ever occurring. And so I will be interested in what you say about you are removing samples to assess mechanical property changes and that sort of thing.

MR. SRINIVASAN: In the AGR case, in the

UK's AGR they have done that. Yes, that is what I am trying to say is that they cut off samples and they make mechanical strength measurements, Young's modulus measurements, CTE measurements, and thermal conductivity measurements. Basically, those are the things. Creep they don't do, really, and density.

MEMBER RAY: Okay. Well, that is fine. That is enough on that. I just, it, I am more skeptical, I guess about being able to discern changes in mechanical properties than I am about being able to detect changes in dimensional characteristics, just because of the problem of sampling and so on.

MR. SRINIVASAN: Yes, you do have to take out samples and measure that, really, you know.

MEMBER BLEY: Srini, I have a question. You said the end of life is where you change from the shrink mode to the swelling mode. Is the rate of swell much different from the rate of shrink was before that? You say you are trying to beat that point. Is it because it takes off fast after that?

MR. SRINIVASAN: No, not because of that. The data that I have seen is that if you look at it going down and coming up, it looks to be approximately the same slope, if you will, so I would not say that.

The reason that you want to do it is

really remember these are very, very, -- you know, if somebody wants to talk about statistics or something, we don't have statistics at all, really because you know, that the radiation experiments are hard to come by. They are very costly and things so there are very few samples. So when you look at the dimensional changes of functional neutron dose in the prior discussion, there are hardly five or six points that define your turnaround. And therefore, the uncertainty in that is quite large. So, you want to move away from that to have some kind of a confidence at some level, really. And that is the reason you want to be, you know, some at least, you know, five years before or three years, pick a number kind of a thing.

CHAIR CORRADINI: Is there a fluence level that or is the fluence level dependent upon the type of graphite you make?

MR. SRINIVASAN: The fluence level?

CHAIR CORRADINI: In other words, I assume it is a fluence number that says once this block of stuff sees greater than something, we start getting concerned about the uncertainty of what is going to occur. But is it also a function of how you made it? I assume it is.

MR. SRINIVASAN: It is. It is a function of how you made it. It is a function of temperature of irradiation.

MEMBER RAY: That's what I don't like about in the mechanical properties, which are less obvious than dimensional changes, how do you know that you found the variation that is introduced by manufacturing clearances?

MR. SRINIVASAN: Good point. Let me just address that quick right now really. In terms of that graphite, the strength of graphite increases with temperature. Okay, there's one thing.

CHAIR CORRADINI: Compressor strength, I assume it.

MR. SRINIVASAN: Tensile strength, also.

Okay, secondly, and in my opinion more importantly, the strength of graphite increases with dose. Okay? So those two things.

Now, there is a critical dose level and things that is beyond which things happen really that you don't want. But that is well below the turnaround, end of life turnaround, really. That is one thing. Secondly, if you look at all of the mechanical properties in the sense there are only Young's modulus change Parson's ratio that also varies with neutron dose, creep, and that is about it really. And the others are thermal properties, thermal connectivity, thermal expansion, and so forth.

In terms of the dimensional changes in most particular property and that is why people have this turnaround end of life and things here.

MEMBER ARMIJO: This material, it is mostly designed to operating compression. Right? Do you design, are there any significant components in a graphite core that operate with tensile loads, significant tensile loads?

MR. SRINIVASAN: It compression because it is all stacked up and all those things.

MEMBER ARMIJO: Right.

MR. SRINIVASAN: The tension arises at the keyways and keyway hoops. Okay, that is where you have the tension. And because of somewhere it is expansion, somewhere it is compressed.

CHAIR CORRADINI: Differential expansion.

MR. SRINIVASAN: Differential expansion an things, then it will introduce tension. Mostly are the keyway hoops that is where the tension arises.

MEMBER ABDEL-KHALIK: So typically, what is the dpa at this turnaround point?

MR. SRINIVASAN: Oh, great, you are ahead of me. Let me tell you --

CHAIR CORRADINI: We should let you go on.

MR. SRINIVASAN: No, that's okay.

CHAIR CORRADINI: We would like you to go on.

MR. SRINIVASAN: The talk on dpa is about that. Okay?

CHAIR CORRADINI: You get back -- we will get back.

MR. SRINIVASAN: All right. We go back to this April 2007, we did a PIRT to help us really get going on what kind of a graphite research that NRC should do. I'm sorry, I am reading this but I hope it is okay and things because I don't want to miss anything and so forth. If it is not clear, you can ask questions.

The graphite PIRT panel identified several graphite behavioral phenomena that could potentially lead to increases in the likelihood of radionuclide releases or, in the severity of releases should they occur.

I think I am going to go faster on this.

CHAIR CORRADINI: That would be good.

MR. SRINIVASAN: I think we talked about these kinds of things, really. But the important thing is that these were -- there were five phenomena of graphite properties that were identified by the PIRT panel as of high importance and low knowledge.

CHAIR CORRADINI: Just a clarification. When Ms. Hull was up, she pointed out that the PIRT identified a list of things then they binned them and then they looked for commonalities to get down to a subgroup of about four or five key thrust areas. Is that the same thing that we have done?

MR. SRINIVASAN: That is the same thing, exactly. Yes, the same kind of a thing.

Okay, here is where we have the problem really. That is, these are the phenomena that are ranked of high importance because it might lead to some general distortion that you don't want, whatever it is and things. The highest came about is the irradiation-induced creep; then came about the irradiation-induced coefficient of thermal expansion; then the changes in mechanical properties; and finally spalling, you know, if the graphite breaks away and then gets into the channels somehow, then you will have a problem and so forth.

Out of these things, I just want to let you know that one through three are already being addressed in various programs around the world, either by DOE or by European Union in their program and things like that. And we expect to have information and data that will help us in our decision-making.

There is not that much of information about spalling issues but then spalling is a derivative of other properties, so modeling will help us to get into those things.

MEMBER ABDEL-KHALIK: How about dust formation?

MR. SRINIVASAN: I will defer that for a while.

CHAIR CORRADINI: He promises to do that.

MR. SRINIVASAN: I will do that in detail, by the way.

MEMBER ARMIJO: Is spalling caused by friction between materials or is it just something, material just sitting there, high temperature, high fluence, all of a sudden it starts to spall? You know, what is causing the spalling?

MR. SRINIVASAN: What causes it to spall is as follows. You have the graphite block. You have a crack, let us say, that is formed, and at some angle to the vertical axis, let's say. And then you have another crack that forms at another angle. And these two intersect and become weak. And it may fall apart, really.

Or, in the case of channels, or in the case of keyways, for examples, in the key hoops and keyways, if you didn't do your machining properly and if you don't do your inspection properly, and things, those are chipping and falling from those areas are possibilities also.

MEMBER RAY: The core support posts are just columns, right?

MR. SRINIVASAN: Core support is different. I am talking about a graphite core components. So you have graphite blocks there.

MEMBER RAY: I understand. But the point is we are talking about structural material --

MR. SRINIVASAN: Right.

MEMBER RAY: -- performance. And in a column form, the core support columns, you would get tension just due to column stability that would induce spalling, it would seem to me.

MR. SRINIVASAN: It could, you by bending stresses and things. There is another possibility.

MEMBER RAY: I mean there are columns --

MEMBER ARMIJO: But the initiating event is cracking of the graphite.

MR. SRINIVASAN: Cracking of the graphite by thermal and by irradiation damage that occurs.

MEMBER ABDEL-KHALIK: Are there any rapid mechanisms for stress propagation during transients that would lead to spallation?

MR. SRINIVASAN: It is quite possible. One cannot say with any certainty that it would not happen because even if you don't find a crack in things, there could be at a certain stage. All it needs is a little extra stress, if you will or extra dynamic stress, what have you. So conditions might lead to that and then cause.

But the spalling could occur if there was a chipping away, in other words, that could be two cracks or three cracks and multiple cracks that leads to a chunk getting out of graphite. But so dome stresses are being, are one of the components in the stress analysis in the design itself. Not necessarily through spalling. That is a difficult question to answer.

Any other question on the previous slide?

Okay, the next is the phenomena that are ranked as high importance but only in the panel's opinion only medium knowledge is available. And these are listed in this slide. But basically, all these things are being dealt with, you know, there is sufficient medium knowledge, it is a second report and this kind of a thing but it is something that one should be concerned about and one should address in regulatory guides and in the review of the applicants' submittal itself.

One of the issue that the panel did not think of high importance or something is the tribology of dust and things. I will come to that later, really. But for specific reasons, for accident analysis and evaluation models and things, NRC research might be, or may be, or will be needed for tribology of graphite in impure helium environment. More on this --

CHAIR CORRADINI: Tribology of graphite in an impure helium environment is code for what?

MEMBER ARMIJO: Getting the control rod into a channel?

MR. SRINIVASAN: Size -- I will come to that.

CHAIR CORRADINI: I mean, tribology is wear. That is what I thought.

MR. SRINIVASAN: Yes, friction wear is what is contributing. I think you had a question yesterday about not necessarily rubbing things but fluid movement causing and so forth. So, I will come to both of these.

CHAIR CORRADINI: Okay, thank you.

MR. SRINIVASAN: Okay, I mean, I think we have to address that as a separate issue yesterday that was cause of all the questions and I don't have specific things here.

Okay, here is $64 million question or what have you about the turnaround and what happens and things really. As you see here, this is the European Union program in high flux, whoops, sorry, high flux reactor in Petten. It is, there were 12 different grades of graphite that are contemplated for HTGR use that were irradiated or irradiation currently in progress are 750 degrees Celsius and 950 degrees Celsius.

The irradiate all the way to 16 dpa and the PIE is being completed. To protect the innocent and the guilty parties and things, we don't know as yet the different grades for manufacture and all these things, unfortunately, at this time.

CHAIR CORRADINI: But the various colors are manufacturing techniques, not irradiation -- not temperatures?

MR. SRINIVASAN: The one that you are looking at is at 750 degrees Celsius temperature, constant temperature. But irradiation is due for different grades of material and for different manufacturers and we don't know what those things are.

CHAIR CORRADINI: Okay.

MS. BANERJEE: Just to give you a rough idea, I have a rule of thumb, which is rule of thumb only and it is not precise and I don't like it myself, approximately let's say one dpa per year or something, usable year. So, you are looking at about eight to ten years of actual reactor being there.

CHAIR CORRADINI: And to go back to your discussion with, I think, Said, and Harold, your point is that you want to pull it out before the uncertainty and the wiggles of this, before the scatter becomes inordinately large. Before I start not knowing what next to expect, is what I --

MR. SRINIVASAN: Right. Suppose, let's say here -- okay, good. This things turns around like so, let's say.

CHAIR CORRADINI: Yes.

MR. SRINIVASAN: Okay. Whoops, I don't know why I am doing this.

MEMBER ARMIJO: Typically, at what dpa do these things start to turn around?

MR. SRINIVASAN: Well, typically, as I

said, between seven and nine, something like that.

MEMBER ARMIJO: Well these are kind of late in their turnarounds.

MR. SRINIVASAN: Yes, that is right. This above the turnaround thing, really. In fact, I know that for sure because they have conducted beyond and it is not in the plot and it is going back. Typically, that is about it, really.

CHAIR CORRADINI: So that means, let me just say it differently, that means conservatively, you have to change out the moderator in the machine somewhere between six to eight years.

MR. SRINIVASAN: The sort of medium reflectors --

MR. RUBIN: Please, you have to understand that the fuel itself is being removed, whether it be pebbles or whether it be blocks. It is the reflectors --

CHAIR CORRADINI: I'm sorry. I should have said.

MR. RUBIN: -- what is in the high radiation zones. Yes.

CHAIR CORRADINI: I'm sorry.

MR. SRINIVASAN: That is right. This is the -- that is why in the PBMR case, originally they are going to replace it every six years, then it became nine and things. And we again, that is uncertainty. Why six? Why not four? I mean those are the things that has to be debated and then understood and then some sort of a safety, you know structural safety module of fuel and things.

MEMBER ABDEL-KHALIK: So the prismatic blocks, in and of themselves would be considered waste?

MR. RUBIN: Well, I mean in terms of this turnaround, I am not sure if that is --

CHAIR CORRADINI: It would be replaced, I think that is a fair --

MR. RUBIN: It would be replaced with thresh on irradiation and then be removed. So, I don't think those are the limiting blocks. The limiting blocks that would just stay in there.

MR. SRINIVASAN: But it is really -- the answer is really decommissioning of graphite is an important issue and that is an issue by itself, really, yes.

MR. RUBIN: Once they've drained, the blocks are still at the site, I believe. The fuel is owned by DOE, but it has not been moved from the site, I believe.

MEMBER ABDEL-KHALIK: And typically what is the volume ratio with wind? I mean, I can figure it out from the geometry. But it is between the graphite blocks and the fuel rods?

MR. RUBIN: Well keep in mind the fuel is made up of compacts. And I think the idea ultimately is remove your compacts from the bulk block and so you can consolidate the fuel compacts from that.

MEMBER ABDEL-KHALIK: Separate the high levels.

MR. RUBIN: Separate the high from the blocks. The blocks would not go to the repository, for example.

MEMBER ARMIJO: This is a real dumb question. If this thing is turning around, why isn't that a good thing? Just leave it alone. I shrank a couple of percent and now it is going to grow back a couple of percent. Everything is back to zero. What's wrong? Is it ratcheting or --

MR. SRINIVASAN: It is exhaustion and it is really a lot of uncertainty. When you mentioned about the getting back and things, you don't want it to go to the swelling stage and things really. Then it becomes much more amenable to chipping, if you will, or spalling.

MEMBER ARMIJO: So this is just industry consensus, get it out --

MR. SRINIVASAN: Get it out.

CHAIR CORRADINI: I guess maybe I am not understanding. I guess I worry that you even got close to the well because of coolant bypass flow and how that effects any sort of accident analysis. If I start shrinking where I think the coolant is going is not where it is going. It is going somewhere else, which means if I have any sort of transient close to that bottom well, I have a real problem, potentially. I have changed my whole temperature distribution.

MEMBER ARMIJO: This has got to lead to gaps somewhere.

CHAIR CORRADINI: Well that is my point.

MR. RUBIN: There is a whole host of safety issues. One of them is the rods insertion. Another one is the cracks in the bypass. There are a number of safety issues you worry about, thermal and shutdown and the like.

MR. SRINIVASAN: I just wanted to let you know that you will notice monitoring worldwide and things. At this point in time, in our system, we don't have any actual real work going on and things, other than being aware of works going on elsewhere and things.

All right. Currently, there is one contract, a small contract at Oak Ridge National Laboratory and we have asked them to compare and evaluate the NGNP PIRT on graphite with the DOE planned research and see the gaps and so forth for NRC to pursue.

In addition, we are also going to conduct an international workshop with international graphite, nuclear graphite specialist experts to tell us about compare the requirements from the INL information and then the HTGR requirements and what kind of research that NRC in the future should pursue. And that is expected to happen by about May of this year.

So as part of the strategy that NRC has been involved has been to participate in codes and standards in international and national meetings as well. Participate in international and national graphite irradiation programs, when we can do that. You know, right now we don't have participation but we will participate, hopefully, to understand irradiation creep, thermal conductivity, and dimensional changes, which have been identified as top issues by the PIRT panel.

For specific area, for example, graphite wear and friction and dust generation, NRC might conduct or will conduct research with respect to these effects, so that we can provide some safety information to the evaluation models.

One area where we have not done any work is with respect to graphite-graphite, carbon-carbon composites and ceramic insulation. And basically what we would do is that we would use our lessons learned from graphite and metallic materials research and then monitor ongoing activities from other sources and participate in codes and standards.

MEMBER ARMIJO: Carbon-carbon is not included in the ASTM or the ASME codes?

MR. SRINIVASAN: No. There is an effort right now that is going on to start working on that because of the tie rods and things, carbon-carbon tie rods is not supposed to be.

This is an area -- we talked about dust. This is an opportunity for me to tell you something about it. One of the things is that there is a lot of ceramic insulation. So, the insulation material, whether it is aluminum silicate materials or aluminum based material, or zirconium based material, it doesn't matter really, in the fibrous form or in the fused gas form can be expected to erode. And if you are talking about thermal spalling in graphite, these can spall quite easily. And these can be carried out or this is something that has to be thought about and things.

MEMBER ARMIJO: I guess didn't understand. We have been talking about graphite dust --

MR. SRINIVASAN: Right.

MEMBER ARMIJO: -- or carbon dust and you talked about other materials.

MR. SRINIVASAN: Right.

MEMBER ARMIJO: Are these other materials in the gas reactor that are causing the dust or am I confused?

MR. SRINIVASAN: You have the metallic ducts and metallic temperature. I mean, the metals are, the tubings, if you will, are the metal, what do you call it? They are protected by insulation. So the temperature is kept low for creep and other purposes.

MEMBER ARMIJO: That insulation is not graphite?

MR. SRINIVASAN: That insulation is not graphite.

MEMBER ARMIJO: Okay.

MR. SRINIVASAN: No. So that is a thing

that might be of consideration.

MR. RUBIN: For example, the exhaust duct that takes the hot gas out and sends it to the secondary plan is a composite material, --

MR. SRINIVASAN: Right.

MR. RUBIN: -- an inner sleeve that protects the pressure boundary from seeing those high temperatures. And it is that material that we are talking about.

CHAIR CORRADINI: And that is yet to be specified? Let me put it this way. There is a range of candidate materials --

MR. RUBIN: That is right.

CHAIR CORRADINI: -- that are of various ceramics.

MEMBER ARMIJO: So it is those materials, when we talk about dust, issues with dust, is it those materials that you are worried about or is it the carbon dust?

MR. RUBIN: The primary area of interest is dust associated with the fuel. Because it is the fuel that is providing the metallic radionuclides that can then be absorbed into the dust. And then be carried away to settle into other spots. So, it is really the fuels area and, principally, the focus to start out with would be the pebble balls and that is a very specific matrix material which has its own hardness and friction coefficients, etcetera. So we have to be very specific in terms of dust generation rates for those balls.

In terms of what we would be doing there, these are issues that are emerging recently and the vendor is also pursuing getting data. And we are not sure completely but we understand that they pursue some sort of a test facility where they would actually put balls of the material that they used for the fuel in a high temperature helium environment through a loop and allow for movement and to collect data directly that would be scaled in terms of the material, in terms of the loading zone, in terms of the temperatures and the like. And we will be monitoring that.

So, we are not going to get out ahead of the industry on that.

MEMBER ABDEL-KHALIK: Can cracks in these thermal insulation sleeves of the piping lead to localized heating of the pressure boundary and possible failure?

MR. RUBIN: What we have been taught -- Well, for those designs which are direct cycle where you have a grading cycle, where the high temperature here goes to a high temperature of heating and then returns as cold air. When you have a crack and you have leakage between that high temperature, high pressure, and the returning air, you start to lose your ability to maintain that Brayton cycle.

MEMBER ABDEL-KHALIK: I'm not talking about that.

MR. RUBIN: No, the point is the system shuts down when that starts to occur.

CHAIR CORRADINI: Maybe --

MEMBER ARMIJO: There is a crack in the insulation leading to a hot spot on the duct.

MR. RUBIN: That was before. I mean, the industry is telling us that the system will tell us that that is happening because the system will shut down. You cannot sustain the Brayton cycle with that kind of a leak.

CHAIR CORRADINI: But just to clarify what I think -- just a point of information. The way they have, at least the way I have seen the designs, the hot leg is flowing as an inner core to an annular cold leg that is flowing back.

MR. RUBIN: The other way. Counter-current.

CHAIR CORRADINI: Yes, counter-current. So the cold helium is the closest to the pressure boundary.

MR. RUBIN: Right.

CHAIR CORRADINI: But even then you still have what you are saying as the ceramic.

MR. RUBIN: Well it said ceramic. That is the boundary between the cold coming back and the hot going out.

CHAIR CORRADINI: Right.

MR. RUBIN: But you are saying let's say we punch a hole in that. So you have now the hot air leaking into the cold air.

CHAIR CORRADINI: Yes, you would know right away.

MR. RUBIN: Can you maintain the cycle, the power cycle when that happens? That is the issue.

MEMBER ABDEL-KHALIK: So let's say we have a concentric tube and the hot fluid is going on the inside and the cold fluid is going counter-current on the outside. Where are these insulating sleeves located?

CHAIR CORRADINI: In between the two.

MEMBER ABDEL-KHALIK: In between on the outside of the inner wall or on the inside?

MR. RUBIN: I don't know.

MEMBER ABDEL-KHALIK: Inside inner tube wall.

MR. RUBIN: Right. That is my understanding. That is where your hottest temperature. MEMBER APOSTOLAKIS: That is not a good idea. It should be on the outside, the outer diameter of the inner tube. We did some calculations there. It turns out it is better way to do it.

MR. RUBIN: We don't have the design details. But the issue has always been from the day one is well what happens if that hot gas impinges on this pressure boundary that it is not designed to actually withstand. The argument has been, if you do develop that leak, the system will shut down. You can't sustain that thermal --

CHAIR CORRADINI: It will short circuit.

MR. RUBIN: It will short circuit, yes. Now that we are going to one where perhaps we are not going to that Brayton cycle, we have an IHX. It may come back.

CHAIR CORRADINI: Why -- I guess I don't appreciate that. You would still maintain the same mechanical design, even though you are going to an

IHX, would you not?

MR. RUBIN: Well, we are being told that there may be an IHX between the power turbine --

CHAIR CORRADINI: Right. I understand that. But when you take it to the IHX, you would probably keep the same mechanical inner-outer design from a structural standpoint, I would assume. I would assume but don't know.

MR. RUBIN: Don't know.

CHAIR CORRADINI: Okay.

MEMBER ABDEL-KHALIK: But could you imagine a very narrow crack in this thermal sleeve in which the flow rate through the crack is relatively small compared to the total flow rate in the system that would lead to localized temperature gradients and lead to failure?

MR. RUBIN: I think you have a very good point and that is where the whole issue of the risk-informed approach comes in. Do we really understand all the mechanisms in these designs to rule out certain kinds of failures, pressure boundary failures and issues like that? Seismic and those issues will come up in deciding if we are going to postulate those kinds of failures because we don't have a wave monitoring and we don't really have the ability to build for sure.

CHAIR CORRADINI: But --

MR. RUBIN: It is those things we have to look at. We want to prevent it, certainly. But do we analyze for it anyway? That kind of a failure mode.

CHAIR CORRADINI: Can I try -- I think from the standpoint of the dpa or the X analysis when Joe was up here, I think they are literally jumping and assuming a large break right at that location. That is the only way you can get your depressurizations on the order of a minute and then your block exchange, etcetera, etcetera.

MR. RUBIN: That is a duct. It is a very large duct.

CHAIR CORRADINI: Yes.

MR. RUBIN: The argument is being made that it is a vessel. You don't usually have vessels fail.

CHAIR CORRADINI: But it breaks somewhere around there.

MR. RUBIN: But you have localized issues just of that sort.

MEMBER ABDEL-KHALIK: So where in your material research program are you looking at the behavior of these thermal insulating sleeve materials?

MR. SRINIVASAN: We do not at, the present time. We don't have anything at the present time of thermal insulation materials research. We are not doing any thermal insulation materials research.

MEMBER ABDEL-KHALIK: Isn't this something that you should understand?

MR. SRINIVASAN: Yes. I think that there is, in the plan that I have seen for INL, they have in the research plan, the DOE has, I have seen information on properties. You know, thermal properties, research for the insulation materials.

MR. RUBIN: There is one part that I think we probably should have done, which was looking at the potential failure of new and different kinds of internal components and the kind of effects it might have on the system safety. We didn't do that. Okay?

I do believe we were told that they were going to be doing that in South Africa as part of the licensing, to look at the current issues that you were talking about. So, we have our arms around those kinds of failure modes and effects. We need to understand those because we are not experts in those issues. And we need to get expert opinion and take a look at that.

CHAIR CORRADINI: I mean, let me broaden

Said's question a bit but I do think he has hit upon something at least that even though you guys are in a position of watching what DOE is doing and then have to decide what you need to do. And it just seems to me that this issue of what is the type of break is different in the light-water reactor.

And so when the PIRT was done at the time, I don't remember any panel that asked sort of questions about what is the initiator, particularly when the assumption is that you are going to have a depressurization action with various cascading severities. What is the type of depressurization? What is the mechanism of the depressurization? What is the flaw, this sort of stuff. And I think that is kind of getting to a broader question of what he has asked.

MR. RUBIN: Absolutely.

CHAIR CORRADINI: Go ahead.

MR. SRINIVASAN: This is the last slide here. The only thing that I want to say is that at the moment we are keeping our research options open because, you know, we still don't know the DOE's design selection and exactly what research that might be conducted by DOE or the NGNP applicant.

And the other thing I want to say is we

will be doing research with respect to graphite dust generation, air and water ingress effects as appropriate in the future.

That is the extent of the prepared ones and then I can go back to some other --

CHAIR CORRADINI: I was going to say if people have questions, this is the time. Questions from the Committee?

Okay, on your last bullet, this is where I like to have some fun, so I want to understand when you say water ingress, you specifically are looking for water into the core versus moist air, where I have some sort of vaporization source and then just carries a combination of air and steam in. Do I understand what you mean by water ingress?

MR. SRINIVASAN: That's right.

CHAIR CORRADINI: In terms of graphite dust generation, are you stimulating the DOE and their contractors to consider this phenomena or are they already stimulated or are you going to do some separate work on that? That is what I am -- when you say conduct research, I am trying to understand are you trying to politely get them to do stuff or are you going to do something independent?

MR. RUBIN: I think the evaluation model

people have been having that dialogue with DOE --

CHAIR CORRADINI: Okay.

MR. RUBIN: -- and the vendors, rather than from just a materials standpoint. Oh, it's happening.

CHAIR CORRADINI: Okay. And then a materials question. You mention and maybe I went off and I may have missed it. If I take it out of the PBMR or the PBR, whatever it is called now, realm and into the prismatic realm, if I have helium flow, I would expect corrosion or not corrosion, erosion dust generation, just normally. Is there any operational data on that so that one knows what one can expect from that or is that an open question?

MR. SRINIVASAN: To the best of my knowledge, it is an open question. I don't think there is any -- you know, like in the AVR case, they know how many pounds and so forth. They have some idea. But in the case of a prismatic one, the only experience that we -- not the only experience. One of the experience that we have currently is the HTGR in Japan. And the people that I have talked to and so forth, so far in the operations, even when they took it to 950 degrees and so forth, they have not seen dust accumulation.

CHAIR CORRADINI: And that is because of in-service inspection. They actually look in the crannies and the low velocity points and they don't see anything built up.

MR. SRINIVASAN: That's right. But I don't know, again, I don't know the quantifications.

CHAIR CORRADINI: That's fine. I am just trying to get a qualitative feel. And then I am curious about any of these designs or in the ACTR, as you have in the light water reactor like the CVCS system for PWR, I would expect you have a cleanup system that by design will try to clean up the coolant flow. Is that in these designs? Or let's just talk about the Japanese test reactor. Do they have the equivalent of a cleanup system? So that I put in a design spec that says that I am checking to make sure it is less than X.

MS. BANERJEE: I don't know.

MR. RUBIN: Let me try to help you. In terms of coolant activity, there are systems installed to remove coolant activity and other particulates. Okay?

CHAIR CORRADINI: There are.

MR. RUBIN: There are filters in the system to try to capture dust as it passes through various points in the system. Okay? I think they want to keep that dust away from the rotating equipment, for example. Okay?

One of the issues is, are you going to be able to capture all of it that way? Some of it goes settle out into the low velocity points that are just going to accumulate there. So, they are not 100 percent. We don't know what percent effective.

CHAIR CORRADINI: No, I understand that but I am just curious about the operating. There are systems.

MR. RUBIN: Yes.

MEMBER ARMIJO: How about the heat impurity, you know, particularly at startup. There has got to be some degassing, maybe some volatiles and stuff like that. But do they have systems in there to maintain helium purity, oxygen levels, whatever?

MR. RUBIN: There are specifications.

MEMBER ARMIJO: Okay and those would define the operating environment, whatever the capabilities of those systems. That would affect how you do your R and D too, I would guess.

MEMBER RAY: Is this the point at which we have covered the issue of in-service inspection of graphite as a structural material?

CHAIR CORRADINI: I think that you are going to have this young man right here at your disposal next.

MR. RUBIN: Okay. He's the graphite man.

MEMBER RAY: The graphite is all I am talking about.

CHAIR CORRADINI: Oh, I'm sorry.

MEMBER RAY: Yes. So we have covered -- I guess, you know, I listened carefully to the answer to the comment about materials properties and I am always concerned about these core support posts because they worry me a lot more than the blocks themselves, whether they are reflector or fuel blocks.

In turn, is there an absolute requirement to be able to verify the structural characteristics of those core support posts somewhere, either in the ASME code development or --

MR. RUBIN: I won't answer that directly but let me start by saying that the irradiation environment of those posts is much different than the irradiation environment of the reflectors. There are other issues, oxidation issues, dirty air regress events, things of that sort. So the high irradiation issues as far as not necessarily the key ones, but the point here remains. The inspection of those four, the active degradation mechanisms, those graphites in our locations, I agree with you there.

MR. RUBIN: And so, I am going back. This was a controversy 25 years ago and I am just trying to see has it been solved? Is there a requirement to inspect those structural supports? Because I can tell you for sure that in the past there wasn't and you had to believe that they were going to be okay for the live of the plant, period.

MR. GRAVES: Yes, well, that is one of the issues that we have identified. We haven't done any research on it but we have identified that issue as something to look into.

MEMBER RAY: Okay, well you are re-identifying it.

MR. GRAVES: We are re-identifying it.

MEMBER RAY: Because you know, I put together a PSAR for an HTGR a long time ago and that was a problem that we never solved. And it was a major controversy and I am just wondering if that is still the case.

MEMBER APOSTOLAKIS: Which HTGR was that?

MEMBER RAY: It was the Videll plant.

CHAIR CORRADINI: Oh.

MEMBER RAY: Do you want to know

specifically?

CHAIR CORRADINI: I was guessing Fulton. We were trying to guess which one it was.

MEMBER RAY: Videll. It is a place out in the California desert but that is another story and not important here. But the point is, it is at least in my opinion not a trivial problem and one that isn't so.

MR. RUBIN: I think that the licensing strategy talks about inspectability of critical components and it would be fair to say that we will want there to be an inspection of those critical components. The periodicity of that needs to be pinned down, --

MR. SRINIVASAN: Absolutely, yes.

MR. RUBIN: -- mechanisms that would be whether it is five years or ten years is the right period but would you expect that be accessible?

MEMBER RAY: We couldn't even figure out how to do it. That was the problem then.

MEMBER ARMIJO: Even if you could require it, you didn't know how to pull it off.

MEMBER RAY: That's right. And so that is the question that I am asking and I will just leave it there for now.

CHAIR CORRADINI: Any other comments?

MS. BANERJEE: Can I say I have?

CHAIR CORRADINI: Yes, you can.

MS. BANERJEE: Okay, thank you. This is Maitri Banerjee. I have two questions. Probably you said it but it sometimes passes over my head and I don't catch it.

I think Said also mentioned dust. Does that affect the thermal conductive properties of graphite structure of such and could become a concern like emissivity? And the second question is, in your ARRP, you did talk about applicability of graphite properties from small components to large block graphite properties. Did you say anything about that? I may have missed it.

MR. SRINIVASAN: Okay, the first one with respect to the graphite dust affecting the thermal properties of graphite itself, it is the dust will be expected to be on the surface on graphite and more than likely, the effect, its ineffect or something is not going to affect that, you know, that is a mode of conducting material and so forth really.

MEMBER ARMIJO: But could effect the emissivity but probably in a good direction if it can really find for us dust.

MR. SRINIVASAN: That is a good point. The second question is on the translation from small sample to large samples.

MS. BANERJEE: Right.

MR. SRINIVASAN: With respect to that, there are provisions in the ceramic design, brittle material design that can incorporate the associated issues and it is taken care of in the design really of the large components. And the problem Maitri with respect to something else that I want to address is really the properties that are measured in small samples in the MTR to translate into larger one is an issue still.

For example, in the ASTM properties specification, the ASTM material specification refers to properties that are determined by standards but those standards, whether it is tension or thermal conductivity and things are made on large samples. But actually radiator properties are made on small samples. The correlation between properties that are measured on small samples and irradiation to what happens in the irradiation properties is yet to be determined. There has been some important going back and forth and things but there are no ASTM specifications or these standards that matter that will give us some guidance as to appropriateness and how to do it and things.

It has been done in the past by individuals and individual laboratories but there has not been a consensus. That is one way to do things. Did I answer your question?

MS. BANERJEE: Thank you.

MR. SRINIVASAN: Going back to yesterday's question came up on things I just wanted to mention. A couple of things, really.

Quickly, quality. You mentioned about that I hope that material specification of the ASTM addresses that to some extent. It is also expected that the Appendix B requirements would apply and it is expected that the regulator NRC will go and inspect the graphite manufacturer for the procedures and so forth, that kind of a thing.

In-service inspection we talked about. There is a lot to do. There is a channel board measurement unit that the British use in terms of the circularity and modality, as well as the surface roughness and things. In fact, they have found cracks that way. And the people at HTGR Japan also use a television camera. So similar methods are expected to be applied for core support components and things in the air. ASME, when they write the code and things that will be a part of the installation inspection programs, as well as in-service inspection.

With respect to graphite dust, there is a lot of things that has been said.

CHAIR CORRADINI: We wrote it all down. We wrote it all down. We have all your promises down.

MR. SRINIVASAN: Quickly, quickly I just wanted to because there was a question that came about detonation issues yesterday also, that type of a thing. I just want to let you know a lot of dust is manufactured during -- a lot of graphite dust is raised during graphite manufacture, as well as graphite machining. Okay, this has been there, really. And somebody, some of you went to Niagara Falls ten years ago and things you would have seen graphite dust even on the streets, really, it has been pretty bad really in those days.

In making graphite, basically they also put graphite around, powder around really to actually provide graphite oxidation, if you will. Now, the question raises with respect to the flammability or the detonation and things. Now, this is a concern that has been come about in the last three years. There has been IAEA wood that went down in the last couple of years that is a 2007 report on that and because the British reactors are under decommissioning, they have to do something about it. So, what are we going to do with the graphite dust, will it ignite and that kind of an issue.

Just a quick thing as long as I have it and things I want to show you something.

CHAIR CORRADINI: Quick now.

MR. SRINIVASAN: Very quick. I am sorry.

CHAIR CORRADINI: Oh, visual aids.

MR. SRINIVASAN: But first I thank Dr. Tony Wickham, Anthony Wickham, he is -- you probably know him. Manchester, right. I mean, he lives in Welsh and Manchester, these are all, you know, how they did the experiments and things like that. But I just want to -- where are we? Did I pass by? I don't think so.

CHAIR CORRADINI: You are showing this now. So, it is in the open session. So --

MR. SRINIVASAN: Yes, yes. Yes, it is.

CHAIR CORRADINI: So this is take-able and send-able?

MR. SRINIVASAN: Yes, sir.

MEMBER APOSTOLAKIS: It is what?

CHAIR CORRADINI: Okay. I want a copy.

MR. SRINIVASAN: Okay, this is the experimental facility that they did. Reactor assembly, I don't want to go into the details but this is what I want to let you know. This is the empty tube. Just watch right here. These are some ignition powers and duration of incandescence 76 milliseconds and so forth. Okay? Just keep watching.

CHAIR CORRADINI: Bingo.

MR. SRINIVASAN: Okay? This is the graphite dust.

CHAIR CORRADINI: What were you blowing in the empty tube? Oh, an igniter?

MR. SRINIVASAN: Yes.

MEMBER ARMIJO: Now you are filling it with dust.

MS. BANERJEE: The dust is inside the tube?

MR. SRINIVASAN: Now it is the graphite dust.

No, nothing. Wait a minute. I didn't do it right. Now watch.

MEMBER ARMIJO: That's bigger.

CHAIR CORRADINI: So did they do it with helium?

MR. SRINIVASAN: No.

CHAIR CORRADINI: I get very nervous when you start showing things like this because when you are going to have the accident, you are essentially going to have a co-mixed stream of dust and helium that has to mix and it is going to be gas-side diffusion, gas-side mixing that is going to drive this, not oxidation of the coal particles. You don't have a pulverized coal combustor here. Right? You have got helium all over the place.

MR. SRINIVASAN: You are absolutely right.

CHAIR CORRADINI: Decommissioning is a different problem. That is a British problem.

MR. SRINIVASAN: The purpose I wanted to show was that the experiments are being done.

CHAIR CORRADINI: Okay.

MR. SRINIVASAN: That's all. You know when look at that your own requirements and things.

This is the maize flower here. Okay? That's all folks.

MEMBER ARMIJO: And so they do it with corn flower, with nothing and with graphite.

MR. SRINIVASAN: Right.

MEMBER ARMIJO: The one that looked more violent was the graphite but that depends on the amount.

MR. SRINIVASAN: Actually it was the corn flower but you know, --

CHAIR CORRADINI: It was the corn flower. So Cargill should start being worried.

Okay, thank you very much.

MR. SRINIVASAN: And that presentation by Tony Wickham is available for anybody. I can give you that and it is a public one.

CHAIR CORRADINI: Give it to Maitri.

Mr. Graves is up.

MR. GRAVES: My name is Herman Graves. I am senior structural engineer Office of Research, Division of Engineering. I am working on the things we have to research plan for some time looking at structural and seismic issues.

Helping me with the research plan is Dr. Syed Ali who just came into the room. He is a senior level advisor in the Division of Engineering and also Dr. Annie Kemmerer, who has worked with me for the last couple of years on seismic issues for advanced reactors.

We have identified several issues that we wanted to look into based on pre-application reviews that were done and also information meetings. And that is a result of technical advisory group recommendations. That is what the plan consists of.

Objectives like you have been hearing yesterday is to develop data and information that the staff can use to do some independent reviews. We took a look at the existing regulatory guides and standard review plans to determine where the gaps where that we needed to license advance reactor designs, the core structures that have been mentioned here, and also what we need to look at the seismic criteria.

Some of the background. We issued in March '07 a performance-based regulatory guide, which advanced reactor licensed applications are now using this guide for their seismic design of the plants. We also did a NUREG/CR-6896. Based on some pre-applications on information that came to us that said that these plants would be buried completely below ground or half of the reactor would be below ground because all of the existing nuclear plants now are pretty much standard embedment which was a quarter of a plant height is below ground. So, there were some issues that we studied in this NUREG.

MEMBER SHACK: I mean, your reg guide, I mean, that really is sort of a light-water-specific kind of criterion and you make assumptions about damage frequencies, about seismic hazard, and your fragilities. Would you expect that to be applicable to this reactor?

MR. GRAVES: Well, not for the buried one but for other reactors that are being reviewed by the staff at this time.

MEMBER SHACK: Other light-water reactors or reactors of any kind?

MR. GRAVES: Of advanced reactors that are currently being reviewed, such as PBR.

MEMBER SHACK: Oh, okay, light-water reactors.

I mean, in this terminology --

CHAIR CORRADINI: I think what Bill is asking though is you look at the Toshiba 4S or the other non-light-water-cooled reactors, where does this guide kind of start becoming inapplicable?

MR. GRAVES: Well, it could be used by those reactors but we need additional guidance when you talk about putting a reactor completely below ground. That is what I am going to say.

MEMBER SHACK: Well, I was thinking that it was developed for a very different kind of reactor system. You, know, there was an implicit assumption in there that you were looking for a core damage frequency of ten to the minus five, based on, you know, onset of plastic deformation. Well, I am not sure any of those assumptions apply to the 4S, to this reactor.

MR. GRAVES: Well in that regard, you are correct. So, it wouldn't apply if you are looking at any onset an elastic design.

MEMBER SHACK: Right. And so what does it mean to even cite this reg guide for this particular application?

MR. GRAVES: Well what it means, it shows that the staff has looked at seismic criteria that we have on the books. And this is the latest thinking of the staff for recommending.

MEMBER APOSTOLAKIS: With the methodology -- first of all, this is an option, isn't it?

MEMBER SHACK: No, no -- well, yes, I guess it is. It could still go back the other way.

MR. GRAVES: Right. Yes, it is an option because you still have the deterministic guide also on the book.

MEMBER SHACK: Right.

MEMBER APOSTOLAKIS: But the way I understand it is if someone decides to use this for an HTGR, there is some work that will have to be done to adopt this to that reactor. Is that really what you are saying? Because it originally was for LWRs.

MEMBER SHACK: Well, I am just trying to think.

MEMBER APOSTOLAKIS: If they want to do that, that is more power to them.

MEMBER SHACK: Yes but the question is whether the guide as written tells you to do that or it just gives you --

MEMBER APOSTOLAKIS: Oh, I don't know. I don't know.

I mean if it says it is exclusively for LWRs, then it says.

MEMBER SHACK: That is a good question. I don't know remember what it says.

MR. ALI: This is Said Ali from the Office of Research. That you are correct. The way it is written right now, it is for light-water reactors because it uses the core damage frequency. So, I think the idea of referencing it here is while we will need to develop a similar performance-based criteria for the reactors for which the core damage frequency may not be the appropriate criteria.

MEMBER SHACK: Okay, so that kind of approach is applicable --

MR. ALI: Exactly.

MEMBER SHACK: -- but the specific --

MR. ALI: None of the specifics of this reg.

MR. KRESS: Unless you had some specification for these reactors that would be equivalent to the core damage.

MR. ALI: Which we don't know yet and we don't have that.

MR. KRESS: Well tell the ACRS files.

MR. GRAVES: Yes, I put it in here to show you what the latest staff approach was looking at performance-based.

CHAIR CORRADINI: Yes, that's fine. Go ahead.

MEMBER APOSTOLAKIS: So is the main comment here about the notion of core damage may not be applicable? You remember we got a letter from somebody years ago that we shouldn't talk about core damage when we came to a gas reactor.

MEMBER SHACK: I think it is just that you need to be careful of what your performance-based criteria is.

MEMBER APOSTOLAKIS: Yes, I know.

MEMBER SHACK: So, I think that is a fair enough comment.

MEMBER APOSTOLAKIS: For a step, yes. Do you still want to focus on that.

MR. GRAVES: Some of the issues, safety and technical issues that would identify we want to protect against external hazards and events, confine radionuclides and also limit chemical attacks.

Some of the technical issues that we have identified is the structural integrity under these long-term high temperature or elevated temperatures for the concrete structures. We also need to look at the specs and methods if you are going to put a plant below ground. We also identified a design of the support systems for conduction cool down.

We want to develop some structural models. We have been talking about core supports so we have identified a need to evaluate the substance and assess the limitations of the core supports for these nonlinear configurations. And that is aimed at looking at the prismatic core behavior.

We also need to take a look at the high temperature behavior of the concrete during heating and cooling. For pebble bed and some of the other reactors, they are going to be built in what they call a modular fashion. For the seismic plant, it really depends, the seismic behavior really depends on the overall foundation size of the module. So, if you have a module plant that has two modules, it is going to behave different than a plant that has two or greater than two modules.

CHAIR CORRADINI: Why is that? I don't think I --

MR. GRAVES: Well, why is that, if you have a foundation that is a small size --

CHAIR CORRADINI: Oh, you mean the size of the --

MR. GRAVES: The size of the footprint.

CHAIR CORRADINI: I understand.

MR. GRAVES: All right, so it is a footprint issue.

CHAIR CORRADINI: All right, thank you.

MR. GRAVES: These are some of the current findings that are related to what we are trying to do with the high temperature. The core supports that we talked about at the graphite base, lower plenum hot streaking, and also the effectiveness of reactor cavity cooling system. So that would affect the concrete and the reactor cavity area as to how often you could bring it online and take it down because of thermal cycling on the concrete is very critical.

MEMBER APOSTOLAKIS: Before you go into

this it seems to me you ought to have some investigation into the issues we just discussed, whether the performance-based approach. How would a performance-based approach be applied on LWRs and non-LWRs?

On this again, we wait until the industry does something. They submit it, then there is panic, we have to review it. I mean, since we know already where they are coming from, you couldn't jump into the details of the structural.

CHAIR CORRADINI: Are you trying to develop a policy before there is an actual thing, George?

MR. RUBIN: So I don't believe this is seismic, specifically, this piece here.

MEMBER APOSTOLAKIS: Yes, but since the performance-based approach was mentioned, who is going to do that then? If this is not it, who is going to do it?

MR. RUBIN: Okay, my view is this is a deterministic issue to make sure that the structures that hold up the safety systems and the safety components are capable of withstanding the environments, the high temperature environments. They see it during normal operation and during accidents.

Okay? Now that is a performance requirement.

MEMBER APOSTOLAKIS: So who is going to do the other?

CHAIR CORRADINI: George can I give you an empirical -- I was going to say empirically it seems to me, at least with the accident analysis folks yesterday, I got the impression that if I proceeded from something that was a depressurization loss of an air ingress, leading to something even more severe, that that creates an environment analogous to. So, I am looking for some issue that would give me that low severity of an accident. That is what I think.

MR. RUBIN: Well, I mean, the scenario would be you have the blowdown, you have heat up, radiation heat transfer moving out, what is behind the RCCS, concrete walls. What is holding up the vessel? Those concrete walls, ultimately, with the vessel supports attached to them. You want to make sure that that concrete doesn't start to lose its strength and have the whole vessel pull down and away from the coolant panels. And then you are in them.

So you need to do that kind of analysis. Make sure the systems are going to the --

CHAIR CORRADINI: But I think that is empirically what I thought Stu was suggesting is that it is that level of severity.

MEMBER APOSTOLAKIS: Well, I mean, if you go to a little higher level when I think we were a little bit surprised when as part of an ESP and NRC with performance-based approach to seismic analysis. And I am asking, who is making sure that we will not be equally surprised or shocked if the industry does the same thing with a gas leak out of other reactors?

I don't know that it is Mr. Graves' problem. It probably isn't but you mentioned it. But Stu, it seems to me, somebody has to think about it. I mean, it is not, unless you expect the PRA people to do it. But the PRA people are just assessing. We are not developing methods for doing performance-based evaluations.

So somebody ought to think about it. At least identify the issues. As Bill said, you know, it was the, it started with a core damage frequency goal, went backwards, made certain assumptions. Is somebody identifying now which ones of these assumptions would not be applicable to a high temperature reactor?

MR. JOLICOEUR: This is John Jolicoeur from research.

MEMBER APOSTOLAKIS: Yes.

MR. JOLICOEUR: We are working with the

folks from ILN who are putting together a licensing specification for how they expect to proceed. And we will discussing with them as they go on, I am sure this will be one of the topics today to discuss, because they are looking at gaps in the current regulatory framework.

MEMBER APOSTOLAKIS: But you have to guide them, too.

MR. JOLICOEUR: Yes. We will have to discuss it with them.

MEMBER APOSTOLAKIS: So at some point, we will discuss this.

MR. JOLICOEUR: Yes.

MR. ALI: Said Ali again. I think what you said is kind of somewhat outside of the scope of what Herman is looking at. I think it is the combination of the seismologists and the systems people. You know, the systems people define what is the equal end of the core damage in these kind of reactors and the seismologist that come over there with a performance-based --

MEMBER APOSTOLAKIS: It is an approach as to seismic management that affects what you guys are doing and what the industry or the applicant is doing. Seismologists will get involved at some point but the methodology, it seems to me, we have to explore how much of that is applicable to non-light-water --

MEMBER SHACK: Or else you could go back to your older approach for probabilistic seismic hazard of a recurrence frequency of ten to the minus five. I mean, that would be applicable. You know, whether again -- yes, I mean, that would be applicable, whether it -- you know, it is not performance-based. That is kind of a frequency-driven one. You know, that certainly works. But again, in a performance-based sense, I think you do have to have a performance criterion and that is going to be different than --

MEMBER APOSTOLAKIS: All we are saying is have someone look at this.

MEMBER SHACK: But all the analysis he is doing is fine. I mean, he has to be able to analyze these things, what is the acceptance criteria and that sort of comes a little bit later in the process. But he is more worried about how to do the analysis than --

MR. GRAVES: Oh, okay.

CHAIR CORRADINI: Why don't you continue and we will take note. I think I have got your comment captured.

MR. GRAVES: All right.

CHAIR CORRADINI: Keep on going, please.

MR. GRAVES: In addition to the PIRT findings based on the technical advisory group's input and the staff's input, we basically focused our research on three areas that are pointed out here. The nonlinear seismic analysis of the reactor vessel and the core support structures; the effect of high temperatures on concrete; and the seismic capacity of multi-module plant. So, those are the three areas.

The only area that we have done work on, currently doing work on is the second one, is the effect of high temperature on concrete. The other two areas, we have not conducted any research, although we have discussed it in the plan.

More on the nonlinear seismic analysis of reactor vessel. The objective here is to conduct research to determine the response during a horizontal or a vertical earthquake. So we need to look at the substance and the limitations of any finite element code that one would use to analyze the core that we have seen, for the reactor internal. That is the prismatic core.

So we want to conduct some research on this nonlinear dynamic structural behavior of these long, I call them fuel sleeves or tubes. Because if you see them with the prismatic numbers, they are stacked and then they have sleeves that fit over the members and they end up being very tall.

And here you see the picture here. This is the control rod guide tube and this is the fuel element. But the overall height is going to be greater than about 24 meters. This is a very tall fuel sleeve tube, which is much smaller than what we have for the current fuel elements.

I think yesterday Tony Ulses mentioned or showed some nuclear research that was done at Fort St. Vrain or Peach Bottom 1. And at that time, they also did some analytical work in looking at the seismic behavior of these fuel elements. So, we can take advantage of that work that was done at the time and start from there.

MEMBER SHACK: Were those as tall as this?

MR. GRAVES: I'm not sure. I haven't gotten all the details on that but I do know that there was some analysis done of those few elements.

CHAIR CORRADINI: The PTRV at Fort St. Vrain I thought was of the same size. It's shorter? Is it shorter?

MR. RUBIN: Well, I mean it's very tall so that you can radiate it. They --

CHAIR CORRADINI: I mean, this is more of a cigar than it is an --

MR. RUBIN: Yes, exactly.

CHAIR CORRADINI: Okay.

MEMBER ARMIJO: What is the core height, active core height here? Are we talking four meters or less?

CHAIR CORRADINI: Oh, ten.

MR. GRAVES: Eight to eleven meters, depending on the design.

MEMBER SHACK: They need to pt the guy standing there to get this thing listed.

MR. GRAVES: This was identified by the groups that gave us input into the plans. Like I said, we haven't done any research at this point.

The work that we conducted for high temperature effects on concrete was to look at externals that have been conducted. The Japanese have done a lot of testing on high temperature effects on concrete. We looked at what the American Concrete Institute Code Committee's recommendation for the current class of reactors limits for concrete in the code. The normal operating, which is long-term, is the surface that is the general surface area of 150 degrees or 65 Celsius. If you had a local penetration, then one could go up to as high as 200 degrees. And for accident condition, the current code limits is 350 for surface but you could go as high as something like a steam penetration 650 degrees Fahrenheit, it would be 343 degrees Celsius.

So what the staff was concerned about is that these higher temperature gas reactors are going to be operating at higher temperatures than what we currently see. So what would be the --

MEMBER ARMIJO: Why isn't that the designer's responsibility to design the system so it doesn't do that or develop a superior concrete or something, rather than just say well, we are just going to go beyond the current limits?

MR. GRAVES: Well, we have approached ACI and we told them of our concerns and they are taking a look at maybe extending these limits.

MEMBER APOSTOLAKIS: Have the designers done an experiment and research to support your conclusions? I mean --

MEMBER ARMIJO: Design it differently.

MR. GRAVES: Well, I am --

MEMBER APOSTOLAKIS: ACI is not the correct place. Is it?

MR. GRAVES: Well that is what we currently have that they have to make in the standard review plan and the regulatory --

CHAIR CORRADINI: Are you saying that the point designs you have seen can't meet this?

MR. GRAVES: Well no, I am not saying that they cannot meet it because they do have concrete mixes that are capable. And they have designed -- what I am saying is that the current staff guide is for review --

CHAIR CORRADINI: Oh.

MR. GRAVES: -- is limited to these variables. So we have go change our guidance.

MEMBER APOSTOLAKIS: It was mentioned yesterday, and maybe today, too, that you guys are asking, you know, to see what kind of data in other areas.

MR. GRAVES: Right.

MEMBER APOSTOLAKIS: Why aren't you doing the same thing here?

MR. GRAVES: Well we are. We are. The contract that we have with Oak Ridge, as this one points out, we have accumulated a lot of data, a lot of test data from not only in the U.S. but in Europe and Japan. And we have a report that should be out sometime this year that discusses this data.

In addition to accumulating the data, we also have taken a look at the analytical methods that people use for high temperature concrete design. So it is, I am going to say a new frontier, but there is some concern because there are various analytical methods that have not been validated because of the lack of high temperature test data on concrete methods.

So, depending on the analytical technique that is approved, it could be very different for the design.

We were asked to apply the compressive strength of concrete and how it changes with temperature. Of course we know that concrete is a composite of a cement aggregate size and the heating rate and the water-cement ratio. So these have very little effect of the relative strength versus temperature. But what happens when you heat it up with the aggregate and the cement paste and the presence of stress during the temperature, it would influence the compressive strength.

I don't have a part of the tensile strength but it also will effect the tensile strength, especially when you get into the region of greater than 200 degrees Celsius.

MEMBER APOSTOLAKIS: So what are we looking at?

MR. GRAVES: What you are looking at here is the compressive strength of concrete. And this is the temperature --

MEMBER APOSTOLAKIS: Right.

MR. GRAVES: -- on the X axis. So we have different aggregate here. Different types of aggregate are used in different types of concrete. So, I have six different aggregates, so six different basic concrete mixes. And this shows how they are affected, the compressor strength is affected by the temperature increase.

So, I am saying right here when you get greater than 350, there is a decrease, as you can see here, in the strength of those concretes.

MEMBER APOSTOLAKIS: And what would be the operating temperature that we expect, anticipate?

MR. GRAVES: Well those numbers haven't been given to me exactly yet. So, but we expect them to be in this range.

CHAIR CORRADINI: Where? I am sorry.

MR. GRAVES: I am thinking between 300 and 400. I don't know if it is going to be --

CHAIR CORRADINI: This is in the citadel region of the cavity?

MEMBER ARMIJO: That would be for an accident or --

CHAIR CORRADINI: Oh, that would be for an accident. Excuse me.

MEMBER ARMIJO: Well, the steady state --

MR. RUBIN: Let me just say that in designing the HTTR, one of the difficulties that they had was actually making sure that the temperature behind those coolant channels due to convective flows, didn't get so high as to run into this problem. Okay? Again, you can't stop those convective. We want to make sure that we understand what those limits are when we start looking at those issues in the NGNP.

CHAIR CORRADINI: So, it is normal operation, then, is the answer.

MR. RUBIN: It would be normal operation as well as accidents.

MEMBER APOSTOLAKIS: What kinds of temperatures are we talking about?

MR. RUBIN: Normal operation or an accident?

MEMBER APOSTOLAKIS: Both.

MEMBER ARMIJO: Three hundred or four

hundred for normal operation.

MEMBER APOSTOLAKIS: So you say it is between 300 and 400 degrees for the accident?

MR. RUBIN: We don't have the information but we want to have data when we do have that information to be able to tell them what they have to monitor. We may say you need to put a thermal couple there because you say the calculation shows it is this temperature, we are fine. But we want to make sure because you are going to lose strength if they get high.

CHAIR CORRADINI: Okay, we get it.

MR. RUBIN: You have to understand.

MR. GRAVES: Yes, what I can say is that we do know that it is going to be something greater than what --

CHAIR CORRADINI: I think, my interpretation of the answer to your question, George, is given the variability and the point designs, there is a wide range of values.

MEMBER APOSTOLAKIS: Some idea guys.

MR. KRESS: Well the pressure vessel is not insulated in these things.

MR. RUBIN: No, it is not.

MR. KRESS: And it is operating somewhere around 600, I think.

CHAIR CORRADINI: Sounds right.

MR. KRESS: And so if you are talking about radiation and the pressure vessel is straight to the darn concrete in the cavity, you are going to be pretty hot.

MR. RUBIN: You are going to see a several percent of reactor power continuously.

MR. KRESS: Right there in the first stage of the concrete, you are going to be pretty hot for normal operation.

MR. GRAVES: Yes, but they do have the reactor cavity cooling system that will bring that temperature down.

MR. RUBIN: That is the owner's desire to have it there just for that purpose, so they have a 40 year lifetime plan so that the concrete does not degrade during normal operation. That is why it is there.

MEMBER APOSTOLAKIS: They are shooting for 40 years?

MR. RUBIN: Fifty, sixty, whatever it is. It is protecting their investment, their concrete.

CHAIR CORRADINI: Keep on going. I think we get the message.

MR. GRAVES: Right, what I am showing here is, --

CHAIR CORRADINI: But you're not going to get an answer.

MEMBER APOSTOLAKIS: I give up.

MR. GRAVES: -- for the thermal -- right. I am showing here a thermal cycling, what thermal cycling effect has on the concrete.

So for concrete strengths and the 200 to 300 degree Celsius, the first thermal cycle you see a big decrease in the compressive strength. And you don't see that at 65 degrees Celsius in normal operating conditions. So, where this becomes an issue would be the concrete design for the reactor cavity. So, if they are going to bring it up and down, that could be an issue. So we may have to limit the thermal cycling there.

MEMBER RAY: You are looking at Concrete here. But of course, what we really have is reinforced concrete. So you have got steel in addition to the concrete. How does that affect? It seems like a differential expansion between the concrete and the steel could be problematic as well.

MR. GRAVES: It could be but I think we take this into effect when they were doing --

MEMBER RAY: I guess that is what I am asking. Is this reinforced concrete or concrete? It's got to be reinforced.

MR. GRAVES: Yes, it is reinforced concrete but now the ratio of the steel to the concrete, I don't know that. But it could be.

MEMBER RAY: No, I understand but it is reinforced.

MR. GRAVES: Right but the behavior will be what we --

MEMBER RAY: Yes, well then that big drop may have to do with a loss of bonding between the steel and the concrete. I don't know.

MR. GRAVES: But this would be typical of what you would have in the reactive cavity of the concrete wall.

MEMBER RAY: Well all right. Just to make a note, mental note, if you want, whatever.

MR. GRAVES: Okay.

MEMBER RAY: Is this reinforced or not?

MR. GRAVES: Right, okay.

MR. ALI: This is Said Ali. I just want to add that for reinforced concrete, we count on concrete for the strength in compression and generally steel for providing the tensile strength.

Now, steel is kind of insulated from these temperatures. So, the steel being inside the concrete will not see this much temperatures and will not be losing the strength. So the concern here is the loss of strength in concrete because of high temperature because that is what we are counting on for the compressive strength.

MEMBER ARMIJO: Well chemically when you heat this stuff up, water hydration --

CHAIR CORRADINI: Well there isn't any water in the interstitials anymore after 100 C.

MEMBER ARMIJO: That's right. So, you change it, the whole chemical structure of that concrete. And I just don't see why somebody wouldn't just make an effort to protect it.

CHAIR CORRADINI: Sam wants a criteria. I can see it coming.

MEMBER ARMIJO: You know, this is crazy. Designers can insulate it. They can protect it in some way, even with a cavity cooling system.

MR. RUBIN: Exactly. That's it but it may not be effective.

CHAIR CORRADINI: Keep on going.

MEMBER ABDEL-KHALIK: Okay. The thermal cycling effects, are these sort of normalized over and above the changes that we see in the previous graph?

MR. GRAVES: Well yes, this one is. Right. These values are not related to the previous graph. It is different, different test.

MEMBER ABDEL-KHALIK: In other words, if I look at the previous graph, if I am operating at 400 degrees, then I am down to 50 percent of strength at room temperature. And you might have a similar graph on this after three cycles I brought to 50 percent of the original, which means I am dropping to 25 percent of the strength at room temperature. Is that what this means?

MR. GRAVES: So it is an issue.

CHAIR CORRADINI: A little one.

MR. GRAVES: We have some work at Oak Ridge that was started in August of '07. We should have a report, a direct report sometime by mid-'09. And they have gathered and evaluated this data and the concrete test data. And they looked at the physical properties of the concrete, the stiffness, the strength, the bond. And they may have some suggestions for design and evaluation criteria in the report.

MEMBER ABDEL-KHALIK: Can you ever avoid this thermal cycling, if you have to refuel?

MR. GRAVES: That depends on how they, I guess finding out what temperature that would bring up the reactor to. You are going to have a drop in the temperature.

MEMBER ARMIJO: You can't refuel a prismatic without cooling this thing.

MEMBER ABDEL-KHALIK: Right.

MEMBER ARMIJO: So you are always going to have those cycles. Maybe the pebble bed, you reduce it with long cycles.

MR. GRAVES: Right, so what would be the issue would be the number of times that you could refuel it.

CHAIR CORRADINI: Can I just -- well, I mean, I look at it differently. If you have the whole bloody cavity concrete like this, it won't ever get cold during your refueling. You are going to be transferring heat back to the vessel from the cavity. If you cook this thing at 300 C, it is going to cook you while you are refueling. The time-constant is weeks.

MEMBER ARMIJO: Well I think if NASA can cool a space shuttle coming back and insulate that, they ought to be able to insulate a right circular cylinder.

CHAIR CORRADINI: Let's keep going.

MR. GRAVES: We talked already about the seismic response of the footprint size of the modular unit. We have not done any work but we understand that down at South Africa for the pebble bed, they may be looking at this issue. So, we may be able to take advantage of whatever work that they did.

MEMBER SHACK: I remember back in the days when they were doing the modular liquid metal reactor they were talking about putting them on seismic isolation kind of pads. Has anybody talked about that for this?

MR. GRAVES: We haven't. Well, we have had some meetings where seismic isolation has come up. We had a meeting with Mitsubishi about two weeks ago and I think they plan to use seismic isolators. Also we know that there was some test work done for seismic --

CHAIR CORRADINI: For the big plant?

MR. GRAVES: This is for a sodium.

MEMBER APOSTOLAKIS: In sodium reactors, you have to cover the HTGR.

MR. GRAVES: Not for the HTGR. No, we haven't seen any seismics.

CHAIR CORRADINI: But if you get down to

the module sizes of it, I guess, I think this applies to the 4S, this applies to NuScale. I mean, this is a generic issue but if you shrink the module size enough, you then ask about the seismicity. It becomes sort of more attractive.

MR. GRAVES: Yes, but now we haven't seen it in connection with --

MEMBER ABDEL-KHALIK: Do we at least know which configuration is more fragile, the one that is fully populated versus the one that is partially populated?

MR. GRAVES: I would say it depends on equipment that is on the modular unit. We haven't done a study to show which one is more fragile but I would think that it would be the smaller let's say two-unit plan versus one that has more than four units.

CHAIR CORRADINI: If they are all connected together.

MR. GRAVES: If they are all connected. You have to worry about the seismic criteria, qualification criteria of the equipment.

MEMBER APOSTOLAKIS: Why is that?

MEMBER ABDEL-KHALIK: I'm just trying to figure out which one is the most fragile configuration. If you have a big pad then you only have one module on it versus the same size pad and you have eight modules on it. Which one is more fragile?

MR. GRAVES: Well, we haven't done analytical work but from what I understand they won't build a big pad if you are only going to have two modules and they know they are not going to expand those in the future. So what you would have is a two-modular unit. So --

MEMBER ABDEL-KHALIK: Okay, so I have a pad --

MR. GRAVES: Right.

MEMBER ABDEL-KHALIK: -- with one unit versus a pad with two units. Which one is more fragile?

MEMBER APOSTOLAKIS: Well, why isn't the two-unit more fragile?

MR. GRAVES: Well let me answer the question this way. What the licensor has to do is say okay, in the future if you are going to add units to a two-unit module, what is the seismic criteria for the overall plant or do I design my one module or two modules for a certain seismic level and I don't have to worry about designing the other modules.

MR. ALI: This is Said Ali again. I think the, you know, first of all, we haven't done that research to answer your question, specifically. But the idea here is that when the vendors or somebody does their seismic analysis, we cannot do the seismic analysis for one configuration but have the plan in a different configuration at a different time.

For example, if it is going to be a two-module construction, they cannot just do an analysis for the two-module construction and then start building it one at a time. They are to do it in both configurations and make sure that the plant can withstand the seismic event in either one of the two configurations. I think that is the main idea. For a multiple-module construction we have to look at the different modes of construction and make sure that it is adequate in all of those modes. But we, you know, we can make guesses as to the answers to your question but we haven't done the work to really answer that question.

MR. GRAVES: Yes, and another issue also could be is interaction between the modules themselves. Because we had some tests where some plants have been built side-by-side and one plant affects the other plant design.

MEMBER APOSTOLAKIS: So if I have one unit and we have certain acceptance criteria for the concrete and for other --

MR. GRAVES: Right, for the equipment.

MEMBER APOSTOLAKIS: If I have two units, would the acceptance criteria change?

MR. GRAVES: That is what we have to figure out. That is exactly what we have to figure out.

MEMBER APOSTOLAKIS: Okay.

MR. ALI: Well, there is no reason to change the acceptance criteria. I mean, it is the same equipment. If it is qualified to the same seismic testing, then it has the same capacities. We just have to make sure that the response, that the one unit is such that it is acceptable and the two units is also acceptable. You cannot just analyze in the final configuration and then start building it one at a time.

MEMBER APOSTOLAKIS: But I will have some external accident sequences when I have two units, won't I?

MR. RUBIN: We are talking about under different stages of construction we have different models of what the seismic model would be. In one case it is built. Now I am starting to maybe excavate over here. I have a partially built one over here. Now, I have a different to do a seismic analysis. the criteria is the same.

MR. ALI: You have to analyze both of them.

MR. RUBIN: You have to analyze all these configurations as you build out. Once you have one operating, you better understand that.

MR. KRESS: That is like analyzing risk during shutdown. I mean, it is a short time compared to the lifetime of the reactor. I think you may have to think about it.

MEMBER APOSTOLAKIS: The units do not communicate, do they?

MR. RUBIN: There are shared systems in these plants. There are some shared systems but not the safety systems, not the DBA systems.

MR. KRESS: Yes, if I was to guess I would say if you seismically design one module, it is good for all the modules. You know, just like CDF. CDF is the CDF whether you have got one or five.

MEMBER APOSTOLAKIS: Not LRF.

MR. KRESS: LRF is different, that is right.

MEMBER RAY: Before you go to PBR, could

you go back to ten please? Slide 10.

Point at the core support posts with your arrow. I just want to -- they are the yellow band right in there. You see that forest of core support posts? I want to say I appreciate the first item on the R and D plan list here as the core supports.

But that is what I am talking about, the catastrophic failure of that forest of core supports is about the worst thing that can happen in this thing. And how to inspect about -- let's not debate. It is one of the worst things. How you inspect those core supports, I think, I heard I think you mentioned or CD presenter presented visual inspection. And we looked at that again, back in this prior to life I am talking about, and concluded it just wasn't going to cut it. There had to be some way to do MDT on those core supports or at least enough of them to know that over time they retained their integrity.

So, like I say, I acknowledge that it is on the list. It is the number one item on the list but I just wanted to reinforce that that is a real problem.

MR. GRAVES: Right. Yes, and as you have pointed out, we have this as an issue or revisit it and we are working with Srini and we will continue tomorrow to what the ASME co-committees are developing in this area and try to point out that we need some instruction. But we haven't done anything.

MEMBER RAY: Well, you are going around this track for at lest the second time. I ma just saying, it is going to be a tough item and I urge you to give a lot of thought to it because it is not an easy problem to solve.

MEMBER ARMIJO: Well I think that the same issue applies to the metallic supports underneath it. Even though they are insulated, they still need to be inspected in some way.

MEMBER RAY: Well yes, but in my judgment less so because if you imagine a seismic event, Sam, with some degraded but undetected degraded condition of those core supports having existed, maybe it was preexisting, who knows, you know, that is a bad --

MEMBER ARMIJO: We don't want the core to drop.

MEMBER RAY: That is what happens. Or at least part of it does. And we went, I am telling you in the past, we went to the idea that okay, we can fail two out of three and the core will still stay up. And that must make it so we don't have to do NDT and stuff like that.

MEMBER ARMIJO: That excessive margin or something.

MEMBER RAY: That's right, yes. But it never was -- there never was closure on it. And I just suggest that you give a lot of thought to it because it is not an easy problem.

MR. GRAVES: Yes, some of the language that we read in the pre-applications, they are going to be intermediate, I think, supports for some of these fuel tools along the height of the vessel. We haven't seen the actual configuration.

MEMBER RAY: Well, I have been on this hobby horse too long and I have taken our colleagues time but I am just telling you, that is a problem.

MEMBER ABDEL-KHALIK: Well I mean, these things are constantly immersed in the hot gas at the exit plenum. So it doesn't matter if they are insulated. They are at the high temperatures.

MEMBER ARMIJO: That is where the graphite.

MR. RUBIN: Yes.

MEMBER RAY: I thought at one time about well what about some ceramic instead that would be easier to inspect but never mind. We are off the -- some other ceramic I should say, I guess.

CHAIR CORRADINI: Let's let him proceed. Keep on going.

MR. GRAVES: Yes, I just put this slide here, this is related to the PIRT findings and reactor cavity designs. So this shows the different configurations of the reactor cavity approaches that --

MEMBER APOSTOLAKIS: Can you explain one of those?

CHAIR CORRADINI: No, don't let him.

MR. GRAVES: This is the concrete would be the -- no, no. What we are saying is that inside this cavity as has been pointed out, that the temperature will probably be on the order of 650. And there is, I believe, I think this is steel and then the concrete would be out here. But the idea is to get those temperatures down by the time it reaches the concrete. And these are just three different approaches for the reactor cavity cooling cavity that had been considered for the GT-MHR.

So we have talked to the codes and standards committee about the need for concrete temperature to increase and I believe that ACI is going to increase those limits for normal operating conditions by about 35 degrees C. We talked about analytical methods or the response of the reactor vessel core supports. So we need to establish limits so we won't be too conservative in the concrete design. And as mentioned, we had at least one conversation with South Africa who are looking at some experiments to look at the full plant seismic issue.

CHAIR CORRADINI: Just for my information, remind me what PTY is. I don't remember. You said it and I forgot it. What is PTY.

MR. JOLICOEUR: It is proprietary. It is part of the name of the company.

CHAIR CORRADINI: Oh.

MR. GRAVES: The company name. It should be PTY Incorporated.

CHAIR CORRADINI: Thank you.

MR. GRAVES: And that's all I wanted to present. We have a very modest effort.

MEMBER APOSTOLAKIS: That was really good.

CHAIR CORRADINI: Questions by the Committee?

MEMBER ARMIJO: I have a comment.

CHAIR CORRADINI: Feel free to put it in.

MEMBER ARMIJO: I think the work on the graphite is exactly on target. I think the fact that you got the codes and standards work going and you are actually making progress is an excellent piece of work. It is going to be valuable for a long time. And it is applicable, no matter what design deal we finally pick. So, that is great.

I think a little more work has got to go into this concrete thing to push back on allowing the designer to let the concrete get hot and try and figure out how to accept it. He has got to design it better or get a better concrete or insulate it or do something to assure that he meets but he doesn't really put that at risk. And I don't see why he can't. It will cost him some money, but that's about it.

MEMBER RAY: What did the PCRB at Fort St. Vrain concrete run at, does anyone know?

MEMBER ARMIJO: Well you know, there is better quality concretes. You know, things designers have options like cavity cooling, superior concrete that has more capabilities. There are a lot of things a designer could do and I would expect them to come in with those kinds of things rather than say well, it's going to get hot and don't worry about it.

CHAIR CORRADINI: I mean, we are kind of going to general comments but I guess a general comment back to Stu and I was talking to Jim prior to it. I do think that, at this point, we are asking the staff, we are looking at the staff relative to your current view of where you sit with your research plan. And given now you have the MOU and now you are going into the implementation, the next time we get together I think we would expect to have DOE at the table and the lab is the contractor so that if we have specific design questions we get specific ranges of answers so we can have that conversation with honing the numbers.

So, I think the next time we get together that would be, we would like to have them part of it. We didn't expect them to be part of it this time but I think next time that would be very important to do.

MEMBER ARMIJO: I had one other comment and that wasn't in the materials area but the seismic issue is. And I am sure it has been addressed but I don't know how you deal with it. But in a seismic event of the pebble bed fuel, we will want to compact. And is that being addressed someway either in your analysis plan or research plan? You know, you really don't want the core reactivity to increase during a seismic event, unless it is very limited.

MR. RUBIN: We are not looking at it as a structural issue as a reactivity.

MEMBER ARMIJO: It is a reactivity issue, yes.

MR. RUBIN: And understanding what that change in porosity would be.

MEMBER ARMIJO: Right. It's only a pebble bed issue.

MR. RUBIN: Sure.

MEMBER ARMIJO: I would like to hear more about that at the appropriate time.

MEMBER APOSTOLAKIS: What next time are you referring to?

CHAIR CORRADINI: This is going to be an ongoing discussion. This subcommittee is -- this is just a starting point where we are going to continue to hear about how the research --

MEMBER APOSTOLAKIS: No, the individual.

CHAIR CORRADINI: Oh, the individual research items and how they work with DOE relative to the design. I think the next step, at least this is kind of the end of the day discussion I like to have is where does the committee want to go in terms of the next topics to consider when Stu comes back with his team.

MR. RUBIN: Well the next stop is the full meet, the full committee, and then beyond that is subcommittees again --

CHAIR CORRADINI: Right.

MR. RUBIN: -- of specifics area for that matter.

CHAIR CORRADINI: Correct.

MS. BANERJEE: Do we need a full committee? Do you need a letter at this time?

CHAIR CORRADINI: We will discuss that at the end of the day.

MS. BANERJEE: Okay.

CHAIR CORRADINI: Okay, any questions for Mr. Graves? Hearing none, we are off to lunch until 1:00.

(Whereupon, at 11:54 a.m., a lunch recess was taken.)

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

(1:00 p.m.)

CHAIR CORRADINI: Okay, why don't we get started?

So we have Jocelyn Mitchell from staff talking to us about reactor consequence analysis relative to the advance reactor plan.

MS. MITCHELL: Yes, indeed. Thank you. Thank you from the Office of Research on Reactor Consequence Analysis.

I wanted to mention the major thing is that the code itself that we use, which is called MACCS, that is a MELCOR Accident Consequence Code System, Version 2, is itself technology neutral. It has no idea where the source term came from. The issue is that today the input is developed for light-water reactor technology. So, what we have to do for the advanced reactor program is to consider any important difference in input that could stem from the advanced reactor technologies.

The offsite consequence analysis is the final aspect of so-called level three of the PRA. The issue is that the mix of the radionuclides and the chemical forms may be different for advanced reactors. That depends on the yield. It depends on the half-life of the radionuclides. It depends on the perceived release fractions. The chemical forms depend on how the accident goes and what exactly is in the reactor itself and in the containment. So, these, the list of radionuclides we would add or subtract as the case may be. And looking at the chemical forms we would look for dose conversion factors, which would depend on the chemical forms.

MR. KRESS: Do you still input the energy of the release?

MS. MITCHELL: Yes.

MR. KRESS: That might be different you think?

MS. MITCHELL: Yes but it may be more different from one accident to the other than it may be from light-water reactors to advanced reactors.

MR. KRESS: And you normally input at height of the release.

MS. MITCHELL: Height of the release.

MR. KRESS: So these things may be ground-level releases.

MS. MITCHELL: They may be ground-level releases. MACCS would handle that.

MR. KRESS: Okay.

MS. MITCHELL: Also the timing, how long after shutdown.

MR. KRESS: That's right.

MS. MITCHELL: All of those things would change as a function of the accident that is occurring and the technology would influence those.

MR. KRESS: How about, if you got a long, extended time of release, which you might expect, does that affect your input any?

MS. MITCHELL: It does now, even for the light-water reactor technology. We used to, in past days, have a catastrophic failure of the containment where you would get a big release and then there would be an extended time. And so we would have two, with the release broken up into two phases. Now we are basically looking at containment failure by excessive leakage. And so there is a very long extended release and there is no big puff release in the beginning at all.

We traditionally now are breaking it up in one hour segments. So we may have 50 one hour releases. So, we can handle, we already do for light-water technology, handle an extended low level release.

CHAIR CORRADINI: Just for my own edification to remind me, when you say that, does that MACCS releases a delta radionuclide mass, and then another delta, and another delta? Okay, that is what I thought you were saying.

MS. MITCHELL: Yes.

CHAIR CORRADINI: Thank you. Go ahead.

MS. MITCHELL: So we would not produce, in this particular area we would not produce any of the analyses that would give the inventories. We would depend on Tony Ulses and his ORIGEN calculation to give us the inventories of the radionuclides.

Other analyses that look at the accidents like the MELCOR would give us the chemical form of the release and the amount of the release. But in this effort, we would determine if there are any additional biologically important radionuclides that we would have to add to our list and what the dose conversion factors are, not only for any new ones but for any old ones, in case the chemical form changes.

And so my very last slide in --

CHAIR CORRADINI: You are doing very well. Keep on going.

MS. MITCHELL: -- in six minutes, what is it that we are going to do now? And the answer is nothing, absolutely nothing. We are going to await all this input from other areas. The techniques for dealing with this are pretty well developed. So, we really don't have any research on how to do this so we really don't need to start any earlier.

That's it. George, you got here for the very last slide.

MEMBER APOSTOLAKIS: That is very impressive, Jocelyn.

CHAIR CORRADINI: Any other questions by the committee members? Thank you, Jocelyn.

MS. MITCHELL: Okay.

MR. KRESS: That is the least questions of any talk we have had so far.

CHAIR CORRADINI: It was so clear.

So now we have a presentation on digital I and C. That's what it says. Including advanced process monitoring.

MR. REBSTOCK: I am Paul Rebstock. I am with the Office of Research in the Digital I and C branch. And one point of confusion, the branch is called Digital I and C. We actually handle all aspects of I and C, including the sensors and analogue stuff. It just sounds nice, I guess.

CHAIR CORRADINI: It sounds advanced.

MR. REBSTOCK: Yes, right. The Other issue is that obviously the I and C design has to follow the process design. Therefore, what we have now is based on what we know now and what we can predict. But we present will evolve as the processes evolve and as the reactor designs and processes become more well defined.

MEMBER BLEY: I mean, just since you said that, --

MR. REBSTOCK: Okay.

MEMBER BLEY: -- we had presentation on human performance aspects yesterday. And I didn't ask Jay so I will ask you. Are you and the human performance people working together looking at this? That is the first half. And the second half, have you thought about is there any place the I and C, especially thinking of human performance with these new reactors ought not be waiting for the design that ought to be suggesting anything to the designers or about new things that you need to be looking at before you actually see the complete design?

MR. REBSTOCK: Well, as far as our interface with human factors is concerned, especially in such a thing as glass control rooms, it is deeply integrated. We at I and C can address the issue of how to make the glass control room and how to handle communications among safety channels if there needs to be some and the relationship between the safety channels and the non-safety channels, all that technical stuff to make it happen and make it happen in accordance with all the rules. The question of what exactly you put on the screen and how many screens do you need and how do you display the information and how do you page from one thing to another, is a human factors concern. There is no way to separate them. You have to work closely together on those.

As far as making recommendations for the design is concerned, we are not designing the plant. If I were an industry then I would be advising the process people and working closely with them as the process is developed as to what we can do, what things we -- we can do an instrumentation that might make the process design a little bit simpler, things that are limitations that need to be accounted for. And there would be a close relationship. But the NRC is not doing the design. So, I am not actually doing that now.

MEMBER BLEY: Okay. I have gotten hints that because of the way that this is set up under law there is a little more interaction between you and the DOE as this progresses than we would normally see between the output content and the NRC, where they would finish everything and then come to see you. So, I was wondering but go ahead.

MR. REBSTOCK: I wouldn't close the door on it but there is a significant issue of jurisdiction there that I think we need to be pretty careful about.

MEMBER BLEY: Please go ahead.

MEMBER ABDEL-KHALIK: Let me ask another big picture question. Is there anything in the current regulations that require a licensee to do in-core flux monitoring so that they would be aware of the reactivity state of the reactor or can they get by without having in-core flux monitoring?

MR. REBSTOCK: All reactors do have in-core flux monitoring.

MEMBER ABDEL-KHALIK: Right but there is a possibility that these reactors may not.

MR. REBSTOCK: I'm not sure that I follow the question. The requirements right now is we do have in-core flux monitoring to look at the reactivity distribution, the neutron flux distribution within the core so that you know the burnup history and all that kind of stuff.

MEMBER ABDEL-KHALIK: I fully understand that. But for the pebble bed reactors, I think the possibility was offered yesterday that they may not have in-core flux monitoring. And I was wondering if the regulations demand that they have in-flux.

MR. REBSTOCK: I don't think the regulations would demand that they have it. And to implement it within the pebble bed, I don't know that anybody knows how to do that right now.

MR. RUBIN: They may have an opportunity for something close to the pebble bed but not within the pebble bed, I guess.

CHAIR CORRADINI: But just to make sure, to get to Said's question, conversely though, in theory, the bill that will interrogate every pebble coming out and will know burnup on a pebble-by-pebble basis.

MR. RUBIN: It's an integrated system and you don't know where it has been, where it got accumulated. It's just another total when it gets out. And you don't even know what it was before --

MEMBER APOSTOLAKIS: How many pebbles are we talking about?

MR. RUBIN: -- the last time.

MEMBER APOSTOLAKIS: We are talking about a lot of pebbles.

MEMBER ABDEL-KHALIK: Right. No, but -- okay. So, how would you infer, especially if the core is very large, how you would infer the reactivity state of the core? By just monitoring power?

MR. RUBIN: Maybe we need our nuclear people. That is why we are here.

MR. ULSES: This is Tony Ulses from Research. I mean, I think it -- I guess I would consider this an open question right now. But if you want to find the analogue in the operating fleet, the way they actually monitor reactivity in a pressurized water reactor is actually using ex-core instrumentation. And that is how they actually signal reactor trips. Whereas, in a BWR, you actually have in-core instrumentation, local power range monitors.

So, you know, there are analogues there. However, in the PWR, they have the ability to run in-core instrumentation periodically to actually check the flux maps, which they can use to compare to their calculations.

So, I guess right now I would consider this to be an open question that we will obviously engaging DOE and INL on to see how we can come to resolution of it, at this point.

MEMBER ABDEL-KHALIK: And given the fact that these pebbles can end up anywhere in the core, tells me that ex-core instrumentation may not really tell you what is going on.

MR. ULSES: Well you know, I think the point that you are trying to make if I understand it, is we use ex-core instrumentation in combination with an actual analysis to try and predict what the local conditions are, which in a pebble bed, it could be more complex. But as you point out, we don't necessarily know the exact state of the pebble bed.

All I can tell you is that is definitely high on my radar screen and it is something that we have in mind and we will definitely be engaging with DOE on this to try and figure out how we are going to work this out in lessons and space. And I don't think we have an answer on that now but it is something we are definitely deliberating.

MR. REBSTOCK: I have that on a later slide as an item of interest but I don't know that we know the answer right now.

CHAIR CORRADINI: A dimension that I had forgotten you guys were telling us about. Tony, don't go anywhere.

MR. ULSES: Oh, I'm sorry.

CHAIR CORRADINI: So in the annular -- in pebble bed in the annular core, are we talking 15 pebbles wide is the annular core? Is that the length scale I remember?

MR. ULSES: I think that's about right, yes.

CHAIR CORRADINI: Okay, so something like this. If they were to change the power from 600 to 200, maybe possibly, they might even change the design essentially to then not an annular core anymore. The need for a central reflector might go away simply because we are changing the whole physical scale. Is that correct? It would start approaching the Chinese design. So, is there any sort of operating experience from the Chinese reactor or the AVR, which was a thing that one can gain from that change in geometry?

In other words, what are the Chinese doing that might help us? That is another way of asking the question.

MR. ULSES: Well, and I can answer that question by saying that you know, we haven't, you know, we are certainly -- we are now just at the beginning stages of trying to engage with the Chinese and these are going to be questions we are going to be talking with them about.

CHAIR CORRADINI: So it is early in this?

MR. ULSES: Oh, yes, most definitely.

CHAIR CORRADINI: Okay.

MR. ULSES: Most definitely.

MEMBER APOSTOLAKIS: Did we talk about this slide?

MR. REBSTOCK: Well yes, some of it. Glass control rooms we mentioned.

MEMBER APOSTOLAKIS: So what is a glass control room?

MR. REBSTOCK: Computer screens, as opposed to hard-wired switches. I am not exactly sure where the term comes from except for the fact that they used to be CRTs and CRTs used to be made out of glass. So, I guess that is where it comes from. But that is the intent, is that it is talking about a computer-based and a hard panel like those displays.

MEMBER SHACK: The laptop has a glossy face. It has got a glass screen. It is only those matt ones that aren't.

MR. REBSTOCK: Yes, actually they may be plastic.

MEMBER SHACK: The matt screens, the squishy ones.

MR. REBSTOCK: Other things that are of interest that we need to look into is un-reviewed technologies, use of Field-Programmable Gate Arrays could be very useful. But we don't have a lot of experience with those in nuclear applications and power applications.

So, there is, in fact, there is a research effort ongoing at the present to look at those devices and see what are the failures and what are the vulnerabilities.

MEMBER BLEY: I don't even know what they are. What are they?

MR. REBSTOCK: Field-Programmable Gate Array, FPGA. It is a lot easier to say. What it is is an integrated circuit that has a very large number of identical replicated devices on it that can be programmed and configured externally. You apply electrical signals to it and cause it to configure itself.

MEMBER BLEY: Oh, external to the devices.

MR. REBSTOCK: External to the device.

MEMBER BLEY: You are not interacting.

MR. REBSTOCK: You take one of these devices --

MEMBER BLEY: Okay, I know what you are --

MR. REBSTOCK: -- and it is like a blank slate. Then you program it and you turn it into you know, some sort of gates, or you turn it into a communications processor. If you are really crazy, you could turn it into a microprocessor.

MEMBER BLEY: Gotcha.

MR. REBSTOCK: I don't know why you would want to do that but you could.

Some of those devices are reprogrammable, some of them you program once and they retain the programs. Some of them you program by creating links. Some you program by removing links.

MEMBER BLEY: Are they widely used in the process industry?

MR. REBSTOCK: I am not sure how widely used. They have been around for a while. They are extremely useful. I mean, they can be in commercial, consumer electronics, they can be used quite a bit. So, there is history on them but not necessarily what we need. And that is what, like I said, there is a research program going on right now to investigate those and look for vulnerabilities in the operation of the devices.

Another issue is advanced control paradigms. And all that we are doing, as far as this research is concerned, the objective is to make it normally for new reactors but to make it applicable to plant upgrades and current reactors as well.

MEMBER APOSTOLAKIS: So, can you elaborate a little bit on advanced control paradigms? What are we talking about?

MR. REBSTOCK: We are talking about different ways of controlling the reactor. The control laws, for one thing, that govern, when you look at the sensors and decide how to actuate, to make the process control. That is one aspect. Another aspect is how many operators do you need and how many plants do you control from one control room and things like that. The issues that are a higher level than the actual feedback control.

MEMBER APOSTOLAKIS: Thank you.

MR. REBSTOCK: Technical and safety issues I think we probably already talked about some of these, like for instance 3D flux mapping. These are things that the technical and safety issues have to do with new kinds of sensors and parameters in extended ranges. One challenge is you need to know the gas flow through the reactor. The temperature is extremely high. The pressure is extremely high. So, you need some sort of a flow sensor that is not going to be destroyed by the process. So, that is one area of research.

CHAIR CORRADINI: Now, is this something you are encouraging the DOE and their contractors to do or is this something you are going to do regardless of what they do?

MR. RUBIN: This is not a major area of interface, but they do have a group that is organized to develop advanced sensor technology for application to the HTGR and high temperature, high-flux capability. They are working on that specifically for this project.

CHAIR CORRADINI: Okay.

MEMBER ABDEL-KHALIK: This is the total core flow rate that you are talking about high temperature?

MR. REBSTOCK: That is just as an example of something.

MEMBER ABDEL-KHALIK: Why wouldn't an elbow flow meter like they use in a PWR work?

MR. REBSTOCK: That is measuring the temperature of water.

MEMBER ABDEL-KHALIK: It is not measuring temperature.

MR. REBSTOCK: I'm sorry. The flow rate of compressed water. We are talking here about the flow rate of a compressible gas.

MEMBER ABDEL-KHALIK: But not a pressurized --

MR. REBSTOCK: So it is compressible fluid. If you have an incompressible fluid is it -- I'm sorry?

CHAIR CORRADINI: I'm waiting for him to say what I am thinking but I will let him do it.

MR. REBSTOCK: Oh.

CHAIR CORRADINI: I know where he is going.

MEMBER ABDEL-KHALIK: It could work.

CHAIR CORRADINI: The sound speed, you are not moving anywhere close to the sound speed, so it is an incompressible fluid for flow measurement purposes. That is what I assume he is about to say.

MEMBER ABDEL-KHALIK: Okay.

CHAIR CORRADINI: So I assume it must be something to do with the temperature that makes the translation from what is in a water reactor to here difficult. Is that the real issue?

MR. REBSTOCK: Yes.

MEMBER ABDEL-KHALIK: The real issue is the density difference, I guess.

MR. REBSTOCK: Yes.

MEMBER ABDEL-KHALIK: It would give you very, very small properties.

MR. REBSTOCK: It is a regime that we

haven't experienced in current reactors.

CHAIR CORRADINI: But let me just press a little more and then we will stop bothering you. I mean, in combined-cycle natural gas plants, I have got an awful hot gas, of combustible gases going to the bottoming steam cycle and they measure the flow.

So, isn't that technology totally replaceable here?

MR. REBSTOCK: Maybe that is not a good example.

CHAIR CORRADINI: Okay.

MEMBER ABDEL-KHALIK: Let me go back to the 3D flux mapping.

MR. REBSTOCK: Yes.

MEMBER ABDEL-KHALIK: Suppose they come back and say we can't do it? There is nothing on the books that allow you to tell them that thou shall know the 3D flux map on demand.

MR. RUBIN: That is correct.

MEMBER ABDEL-KHALIK: There is nothing in there that -- and you would be comfortable with that.

MR. RUBIN: There would have to be some compensatory measures through other things, other marginal things.

MR. ULSES: This is Tony Ulses again. I

guess I would walk back to the discussion we had yesterday about margin versus uncertainty. And when you have an uncertain area like that, if we would deem it to be uncertain, we would have a discussion with the applicant where we would talk about the appropriate compensatory margin to ensure that we don't have a safety concern within the plant.

That is, I guess at this point, that is probably about the best answer I can give you because that is how that deliberation will most likely play out when and if we get down to the licensing phase of something like this.

MEMBER RAY: Yes, just to piggyback on that, I remember when we with in-core instrumentation with San Onofre to II and III. It was to reduce the penalty that we would otherwise have incurred in the core analysis, due to the uncertainty. That is why we did it because we were very skeptical at that time this stuff would even work. Because we had run you know one without any in-core instrumentation. Unless something happened, there is no requirement to put it in. It is just that it reduces the uncertainty in a large core.

CHAIR CORRADINI: Okay.

MR. REBSTOCK: Okay.

As far as the advanced reactor control schemes and multi-module control, what we are talking about there is the concept of running ten pebble beds from one control room with one operator or two operators. If you were looking at, or there has been talk of having automated startup, automated shutdown, highly autonomous control to a degree that we haven't used right now. Whether that happens or not, remains to be seen. I wouldn't want to just brush it off.

CHAIR CORRADINI: I have a question about just understanding if you go from -- so is it the autonomous part that makes it difficult or the fact that there is more than one module?

MR. REBSTOCK: Well, those are two separate problems and --

CHAIR CORRADINI: Okay, so --

MR. REBSTOCK: -- they are both issues.

CHAIR CORRADINI: So take the autonomous off the table --

MR. REBSTOCK: Okay.

CHAIR CORRADINI: -- since I can't believe you would let them do that. Let's say I have got more than one module. If I had one going to two, is that a bigger step, is that a bigger step than two going to four?

MR. REBSTOCK: One of the key elements in that is the nature of the load and the way the load gets balanced among the modules. From one to two or two to four, I don't know. I'm not sure how I can measure that kind of question.

CHAIR CORRADINI: Well, I think you are helping me because I didn't understand what you were worried about. So your point is really the power swing between if I had a two-module plant and they only demanded, let's just pick some numbers, instead of 200 megawatts of electric, they only needed the 100, would one shut down and one stay at 100 percent or both go to 50 percent?

MR. REBSTOCK: That is one --

CHAIR CORRADINI: That is kind of how you answered.

MR. REBSTOCK: Aspect.

CHAIR CORRADINI: Okay.

MR. REBSTOCK: That is one aspect. That is one that I can think of off the top of my head. You get into it and look at it, I am confident that we will find other things that we need to worry about, too, besides that.

CHAIR CORRADINI: Okay, thank you.

MEMBER ABDEL-KHALIK: What guidance can

you give them in the very beginning with regard to the degree of automation in the sense that somebody comes to you and say well, this machine doesn't need a human operator?

MR. REBSTOCK: I would be skeptical that we would accept that.

MEMBER BLEY: Have you --

MEMBER ABDEL-KHALIK: There is something on the books.

MEMBER BLEY: I was just wondering if you have followed what has happened in Europe with respect to automated operations and either learned anything from that, or you know, positive or negative?

MEMBER APOSTOLAKIS: But they do have operators.

MEMBER BLEY: They have operators but it is essentially some of the plants essentially push a button, it runs all the way through startup and bringing the whole plan online, steam system and everything from starting to pull rods. I don't know if you have followed what they have been doing and have any thoughts about it, but it is related.

MR. REBSTOCK: And there you asked the nexus between instrumentation and human factors also. And that is one of the areas that we need to work together on.

MR. RUBIN: Just a point. Several years ago, PBMR came in and talked about the modes and states, starting from coal shutdown all the way up to generating power. And the complexity of that evolution, going through those various modes and states seem to dwarf with the burning cycle processes and bringing things online. So, one could imagine to try to get the human operator out of that. I believe that is what they would like very much to do just what you were describing.

CHAIR CORRADINI: Is it because of the Brayton cycle?

MR. RUBIN: Well, it was part of the complexity of bringing different systems on the line and starting up that cycle and all the components involved in getting started. And the differences between a PWR -- I guess there are four or five modes, and this had various states within modes that you had to stop at to get to the next point where something else would be brought into the process to move a little farther along up to the next mode.

So, I believe if we ever looked at that, it would be very attractive to have an automated, which is what they are telling us they would want to do.

MEMBER ABDEL-KHALIK: You know, your initial immediate reaction was we would be very skeptical of that.

MR. REBSTOCK: Of taking the operator out altogether, not of automating the process. I think there would need to be an operator to supervise, an operator to handle upsets, to handle things that go wrong. I would be skeptical that we could, that there would be -- it seems to me that there is some minimum number of operators that are needed. You don't just phone in from a hundred miles away and tell the plant to start and there is nobody there. That is what I was saying I would be skeptical about.

MEMBER APOSTOLAKIS: I guess an airplane can take off and land automatically and they still have two pilots. I was talking to a --

MEMBER BLEY: Well we don't want to know what they are doing now.

MEMBER APOSTOLAKIS: I was talking to a very distinguished controls guy a few weeks ago. He said the biggest problem that his district has is the reliability. But they don't trust them.

Apparently they cannot -- they have automated the whole thing.

MEMBER BLEY: For a long time.

MEMBER APOSTOLAKIS: Still there are two pilots. So, we should have two.

(Laughter.)

CHAIR CORRADINI: I assume, I mean, just to -- I guess I was talking prior to it. I assume you guys have taken tours of combined-cycle natural gas plants, for example, which will have two to four essentially natural gas fueled gas turbines and then a bottoming steam cycle and see how they staff it and the automation. Because a lot of what you are saying is already there in combined-cycle natural gas plant.

MR. REBSTOCK: I am not saying that none of this stuff has ever been done. I am saying it hasn't been done in this particular context.

CHAIR CORRADINI: And they have two operators.

MR. RUBIN: Well, the last thing I did to startup was 1200 megawatts CCGT. And during the startup phase, we had twice the staffing that you have during normal operation. So I think a lot depends on what you envision to be the maneuvering that has to take place. Because they are, they do require operator action. But on the other hand, once they are up and running, broken in, so to speak through their startup test program, two people are one outside, one inside.

CHAIR CORRADINI: We are not supposed to talk about that today. Can we move on? Let's move on.

MEMBER APOSTOLAKIS: We are on your slide four.

MR. REBSTOCK: I only have six.

MEMBER APOSTOLAKIS: It's not your fault.

MR. REBSTOCK: Okay. We see three main areas and this is really just a title slide for the following, for the ones that follow.

In advanced instrumentation we want to get information to provide information for the staff to use to develop the guidance that is necessary. And all of these areas are intended to begin in this fiscal, the current fiscal year.

And in advanced controls, it is the same thing. The objective is to gain information to be used by the staff, the Office of Research to gain information to be used by the staff to develop the guidance for the advanced instrumentation and controls.

MEMBER APOSTOLAKIS: Is there -- are we going to rely again on the process of developing the instrumentation of the controls to be assured that they are highly reliable?

MR. REBSTOCK: I'm not sure I know what you mean. I mean obviously yes, we are interested in how they develop them but we are interested in how they are constructed.

MEMBER APOSTOLAKIS: Well the main approach now to software reliability that the agency trusts is to have very strict controls on the process of developing the requirements, the specifications of the manufacturing. And then there is a presumption that if you follow that process that you have a pretty reliable product.

When you say, for example, adequate, how do you decide something is adequate?

MR. REBSTOCK: That is part of what we need to determine. I don't know -- all of this is going to depend on the process and the application and the environment. Not just the environment in terms of temperature and pressure but the environment in terms of psychological environment and cultural environment that the operators and the designers are going to work in.

And this is necessarily vague. It is deliberately vague because we don't know all of the details yet. That is part of what we need to find out. Some of it will come through the research. Some of it will come as the designs are developed over on the mechanical and the nuclear side.

MEMBER APOSTOLAKIS: Will there be any efforts to try to understand how these things may fail?

MR. REBSTOCK: That is already going on.

MEMBER APOSTOLAKIS: That is good.

MEMBER BLEY: Well one of the new kinds of things -- that was hoping you were going to be looking at here. Are you just -- this one and the one before are kind of, as you said vague. We will gather information. But is it information about the technology that you might be seeing or about, are you developing how review these kinds of things? How to look for failure modes or potential problem areas? What is your thought about what this plan is about?

MR. REBSTOCK: It would involve both and it will evolve as the designs evolve. What we look into and what we study will depend, in part, on what we have found out in the previous study. So, it is an evolutionary process.

I don't see value in just making up what we think somebody might want to use and then go and investigate it in case they decide to use it.

I think it would make a lot more sense to work with the designers and get an idea of where they are going and then use that as guidance into what it is that we need to check out.

MEMBER BLEY: I couldn't disagree with that.

MR. REBSTOCK: There is lots of other businesses. There is other technical areas of industries that use some of this stuff. They may use it in the same way we would use it and they may not. So, their experience may or may not be applicable.

It is tempting to think that Co-Gen plant would be kind of similar to multiple pebble beds, but that is what we need to find out.

CHAIR CORRADINI: Or at least, I think I appreciate what you are saying. At least with the designers, the DOE and the contractor and the applicant engaged in the discussion so that they check it out, since that is part of their, that will be part of their design responsibility.

MR. REBSTOCK: Yes, and for us to use it to anticipate what may be coming and what areas we need to look into. Because on one hand, we want to be ahead. We want to know. When something comes in, we want to already be ready for it but there is a limited amount. I mean, there is limited accuracy to which you can predict a future like that.

MEMBER ABDEL-KHALIK: From a power-control standpoint, are there any basic differences between the pebble bed design and the prismatic design or in both cases the primary essentially follows the secondary?

MR. REBSTOCK: That is kind of a core physics issue. I am not familiar with that.

MR. ULSES: I'd say to be honest with you, I haven't really looked at that. I can't really answer that question. Don, you want to take a shot at this Don?

MR. CARLSON: I think in general you can say --

MEMBER APOSTOLAKIS: Don, identify yourself and --

MR. CARLSON: Don Carlson, NRO. Yes, but my experience with looking at the recent HTGR designs, whether they are pebble bed or prismatic, is that they do follow the --

MEMBER ABDEL-KHALIK: So you would expect in both cases the reactors to operate all rods out.

MR. CARLSON: Yes, for example the AVR,

they control the power by adjusting the boiler speed. And that is what they talked about for PBMR several weeks ago.

MEMBER BLEY: Let me jump ahead to something I am really interested.

In the current design certifications, most all the I and C, essentially all the I and C is relegated to this stuff called DACC that won't be reviewed until you build the plant. With this thing coming together all at one time, do you envision something like that or are you going to have a full design to review and when you license thing, is it going to be the whole plant?

MR. REBSTOCK: I am not in a position to address that.

MEMBER APOSTOLAKIS: Well the issue of DACC doesn't even arise here.

MEMBER BLEY: I wouldn't think so but --

MEMBER APOSTOLAKIS: I am not submitting anything for design certification it would just come in one shot.

CHAIR CORRADINI: So I am going to thank you.

MR. REBSTOCK: Okay.

MEMBER APOSTOLAKIS: I am just wondering, why are the page numbers in the --

MR. REBSTOCK: We did it. In fact, I printed copies that have those unblocked.

MEMBER APOSTOLAKIS: Oh.

MR. REBSTOCK: But those had already been distributed by the time I got them here.

CHAIR CORRADINI: Did you have another slide? I apologize. I thought you were on your last slide.

MR. REBSTOCK: No, that's okay. No, the other one is just follow along the same thing as advanced diagnostics and prognostic has to do with predicting the condition of the reactor and the condition of the equipment. And it is an area that will be applicable to advanced reactors, new reactors, and old reactors.

MEMBER SHACK: So there is nothing particularly gas reactor about this one.

MR. REBSTOCK: No. Okay?

MR. RUBIN: I wasn't totally focused in on what Don was saying but reactor power is controlled in two ways. By rods and by pressure. Pressure is the usual for load following because you just increase pressure and you increase your following.

MR. REBSTOCK: The helium inventory or the

-- it's the mass flow rate, rally.

MR. RUBIN: Mass flow rate, correct. Work with that variable basically, pressure.

MR. REBSTOCK: Okay?

CHAIR CORRADINI: Thank you. We are going to move now to non-reactor, out-of-reactor issues. Is that correct?

MEMBER APOSTOLAKIS: Yes, the title on the agenda is interesting. Non-reactor nuclear safety analysis.

CHAIR CORRADINI: Do you pronounce your last name Aissa?

MR. AISSA: Aissa, yes.

CHAIR CORRADINI: Welcome, have a seat. Mourad is the proper pronunciation?

MR. AISSA: Yes, and the I has two points.

CHAIR CORRADINI: Go ahead.

MR. AISSA: My talk is going to be 15 minutes to quote Andy Warhol 15 minutes.

MEMBER APOSTOLAKIS: What?

MR. AISSA: Andy Warhol said everybody will be famous for 15 minutes.

This is going to be a short presentation. It is going to be a heads up because there is nothing to really report and no work has started yet. Only part of it was started on the reactor and that is what Tony presented yesterday.

This area is not addressed in the PIRT or in the gap analysis which causes the gaps in the PIRT. And as the PIRT said, as the design mature and we have more information to really get to the details of really doing it. Tony yesterday presented some updates on the code developments that will directly benefit this area.

Basically, this objective from the advanced reactor research plan exactly verbatim. We are going to validate nuclear analysis tools to address out-of-reactor material safety and safeguard review associated with fuel fabrication. In here including from the neutron process to the delivery to the site. Onsite storage, transport, and disposal of HTGR spent fuel and irradiated graphite.

Basically, the issues, all these are associated with the criticality safety for fresh and irradiated fuel. Radiation shielding, personnel and public safety, and also resistance.

So all the stuff that is neutronics, that is neutron physics outside of the reactor.

MEMBER ABDEL-KHALIK: Does refueling fall into this as well?

MR. AISSA: Yes. Yes, because fuel movement, when you move the fuel from one place to the other, of course you will have to obey by certain regulations to make sure you don't go, you don't have inadvertent criticality.

MEMBER ABDEL-KHALIK: Well aside from criticality, in this case, I would imagine --

MR. AISSA: And radiation.

MEMBER ABDEL-KHALIK: -- dose considerations up to the refueling would be paramount.

MR. AISSA: Yes, both.

MEMBER ABDEL-KHALIK: Have they developed a refueling strategy for the prismatic design and how the fuel is actually moved?

MR. RUBIN: Well I think it is going to be similar to Fort St. Vrain, which I am not sure exactly the steps that they would go through there.

MR. CARLSON: What was the question again?

MEMBER ABDEL-KHALIK: The question about dose considerations during refueling.

MR. CARLSON: Yes, the refueling procedure is going to be very much like Fort St. Vrain. And so they move individual blocks.

MEMBER RAY: Their shielded machine.

MR. CARLSON: Yes.

MR. RUBIN: The pebble bed is on the line.

MEMBER ABDEL-KHALIK: Yes, I understand that.

MR. AISSA: Now the two big obvious issues are safety issues. Again, I would like to remind the committee that this is an ongoing process. We expect to identify issues as we go and we decide at that time if more work and more data is needed.

But the two safety issues again, we want to ensure subcritical conditions for fuel that will be significantly higher than what we have now. About nine, ten percent will be pebble and almost 20 percent for the prismatic. Also the material composition, the geometry drastically different from what we have now. So all this stuff to create conditions is that we have not encountered before. And this is safety issue number one, criticality controls.

Number two is radiation-shielding. Everything that has to do with protecting the personnel and the public throughout the lifecycle of the fuel from cradle to grave.

Also another thing to add, just the graphite is somewhat minimal. Designate the super moderator, just like heavy water or iridium. It could induce fission with natural uranium. So there is that added dimension to our regulations that we didn't have before.

CHAIR CORRADINI: So just for my edification. Just historically, these were all taken as exceptions when Fort St. Vrain and Peach Bottom 1 operated, they had deviations from the water reactor regulations to deal with these issues?

MR. AISSA: I admit that I don't know.

CHAIR CORRADINI: I mean, historically, --

MR. AISSA: I am sure there have been some exceptional regulations just to support Fort St. Vrain.

CHAIR CORRADINI: I would expect you guys at least would be ready to imitate that in case policies don't move along as fast as realities.

MR. AISSA: One important product from this will be the complete review of existing regulations that we have and are to handle light-water reactor fuel and see what we are going to beef up or even have just separate regulations just to deal with the issue.

MR. CARLSON: This is Don Carlson and I think I can help answer the question a little bit more extensive.

In historical terms, I don't know exactly what was done for Fort St. Vrain or Peach Bottom but one of the questions that would come up is would they need exemptions. And to me the question is maybe some exemptions that they got wouldn't stand up to scrutiny if we were doing this on a large scale, you know, talking about building these by the dozens.

What I have in mind is for criticality safety under Part 70, 71, 72, that for Part 71 there are exemptions you don't have to do criticality analysis below what one point something enrichment because it is very hard to make that goal critical with light-water moderation.

CHAIR CORRADINI: But that one may be removed because of the --

MR. CARLSON: And now that you have a commerce in fissile materials and a super moderator material that can make natural uranium go critical, maybe we need to rethink those exemptions.

CHAIR CORRADINI: Okay. I see. Thank you. That helps a lot.

MR. AISSA: In specific R and D items for the area number one, which is ensuring subcritical conditions, would extend sensitivity and the uncertainty capability to address burnup up to 80 for pebble and even to 200 gigawatt-days per MTU for the prismatic design. Those are huge departures from existing burnup limits.

We want to enhance radiation-shielding methods and data to address issues unique to the systems. By radiation methods, I am talking about SCALE. As Tony said yesterday, we want to leverage our existing code fleet just to update only the modules that are impacted by the new reactors.

Also, the third bullet is a little cryptic but what it just says is we want to address updates SCALE to 200 graphite specific neutron interactions. We have a lot of work scattering. It is slowing down is different than just the structure. So, that --

CHAIR CORRADINI: Are you talking basic in-depth data?

MR. AISSA: I am talking also about what Tony talked about the updating our SCALE.

CHAIR CORRADINI: Oh, SCALE. The package that takes the data and processes it.

MR. AISSA: Yes.

CHAIR CORRADINI: Okay, thank you.

MR. AISSA: Yes and I am glad that Tony reported some good progress in there yesterday. And all this would be used for criticality analysis, too, because SCALE has several modules or sequences and one of them would do just criticality and one of them will do depletion to get your inventory. And that is where when I said we have not started but actually the measure part has already started, which is the neutronics part.

The other thing as I started I said we haven't really looked closely enough to see what all the failure past of the example, I am talking water ingress, and determine all of the vulnerabilities associated with working with this new material, new combination of graphite with high enriched fuel.

Also we want to adapt SCALE for the analysis of this fuel. We want to have good system that is not only the nuclide inventories but also of the critical condition, how close you are to your condition. And as Tony says, everybody actually most everyone indicated that experiment together is going to be crucial. And in the next slide, I will talk about some of the international interactions we plan to have.

So, not only ensuring criticality during the operation but also storing, once it's discharged. And we want to have access to all the international agencies' data and also the countries of China and Japan and gather any data that we can have.

Also we are going to characterize spent fuel from these new reactors versus the light-water reactor and identify. Again, this is a scoping campaign. Identify and justify areas where more work is needed so we can get something and more experimental data either through us or get DOE to get funds to do this.

And I think that is all I have.

CHAIR CORRADINI: Any questions by the committee? Okay, thank you very much.

MR. AISSA: Thank you.

CHAIR CORRADINI: We now move into the world of risk-informed. Or do we want to take a break, gentlemen?

MR. RUBIN: That's your call.

CHAIR CORRADINI: I'd say let's --

MR. RUBIN: Keep rolling?

CHAIR CORRADINI: Let's keep rolling.

MS. DROUIN: Mike, would it be okay if we took a break because we were waiting for some other people --

CHAIR CORRADINI: Okay.

MS. DROUIN: -- and we emailed them to tell them we were going ahead early.

CHAIR CORRADINI: Okay, so we will take a break until ten after 2:00.

(Whereupon, the foregoing matter went off the record at 1:55 p.m. and resumed at 2:12 p.m.)

CHAIR CORRADINI: All right, let's get started. George will have to catch up. On time -- and in conclusion.

(Laughter.)

CHAIR CORRADINI: Mary you are up.

MS. DROUIN: I'm up. Okay. Mary Drouin with the Office of Research.

I am here to talk about that part of the plan that deals with the risk-informed regulatory infrastructure. The objective, you know, is to develop an infrastructure that can support the establishment of a risk-informed licensing basis for advanced non-LWR, focusing on the risk-informed aspect. There are other technical issues that will addressed but today, you know, this merely focused on the risk aspect with regard to the licensing basis.

And what I mean by that, when you talk about the infrastructure, you know, it is just not these licensing base and you have heard about all these other things that are going on that feed into the infrastructure.

In looking at the infrastructure that is being proposed in the research plan, it is there and it has been designed to support the NGNP licensing strategy and particularly the Option 2 that was recommended. And as you know, Option 2 uses deterministic engineering judgment and analysis that is complimented by design-specific PRA information to establish the licensing basis.

And so consequently the licensing base events and the safety classification is based on deterministic information augmented with the risk insights. So, it is very similar to the approach that, you know, we currently use today.

And also looking at Option 2, the acceptance criteria would be consistent with 10 C.F.R. Pat 20 and 50.34 for the dose limits and it would use a mechanistic source term.

MEMBER APOSTOLAKIS: Oh, no, no. Let's go back. This is no --

MS. DROUIN: I didn't go the right way.

CHAIR CORRADINI: Nice try, Mary. It was a good shot, Mary.

MS. DROUIN: I pressed the down button but it doesn't seem to be going --

MEMBER APOSTOLAKIS: You have to go up for back.

MS. DROUIN: Oh, up for back. That just makes total sense.

MEMBER APOSTOLAKIS: Okay, this is not exactly what the technology neutral framework says. Is that correct or is it very close?

MS. DROUIN: This is what is in the licensing strategy for NGNP.

MEMBER APOSTOLAKIS: Yes, but the TNF slide is a different approach. There, you have the LBE and then the staff has the right also to define the deterministic sequence if they want to make part of their licensing.

MS. DROUIN: Okay, I am going to be getting into that in some slides down the road. Can you bear with me?

MEMBER APOSTOLAKIS: Well, but I still want a clarification here.

MS. DROUIN: Oh, okay.

MEMBER APOSTOLAKIS: How would you make sure -- well, first of all, this gives the appearance that you are really happy with deterministic approach. In other words --

CHAIR CORRADINI: That is Option 2, by the way.

MEMBER APOSTOLAKIS: So, that makes it

right?

CHAIR CORRADINI: No but that is what we concluded was an acceptable approach for the NGNP. I am just repeating what the letter said, that is all. Sorry.

MS. DROUIN: Here, good, better, or indifferent, this is what has been approved and what has gone to congress.

MEMBER APOSTOLAKIS: Yes, but you guys have a lot of, a lot of you have been defining the conservative deterministic.

So, are you going to take any, do you have any measures in place to make sure that this is not really getting out of hand and you have a deterministic guy saying I want all of these and then somebody from PRA comes and says, why don't you add a few more. I mean, --

MS. DROUIN: Okay, that is what I am going to get into later on in the presentation. I am going to get into how we are dealing with this.

MEMBER APOSTOLAKIS: So you are going with Option 2.

MS. DROUIN: Yes.

MEMBER APOSTOLAKIS: You say it has been approved.

MS. DROUIN: Option 2 has been approved.

MEMBER APOSTOLAKIS: By the Commission?

MS. DROUIN: Yes.

MR. KRESS: Is there a licensing strategy report?

MS. DROUIN: I'm sorry?

CHAIR CORRADINI: There is.

MS. DROUIN: Yes.

CHAIR CORRADINI: We got one. The consultants did, too.

MS. DROUIN: I'm going to give you another opportunity, George, to really come in on this.

MEMBER APOSTOLAKIS: Okay. Obviously, you don't want to talk about it now.

MS. DROUIN: Well because I have a place for it.

MEMBER APOSTOLAKIS: Okay. All right. I will wait.

MEMBER ABDEL-KHALIK: Let me ask a question on the selection of the licensing basis events. There may be some heretofore unexplored phenomena that may actually lead to some failure. And an example of that would be cracking of the thermal insulation sleeves that would lead to localized heating and failure of measured piping. How do you establish the frequency of event occurrences for things that we don't understand?

MS. DROUIN: I'm going to get back to this later. I am going to get into all of this. Just bear with me, please.

MEMBER ABDEL-KHALIK: All right.

MS. DROUIN: Okay. Okay. In the plan, in the advanced reactor research plan for this topic, we have identified three tasks. The first task is development of this what we call this integrated technical basis for prioritizing and selecting the needed research for advanced reactors. These are just fancy words for saying what we proposed to do is develop a scoping level PRA. And I am going to come and talk to each one of these in more detail.

The second one is to develop the regulatory guidance for the licensing establishing a risk-informed licensing basis. How are we going to be supporting the NGNP? You know, that is developing this regulatory guide that would implement this under Part 50.52.

And then the last task that is identified in the research plan is develop the guidance with the staff and licensees on how to implement the Commission's policy on defense-in-depth.

And I am going to try and go through each one.

Okay, the first one. You know, the overall objective here is to develop a scoping, what we call the scoping level PRA which will be used to support the identification and the prioritization and selection of R and D topics, which would be done in the context of risk metrics, that are consistent with the policy goals.

MR. KRESS: You are going to develop your own PRA in the house here?

MS. DROUIN: Yes.

CHAIR CORRADINI: For the NGNP.

MS. DROUIN: If the NGNP needs it but right now that is what we are thinking.

CHAIR CORRADINI: I have cruised through your bullets. So, the PRA is going to be a more quantitative version of a PIRT process? I mean, she said prioritization of selection of research. They did a PIRT process two years ago. They have prioritized, they have selected, and they have proceeded.

MS. DROUIN: Right.

CHAIR CORRADINI: So I am trying to understand how that --

MEMBER APOSTOLAKIS: PIRT?

CHAIR CORRADINI: PIRT.

MEMBER APOSTOLAKIS: PIRT refers to specific phenomena. It doesn't look at the whole reactor.

MS. DROUIN: Right.

MEMBER BLEY: And this is integrated.

CHAIR CORRADINI: It is the selection of research topics.

MS. DROUIN: Right but it is within this whole context. So, don't broaden it past that. It is not meant to do that.

MR. KRESS: The more risk-significant things will be higher priority.

MS. DROUIN: Right.

MR. KRESS: And you can only do that with PRA.

MS. DROUIN: Right.

MEMBER APOSTOLAKIS: Well not only that but we were discussing earlier today the seismic issues.

The PIRT guys didn't look at those things. They look at specifics.

CHAIR CORRADINI: I understand that but I just looked at the title and I am trying to understand that the PIRT has certain topics, which they did, and they had certains which they didn't. But in the ones that they did, I am trying to understand what the PRA is going to do that would refine what the PIRT has already done in terms of --

MR. RUBIN: What the PIRT has done I think we advised the members of the out of bounds to think about the probability of the events we are defining. Give them, here are the events, here are the figures of merit. Can you please help us out? What are the important phenomena that we need to be concerned about for these defined events and these figures of merit and prioritize how much we know about this and their significance.

CHAIR CORRADINI: Okay.

MR. RUBIN: Now we would like to overlay that with what was not done by the PIRT members is to bring to bear well how important are the scenarios that we defined for the PIRT and the like.

CHAIR CORRADINI: Okay, thank you.

MS. DROUIN: So in developing the scope and level PRA, there were three tasks that we plan to do. The first one is what we are talking about in the near term is first determine the feasibility. Can we even do this? You know, given where we are right now, you know, what would it take to develop this scope and level PRA? What kind of information do we need? Do we have the necessary information?

So the very first task is just looking at the feasibility of doing this and what that would take. And then --

MEMBER APOSTOLAKIS: Is there a PBMR a PRA that has been --

MS. DROUIN: I'm sorry?

MEMBER APOSTOLAKIS: Is there a PBMR model?

MS. DROUIN: Yes.

MEMBER APOSTOLAKIS: That can be your first example.

MS. DROUIN: I mean, they have done one. How good it is, how much we can use it --

MEMBER APOSTOLAKIS: But for a scoping PRA, that may be a very good place to start.

MS. DROUIN: It could be and those are the kinds of things that we would look at.

MEMBER APOSTOLAKIS: And there is also a PRA, the accident initiation and pressure -- I don't know, 35 years ago for the HTGR.

MS. DROUIN: I mean, there is a lot of information out there.

MEMBER APOSTOLAKIS: There is a lot of information, yes.

MS. DROUIN: And so you know, this feasibility study would look at all those kinds of things.

And then, you know, given the feasibility, then we would actually lay out and develop, you know, the approach. You know, what would be the scope that would be needed? What would be the boundary conditions? What kind of level of detail would we want? Where is the source of data. So establishing all of the inputs that would be needed in terms of --

MR. KRESS: I presume this would be a level one because we have to have fission product release models --

MS. DROUIN: I don't know that it would just be a level one. I think it would be difficult because you get back into how are you defining for damage. So in my mind, it would have to at least go out to level, two. But those are all the things that we are going to have to be thinking about, Tom.

MEMBER APOSTOLAKIS: Actually, if you were using the concept of licensing basis events, you have to go to those.

MS. DROUIN: You have to go all the way to level three, that is correct. Absolutely, you do.

CHAIR CORRADINI: And that is your intent?

MS. DROUIN: Right now, that is the intent.

CHAIR CORRADINI: Oh really? To go all the way to a level three scoping approach?

MS. DROUIN: Oh, in my mind, yes.

CHAIR CORRADINI: Okay, thank you.

MS. DROUIN: But where we end up, you know, is debate. It is still under consideration.

CHAIR CORRADINI: That's fine.

MEMBER APOSTOLAKIS: The acceptance criteria and the technology utilized right? In terms of those.

MS. DROUIN: Yes.

MR. KRESS: Yes, that was a mistake.

CHAIR CORRADINI: Let's keep on going. Mary keep on going.

MS. DROUIN: And then of course, you know, given the first two, then actually develop the scoping level PRA.

Now the one thing I want to point out, all of this work here is very closely coupled and iterative with the next task in the research plan which deals with PRA. So, I am not going to keep saying that. I will try and remember to keep saying it but just remember it is an iterative and this task here is very closely coupled with that task.

Okay. The next task is developing this regulatory guidance for the identification of the licensing base events and the safety classification. And this task, developing this regulatory guide, you know, has three major subtasks to it. And the first one is develop this draft regulatory guide for internal review. And in developing this draft regulatory guide, we anticipate, you know, there is going to be a lot of policy and technical issues that are going to come out of this.

And once we have the draft regulatory guide developed and gone through the internal review process, and I mean internal, we have not gone out with the public yet, we are coming as a consensus among us in our own, you know, across the agency on this, then we are talking about performing a test of this regulatory guide on the concepts and methods and test it against some actual design, whether the design is the NGNP. Mike, you brought up, you know, looking at Fort St. Vrain. So you know, there are places we can test it. Maybe it is the PBMR. All of that is to be decided.

CHAIR CORRADINI: Depending upon what is there at the time when you --

MS. DROUIN: Exactly. Exactly. But it is in the plan to test it.

MEMBER BLEY: So this is a regulatory guide that explains how they should pick the events and how they should be analyzed?

MS. DROUIN: Yes and I am going to go through each of these in the next slides.

MEMBER BLEY: Okay.

MS. DROUIN: And then the last thing, you know, once we have gone through the test and gotten the insights an the lessons learned, then we come back and finalize this guide and, you know, issue it.

MEMBER APOSTOLAKIS: What is the time scale for this?

MS. DROUIN: We haven't totally worked that out yet. But I am going to talk about -- right now we have been working on this guide this past year and we are coming to a place where we are going to start doing some preliminary internal review. And you know, we will be coming ultimately to the ACRS, you know, to discuss it.

MEMBER APOSTOLAKIS: Well is it a year, two years?

MS. DROUIN: I mean for the draft guide right now, our current schedule is to have it complete this year but all that is going to be really dependent on, you know, what comes out of the review.

You know, I mean, at one extreme the reviews could come back and say go back to the drawing board. You know, on the other extreme, they love it.

MEMBER APOSTOLAKIS: Whose interview is that?

MS. DROUIN: NRO.

MEMBER BLEY: But if all goes well, by the end of this year you could have something.

MS. DROUIN: Yes, if all goes well. And I really --

MEMBER APOSTOLAKIS: And then you will come to us? After that you will come to us?

MS. DROUIN: Yes.

MEMBER APOSTOLAKIS: To sell committee on all that so we can say go back to the drawing board. But then you don't have to listen.

MEMBER ABDEL-KHALIK: Was it here that you were planning to answer the question I raised earlier with regard to events that involve heretofore unidentified or unexplored phenomenon?

MS. DROUIN: Yes, I am getting there. I

hope I am getting there because I think this that first bullet, identification selection of the actual events.

MR. KRESS: If you such events and needed a failure probability, you would have to go back to expert opinion. I don't see any other way to do it.

MS. DROUIN: Right. Now, recognize, you know, everything is not worked out here and I wasn't intending in this half hour presentation to get into the details, the technical details but more inform you of, you know, what we are intending and what we are trying to address in this reg guide and is there some technical area that we have left off.

MEMBER ABDEL-KHALIK: But this is sort of a big picture question. It is not necessarily focused on that particular event. But there may be other similar events.

MEMBER APOSTOLAKIS: I believe that Said's question is very relevant here because to identify and select the licensing events, which presumably include the licensing basis events, you must have quantified already. Right?

MS. DROUIN: Okay.

MEMBER APOSTOLAKIS: So if you quantify and you go to each -- I mean, you remember how the

NUREG defines the LBEs. You have to go to the events that have --

MS. DROUIN: Let me go to the next slide then because --

MEMBER APOSTOLAKIS: -- a frequency of greater than ten to the minus eight.

MR. RUBIN: These are the areas.

MS. DROUIN: Yes, these are the areas. So the next slide now gets into the events.

MEMBER RAY: You can't select something you haven't quantified, George?

MEMBER APOSTOLAKIS: Sorry?

MEMBER RAY: You cannot select an event that hasn't been quantified?

MEMBER APOSTOLAKIS: You are given that opportunity.

MR. KRESS: That is the deterministic part of it.

MS. DROUIN: That is the deterministic part.

MEMBER BLEY: But if your uncertainty is very broad and it could be very frequent, that uncertainty is enough to lift something to arrange to be added to the list to resolve it.

CHAIR CORRADINI: I don't want to get

ahead of you, Mary, but I think that actually addresses Said's question which is if you go through the process as specified before in 1860 and something seems to be left out, the group, the team, whatever, has to argue through if there is something out there that is very unquantifiable but concerns you, it could get put into the mix.

MS. DROUIN: Absolutely.

MEMBER APOSTOLAKIS: Right but I think Said's question was different. And I think Tom's answer was, I mean, if you count, you will go to expert opinion.

MEMBER BLEY: And if you came in at the end of that process, it could be very likely. That could be one extreme. You can't show it is not. So there is a chance it is likely enough, you have got to put it on the list until you resolve it.

MR. KRESS: You combine that with the expert.

MEMBER BLEY: What else can you do?

MR. RUBIN: The limiting events, in terms of dose obviously get tied to failures of the pressure boundary. In other words, there is no escape path. So, we are talking about events where you have some failure of the pressure boundary. If you go to risk-informed 50.46, there was expert elicitation on the failure probabilities for BWRs and PWRs and it was based on, relatively speaking, a wealth of data compared to the data we may have here.

Who are the experts in HTGR degradation mechanisms an the like? So that is a challenge. But we will get what we can get. But the uncertainties I expect will be much larger than these designs.

At that point, what is the engineering judgment that one has to apply to those expert opinions? And that is where the deterministic piece will come in. And we can't say at this point how big a break, where it will be. We will all have our say in what that is and where it is.

But you picked out a very good example that joins the issue, that very issue.

MS. DROUIN: At this part of the regulatory guide, which gets into the identification and selection of the event, you know, one of the biggest things up front is the definition of the event. You know, and that is bringing in, you know, how we are doing. We are bringing in the deterministic process. And so there is, and that brings in to support the NGNP but it is also augmented with the risk, so the reg guide also gets into the probabilistic acceptance criteria and how we use that in the selection of the events, along with the deterministic. And also what is the deterministic acceptance criteria.

MEMBER APOSTOLAKIS: So, this is what I have a question on and it comes back to. I have the license basis events. I have done that. In some way I have done that. And I have done the deterministic event or events.

Now, what do I do? Do I go back and do a detailed mechanistic evaluation of which one of these similar to, not similar to what we do now with a large LOCA, for instance? I couldn't find it in the NUREG-1860. Maybe it is there but I couldn't find it. What exactly do I do with these licensing events?

I mean, I have them. I have ten licensing basis events, two additional deterministic events. I come to the NRC. Then you guys will say okay, my thermal hydraulic group will look at the thermal hydraulic analysis of each LB. Then my structures group will look at the structural analysis of each LB and they will have acceptance criteria and so on. Is that the intent? I am not sure.

MR. RUBIN: Maybe I can help you out here.

MEMBER APOSTOLAKIS: Okay.

MR. RUBIN: Say that from a dose point of view, we would be thinking in terms of our evaluation model because that is geared, ultimately, to calculate the dose for any event you want to give me. That is what I am going to categorize. So it is an integration of all of those factors.

The rules that you use, whether you use conservative, whatever that turns out to be in the evaluation model, or best estimate, whatever that turns out to be in the evaluation model, we haven't pinned that down and we need to get the Commission to help us decide. That is a policy issue.

CHAIR CORRADINI: What is a policy issue? I'm sorry.

MR. RUBIN: The rules.

MEMBER APOSTOLAKIS: How are you going to do HLB?

MR. KRESS: Do you use conservative figures of merit and what are the figures of merit and how do you -- what conservatism do you put into the evaluation.

MR. RUBIN: Right. Where are the conservatisms for a conservative analysis? How exactly are you going to do that?

MR. KRESS: It could very well be dose.

MR. RUBIN: What is a particle failure rate model that you are going to use for that?

MR. KRESS: It could be the temperature of the hot spot. You just have to, you have develop every step.

MEMBER SHACK: Every event has to have an evaluation model. You can't do it any other way, George.

MEMBER APOSTOLAKIS: Correct. And my question is what is it? If it is obvious to everybody, give me the answer and we will move on.

MS. DROUIN: 1860 -- that was not part of the scope of 1860.

MEMBER APOSTOLAKIS: I know. That is why I am asking the question --

MS. DROUIN: Okay.

MEMBER APOSTOLAKIS: -- but I couldn't find the answer.

MS. DROUIN: Because it wasn't supposed to be --

MEMBER APOSTOLAKIS: So --

MEMBER SHACK: It could be a best estimate. It could be a conservative.

MEMBER APOSTOLAKIS: I have already used frequencies for that sequence, so you can't come back and --

MEMBER SHACK: No, no. This is evaluating the event itself. The frequency that it occurs is already, that is off the table. You have included it. Now we are just saying okay, I have busted the pipe. Now what. And then what you are saying --

MEMBER BLEY: It is a deterministic analysis.

MEMBER APOSTOLAKIS: So it will be a deterministic analysis of what we do now for the design basis events.

MR. RUBIN: Well, it wasn't spelled out there but that is it.

CHAIR CORRADINI: But as you proceed through the calculation, all the questions you raise, there is going to have to be some decision taken as to okay, if I am interested in the dust loading and what fission products that are in it, what is the failure rate of the fuel? What is there? What is the range of it? And now we have to take a decision as to what I proceed and propagate through the calculation.

MEMBER RAY: Well, there is this choice between best estimate and conservative values that isn't governed by what you just said, I don't think, Mike.

MEMBER BLEY: We have had experiences here when people say, well this is not very likely, let's use best estimate, or the converse. I think maybe that is what George is saying. But we have pushed the best estimate to include uncertainty and that is what at least this group is talking about when they say best estimate.

The intent there was you are not going to do the extremely detailed level analysis on everything in the PRA. So, on this smaller set, you make sure you have got margin. You make sure that --

MEMBER APOSTOLAKIS: But that is the question because you are talking as if it some kind of obvious.

CHAIR CORRADINI: No, no.

MEMBER BLEY: Well we did get into a lot of details here.

MEMBER APOSTOLAKIS: In 1860, as Mary said, it was not their job, their assignment, just LBs. But it has always been, yes, they don't say what to do with them. They say you select them this way, period. Thank you very much. And then they give you all sorts of other things giving the staff a way out of that and say the staff can also pick some according to deterministic. But that is it.

So the question is, and I think a lot of it had to do also with the objections that were raised to the PRA by some members of this committee, because it was never clear what the staff is supposed to, and the applicant too, is supposed to do with these.

One is what we always seem to be saying here --

MR. RUBIN: That is why we started our meeting with what we did yesterday. And what we did yesterday is talk about the evaluation model. And that is where we would go with these, putting it through the evaluation under certain analysis rules.

MEMBER APOSTOLAKIS: And detail thermal hydraulic evaluation. Okay, fine.

CHAIR CORRADINI: But wait a minute. I mean, that sounds like you have solved it when you haven't solved it. All you have done is passed it off to the next level of -- if you say -- I mean, I look upon it on Tom's plot or somebody's plot of frequency and dose. They have now told you what the frequency of the things you have to worry about. Now, where do you place it on the X axis relative to dose? And that is all the evaluation model and all the, essentially the response to the system. Yes.

MEMBER APOSTOLAKIS: That has already been done. It has been done when you are finding in the LBEs. Where you have frequencies of failure, you have calculated doses, and then you have --

CHAIR CORRADINI: How have you calculated the dose? How do you calculate the dose?

MEMBER APOSTOLAKIS: Well, if you haven't, then the TMF collapses.

MR. RUBIN: But the models for doses in the PRA model are not the same models we are talking about an evaluation model.

MS. DROUIN: That is the key right there. You have done a lovely --

MEMBER BLEY: This is not a licensing analysis.

MS. DROUIN: I mean, you pick the events and if we end up using a curve similar to what is in 1860, which is frequency versus dose, you have to have done a level three PRA.

MEMBER APOSTOLAKIS: At some level.

MEMBER BLEY: Mary, the reg guide you are working on, is that just to pick the events or also to get at these questions that are being asked about how to evaluate?

MS. DROUIN: That is what I keep trying to jump in to say. It is just to pick the events.

MEMBER BLEY: Just to pick the events.

MS. DROUIN: Right. You are going to have to go --

MEMBER BLEY: Sometime later, somebody has got to define the reg guide of how to evaluate.

MEMBER APOSTOLAKIS: So Mary --

MS. DROUIN: That is correct.

MEMBER BLEY: Okay.

MEMBER APOSTOLAKIS: So all the licensing basis events and everything else are used for is to define some other set of events that will be the licensing basis?

MS. DROUIN: Say that again.

MEMBER APOSTOLAKIS: I have the licensing basis events. I have also the additional deterministic sequences. Now, is this set automatically the licensing basis, in other words, they have to come with detailed evaluations of each one or you will select a subset and do the detailed thermal hydraulic ending in public.

MS. DROUIN: This is a regulatory guide that is providing the guidance to the licensee of how he selects his licensing base events. The guidance will include how you take the deterministic and the probabilistic and it will use the conditions laid out in Option 2 of the NGNP. So the approach is consistent with what is in Option 2.

MEMBER BLEY: But the list of events are the ones that get analyzed.

MEMBER APOSTOLAKIS: But this is the regulatory guide. This regulatory guide. I am asking a broader question. After I get the results of the regulatory guide, what am I expected to do? How do I convince you guys to give me a license?

CHAIR CORRADINI: You take the same tools you use in the PRA and you change some of the assumptions on the models and you get an upper bound on --

MEMBER APOSTOLAKIS: The PRA.

MEMBER BLEY: No, don't use the PRA.

CHAIR CORRADINI: What tool, let me just ask --

MS. DROUIN: But this is the safety analysis.

CHAIR CORRADINI: The question that we are going around is if somehow the PRA is different. What tool will you use in the license, in the evaluation model that you wouldn't use in the PRA calculations? You are going to use MELCOR. You are going to use all that same set of tools.

MR. RUBIN: For us that is probably true. For us that is probably true.

CHAIR CORRADINI: Fine.

MR. RUBIN: But for an applicant, they will have simplified models in their PRAs.

CHAIR CORRADINI: Okay, but then is George's --

MR. RUBIN: But you still have to do the detail.

CHAIR CORRADINI: But then to clarify George's question, are you asking about what the applicants should do or what the staff is going to do?

MEMBER APOSTOLAKIS: Both. What should the applicant submit?

CHAIR CORRADINI: It sounds to me like the staff is going to use the same tools with different assumptions. What the applicant is going to do is they are going to have to decide a policy on how to handle it.

MEMBER APOSTOLAKIS: The safety evaluations of that this agency performs go much more detailing than the PRA does. And I am asking, what is that level of detail that the LBEs will be subjected to.

MEMBER SHACK: Roughly that level of

detail.

MS. DROUIN: Yes.

MR. KRESS: George, in the --

MEMBER APOSTOLAKIS: We are not approving a PRA here.

CHAIR CORRADINI: You are selecting Chapter 15 events.

MS. DROUIN: That's right.

MR. RUBIN: Right and those would be design basis to beyond design basis. It will all be in there.

MR. KRESS: But George, let me say this. Back in the LWRs, we didn't have exactly how to get the doses or the releases. So what we did, we backed off from figures of merit which were conservative. If you maintained like peak clad temperature and then oxidation, so you backed off on these things and now if you can show that you don't exceed these figures of merit, then you know we are all right.

We will have to come up with some sort of figures of merit that are different than dose, I think. Because then I think you will have to back off and be concerned.

MEMBER APOSTOLAKIS: That is half of my question. Suppose I had the TNF in 1969. And the TNF says the licensing basis event is a large load count. In determining that, I wouldn't have looked into the level of oxidation.

MR. KRESS: No, no. No, you would have --

MEMBER APOSTOLAKIS: So then I would come back here to the NRC and say here is an LB and here is my evaluation which would look now at the amount of oxidation of the clouding of the big clouding temperature and all that. That is a safety analysis. And I am asking, is every LBE going to be subjected to this detailed evaluation?

MS. DROUIN: Yes.

CHAIR CORRADINI: Those that they choose for 15, they will be.

MEMBER BLEY: I think something is a little different in the design basis events exactly. You had to show you wouldn't melt the core --

MS. DROUIN: That's right.

MEMBER BLEY: -- on a design basis event and you used those figures of merit. Some of these events, is that going to be true here or can some of these have core damage but you just have to show you won't exceed certain dose limits of some sort.

MEMBER APOSTOLAKIS: And some of them will. And some of them will. But we are getting into detail and I agree to evaluate that in another guide.

But my only question, as you say, this guide will help us select the LBEs and the deterministic. And then there would be a subset of these that is the licensing basis or all of them? Most likely all of them.

MS. DROUIN: Are you talking about that are evaluated?

MEMBER APOSTOLAKIS: Yes.

MR. RUBIN: They are all evaluated but they will be collapsed into families.

MEMBER APOSTOLAKIS: But they are evaluated the way we do know, where you know, the applicant comes to the thermal hydraulics guys, there is a give and take, and RAIs, --

MS. DROUIN: Absolutely but I would imagine that when you go through this whole process, you will probably be able to group some of them.

MEMBER APOSTOLAKIS: Well hopefully, the number of LBEs would be manageable.

MS. DROUIN: Right.

MEMBER APOSTOLAKIS: And in fact you have rules how to do that.

MS. DROUIN: Yes.

MEMBER APOSTOLAKIS: Yes.

CHAIR CORRADINI: But I guess I am still -- now I think, I didn't understand your question but I think Tom answered your question. It is not the process. It is the interim figures of merit that you are going to have to think about and choose. It might be peaked fuel temperature. It might be a containment pressure. It might be things such as that.

MEMBER SHACK: That remains to be determined.

CHAIR CORRADINI: And remains to be determined.

MEMBER APOSTOLAKIS: But my fundamental question for each LB, I will got down to mechanistical levels. That is correct.

MS. DROUIN: Yes.

MEMBER APOSTOLAKIS: Isn't that correct?

MS. DROUIN: That is correct.

MEMBER APOSTOLAKIS: That is correct. Now, whether we have figure, we call them figures of merit, what kind of analysis and so on, I understand these things --

CHAIR CORRADINI: Just so it is in the record, you somehow think that the mechanistic level is going to change once you do Chapter 15. I don't sense it. It will be different assumptions on the same set of models. You may choose to simplify the models on the applicant side but on the staff side, I see no different suite of calculational tools. It is just the assumptions you make on the same set of calculational tools.

MEMBER APOSTOLAKIS: So what you are saying is that for all this set of LBE and the additional events, there will still be a Chapter 15 the way it is today.

MS. DROUIN: Yes.

MR. RUBIN: Absolutely.

MS. DROUIN: Absolutely.

MEMBER ABDEL-KHALIK: And once you analyze --

MEMBER APOSTOLAKIS: I mean, we are going -- I'm sorry, Said. There are some things -- I think that is why you are doing this, in fact, to see what kind of work this entails. Right? I mean, if it gets out of hand, I don't know how we are going to handle this.

MS. DROUIN: Well, it is also moving away. I mean, the current process right now, you know, the events are strictly chosen from a deterministic.

MEMBER APOSTOLAKIS: Absolutely. I have no problem with that.

MS. DROUIN: Okay. Option 2 brings in the risk insights to help do that.

MEMBER APOSTOLAKIS: So.

MS. DROUIN: So we are writing a regulatory guide of how do you bring those risk insights in and help choosing your set of LBEs.

MR. KRESS: Just to formalize a way to be deterministic, frankly. But that's all right.

But I have one other point. You know, George was asking which of these will end up being the actual design. And I presume all of them that you come up would be easy but I would have liked to have added at least two more. And that would be, in addition to needing all these Chapter 15, you also need some equivalent value for CDF and LRF, required as part of the licensing basis.

MEMBER APOSTOLAKIS: I can't imagine that the staff will tolerate --

CHAIR CORRADINI: We are into discussion. I'm sorry.

MEMBER APOSTOLAKIS: We have plenty of time. We saved so much time earlier.

CHAIR CORRADINI: Yes, but I am going to lose some committee members. I have already lost one and I want Mary to get through her presentation.

MEMBER ABDEL-KHALIK: Okay but I have a question that sort just of carries from where George stopped.

MS. DROUIN: Okay --

MEMBER ABDEL-KHALIK: Once you do these detailed mechanistic analyses of each of the licensing basis events, how would you make the judgment that the plant response is acceptable?

MS. DROUIN: That is a very premature question and I am going to take my direction from Mike and move the presentation along.

MEMBER ABDEL-KHALIK: Premature question in terms of what? I'm sorry.

CHAIR CORRADINI: I think she would prefer to think about it and come back to us on that one.

MR. RUBIN: Well one of the things is the Epstein curve.

MS. DROUIN: I tried to move on, Mike.

CHAIR CORRADINI: I think --

MEMBER ABDEL-KHALIK: So that analysis involves this mechanistic determination all the way to calculating the consequences in terms of dose?

MR. KRESS: You go back and do that with the PRA. And you have PRA exceptions --

MS. DROUIN: I just ask you, gentlemen, we are going to come back, to this committee on this topic with days and hours for you all to come and ask us questions. All we are trying to do here is to give you a high level process of what we are trying to accomplish. We weren't trying to get into a technical discussion. There will be many, many opportunities down the road for this.

This part of the regulatory guide also includes guidance on the safety classification, the other thing in the regulatory guide. Because we are using risk insights, it means we are using a PRA, which means we need to have confidence in that PRA. So the reg guide also at a high level gets into, you know, what is the needed scope, what is the needed level of detail, where are the attributes. And this is at a high level because there is a separate regulatory guide which we will talk about in the next presentation that gets into that.

MEMBER BLEY: Mary, your middle bullet there, you will actually be laying out specific special treatment recommendations in this reg guide or not yet?

MS. DROUIN: Probably not yet. Probably just acknowledge the fact that you could have a graded approach within these because even though something may be significant, significance can be relative. It can be, you know, this whole spectrum.

MR. KRESS: Will you cull out a threshold value for your importance measures?

MS. DROUIN: I would like to think so.

MEMBER APOSTOLAKIS: What did you say? I'm sorry.

MR. KRESS: I was wondering if you are going to use importance measures for SSCs, you need some sort of special value.

MS. DROUIN: I think you need a threshold of what is the bottom cutoff for significance. Absolutely.

MEMBER APOSTOLAKIS: And another question is, do we need to perpetuate the use of the current policy in this case?

MS. DROUIN: That is the thing we are going to have to look at, absolutely.

There is other three things in the regulatory guide. Instead of burying treatment of uncertainties like a technical element, you know, under PRA, we have elevated it so that it is highlighted in the regulatory guide. A large part of it will get into trying to be giving guidance on how to identify the sources of uncertainty. We think this is a particularly important aspect of the regulatory guide because we are in new territory and understanding how to know where those sources are is important. The use of sensitivity bounding analyses will also be addressed because we will be getting, you know, when you talk about particularly the completeness part of it and how much we need to quantify.

The next part of the regulatory guide gets into modifications and updates. And what we mean by that is that since you are using risk insights to help select your licensing base events, and you start off with the scoping PRA, and then as you move over time, and you get more information, and your knowledge is improved, and your tools or methods change, or your data, all that can mean that the results of your PRA change, which means your insights, which could ultimately come back and impact how you selected those events. So you need to stay current so there is a part of the regulatory guide that will get into how you update and maintain the PRA.

MEMBER BLEY: Mary, on the uncertainties, have you gotten far enough to know whether you anticipate substantial differences than you had in 1855? Or you expect in 1855 on this history?

MS. DROUIN: We are looking to 1855 a lot and then hopefully to feedback into 1855 for a modification of 1855, to ultimately support this.

And then the last part, you know, is the documentation. And the reg guide is going to get into, you know, what are those parts of the documentation that need to be in your submittal but also what needs to be archived.

MEMBER APOSTOLAKIS: What is the difference?

MS. DROUIN: I'm sorry?

MEMBER APOSTOLAKIS: What is the difference between the two, archived and submitted?

MS. DROUIN: Submittal is a subset really of your archival.

MEMBER APOSTOLAKIS: Submittal is more horrible --

MS. DROUIN: What you send to the NRC versus --

MEMBER BLEY: The other stuff, the NRC has to go audit at their place if they want to see it.

MS. DROUIN: But in a lot of cases, when you go out to audit, all they kept was the submittal. So, there is other information beyond what you submit that we want them to have. So it differentiates between the two.

Okay, the next part in the research plan was development of the implementation guidance for the defense-in-depth policy statement.

You know, and right now in terms of the implementation this is, of course, closely coupled to the policy statement. So for this next year, you know, all we are doing on this task, you know, is to look at what approach, you know, how this would fit in and trying to lay out a schedule.

And then in the longer term, depending on where we end up with the policy statement, then we would go into developing the actual implementation guidance.

MEMBER APOSTOLAKIS: So there is no policy statement on the ground.

MS. DROUIN: Right now there is no policy statement, so we can't develop the implementation guidance without the policy statement. So this is, you know, again, closely coupled.

MEMBER BLEY: But you will be, is it fair to say you will be proceeding in development of the associated reg guides for dealing with the advance reactor following something like you showed us at your last meeting on defense-in-depth, incorporating defense-in-depth ideas into it?

MS. DROUIN: I guess I am not understanding your question. Let me try and go through here on the status --

MEMBER BLEY: Go ahead.

MS. DROUIN: -- and maybe that will answer it.

MEMBER BLEY: Okay.

MS. DROUIN: Right now in the scoping PRA, we don't have any activities in progress. You know, this is the stuff that we planned.

In terms of the reg guide, you know, we have been working on it and right now for this next year, you know, is to have a draft for, a preliminary draft for NRO review to start sharing with them what we have so far.

And then on the defense-in-depth, the schedule for the draft policy statement is being reevaluated, trying to learn, you know, where we are and where we are going to go. And then depending on that, that will impact then the schedule that is developed for the implementation guidance.

So there is a paper going forward in February to the Commission on this topic. I don't know, John, if you want to add.

MR. MONNINGER: I guess. This is John Monninger from the Office of Nuclear Regulatory Research.

With regard to this action item that was tied to the staffs where it was discussed most recently with the Commission in the Commission paper on a proposed Part 53, a rule-making, a brand new rule-making for risk-informed and performance-based regulation, for both that rule-making and this, we had anticipated learning quite a bit of information through the development of the NGNP licensing strategy and also through the review of the pebble bed, the PBMR white papers.

You know, due to some resource limitations, we haven't really progressed much at all on the review of the white papers. And there hasn't been that many keen insights that have really come out of the development of the licensing strategy that could push us forward on either the rule-making or this policy statement.

There has been and there was significant work done through Mary and Mary's group, other NRC staff, and contractors on defense-in-depth. And a lot of that thought and thinking is in the technology neutral framework. There is other international documents out there on defense-in-depth. So, I guess our thought is right now significant work has been done and we have learned a lot from a top-down approach. Our thought is now we would really like to learn a lot more from specific applications and try to advance this forward once we have some additional lessons learned from specific applications.

MEMBER BLEY: Let me rephrase that question I asked earlier a little.

As DOE is developing the design for the NGNP and they are getting a good hint of where the licensing basis events ideas is going to move, I think it would seem to me they need a pretty good hint about where defense-in-depth is going to be, so that they can integrate their design thinking about that. If this is deferred for a long time, what I was thinking is you would be laying out applications using some of the ideas we had seen the last time around on defense-in-depth as this progresses and using that as a test bed. And that is what I was asking or trying to ask before.

Is this going on the shelf for a while or are they going to get some hints about what it is going to look like or what you think it is going to look like, as far as the part of defense-in-depth and the licensing strategy that they have to deal with.

MR. MONNINGER: I think, you know, are they going to get some hints? I think there is a lot of hints out there with regard to all that has been stated within the framework, etcetera. I think to a certain extent it is a chicken and egg thing. You know, we progress so far and we get a lot of good ideas out there and we try to solicit comments. But a lot of times you come to the point where you don't know how much further you can really proceed without working with a specific design. And so right now, we would like to work more closely with a specific design in trying to advance this forward.

We think there is --

MEMBER BLEY: Is that NGNP or is that maybe some existing designs? I am not sure where this is headed.

MR. MONNINGER: Oh, our thought it would be for advanced reactor designs. When you said some existing designs, I'm not sure if you meant like operating reactors or the notion was the Fort St. Vrain, you know, look back, and that was a very good comment, recommendation to the staff, consider what we did in the Fort St. Vrain licensing.

MEMBER BLEY: I like the idea of

applications but I am just wondering what they are going to be.

MR. MONNINGER: Well in some of this, conceptually within the staff and I think as was discussed at the last ACRS meeting, there were -- were they called principles? I'm not sure if they were called principles. There were five, six, seven, or eight --

MS. DROUIN: Principles.

MR. MONNINGER: -- principles. And I believe it was universal and joint -- universal agreement that they are very good, solid principles that should be used. But then the next thing was the next level down and the application of that. And you spend a lot of time going back and forth between individuals on wording and thought and intent, that you are not as productive as you could potentially be.

CHAIR CORRADINI: Otherwise, are you --

MS. DROUIN: I'm done.

CHAIR CORRADINI: Thank you and we will take a break until 3:15.

MEMBER APOSTOLAKIS: A second break.

CHAIR CORRADINI: That's right. You made me wait. No, no. Then I don't want to take a break. I missed that. I thought I forced us to go forward.

I apologize.

So we are going to go on directly and talk about plant PRA.

MS. DROUIN: Yes and Kevin Coyne is out sick, so I will be giving his presentation.

CHAIR CORRADINI: Oh, well, welcome back Mary.

Is there something in here that is going to be different than what we just talked about?

MS. DROUIN: Yes, it is a different presentation.

CHAIR CORRADINI: Go ahead.

MS. DROUIN: Yes, the answer is yes.

Okay, Kevin Coyne unfortunately was sick. He really wanted to be here but --

CHAIR CORRADINI: But he found a way to get out of it. Is that what you are saying?

MR. RUBIN: He probably had a tooth extraction.

MS. DROUIN: No, he thinks he is coming down with chicken pox, so I don't think you all want him to be here. So please bear with me while I try and go through his view graphs.

When you look at the research plan on PRA, there is two major tasks in there and the first one is developing what we call review guidance to ensure that the applicant's PRA is of sufficient technical acceptability. Because again, we are now using PRA much more. So this is kind of similar to what we are doing in Reg Guide 1.200, you know providing the staff position on what constitutes a technically acceptable PRA for these kinds of applications for advanced reactors. And that is in the short-term.

And then in the long-term, is developing the PRA tools to support like the reactor oversight process. You know, once the plant is built and operating, you know, how do we bring risk in looking at the plant performance?

MR. KRESS: So when you say PRA tools, you mean an actual PRA.

MS. DROUIN: Right. You know, since we just went through the previous presentation and discussed the different options, I am going to skip the slides on the licensing strategy.

I told you they were two-task. On this slide, it is broken that first two-task. Because the first one in developing this guidance, it might be that we need to develop also in the short-term some methods, tools and data in order to develop the PRA. And then again the next task is developing the actual

PRA model, something akin to a SPAR model to be used.

Okay, let's try and go through each one of these. On the first task, notice it says develop this regulatory guidance. And in developing this regulatory guide, you know, what we are talking about is identifying the uses of the PRA because it is the uses of the PRA that dictate the kind of PRA you need.

You know, a scoping level PRA, depending on these, may be adequate or you may need something that is a lot more detailed. My point is is that you need to understand how the PRA is going to be used in determining what the scope and level of details of the regulatory guide. We will get into that. Identifying the uses, and then based on that the scope, and then what the technical elements.

Along with that, ASME has already initiated efforts on developing a PRA standard for the advanced reactors. Even though it is meant to be advanced non-LWRs, right now they are writing it in a technology useful perspective. And they feel that they can do that, even though it will be for advanced reactors. So that is where they are. And then once the draft guide is complete, you know, and after public review and comment, then ultimately this guide would be issued for use.

Now, I keep saying and I will just keep saying regulatory guide but it hasn't really been determined at this point in time if this will be a separate regulatory guide or is it more efficient and effective to modify Reg Guide 1.200. Those decisions have not been made. Right now it is going down a path with the thought of it being a separate regulatory guide but it is not clear where that will end up.

Now this task is very iterative with the development of the guide. Because as you develop the guide and you identify this is the scope you need, these are the technical elements you need, here are the attributes and characteristics you need from each of those, then you will be identifying areas where you may not be able to accomplish that.

So, it is that that is driving, you know, what our research should be so that we just don't go off and do research for the sake of doing research, which you know we all love to do sometimes. But the reg guide is laying the foundation for identifying what our research needs are in the PRA areas. But nonetheless, there are things that we know right now that we need to do. We don't have to wait for this regulatory guide and right here are listed, you know, some examples. PRA scope and radiological sources outside the core. Treatment of uncertainties. We know we are going to have to be doing work in that area. Passive component and system reliability. The impact of latent errors during the design. Human reliability analysis methods for advanced reactors could be a really big one also.

So these are areas that we have already identified and we are planning out but there could be a lot more that comes into play.

Now also, recognize that as we identify where we need tools, methods, and data to be developed, it may not all be internally to the NRC. You know, it could be that industry does part of this work. EPRI, for example, is very active in doing stuff. Both the ASME and ANS, they are already looking at where they can start doing some work besides just the standard that has the what to doing the how to.

So I do see this kind of as a collaborative effort, not an official one but you know, NRC working together with NRC, sorry, with industry in determining who is going to be doing what in developing the models, tools, and data.

MEMBER RAY: Mary, could you express an opinion on a subject we have talked about here several times at this meeting?

How do you think about the uncertainty of something that you cannot verify the integrity of as we do, say of light-water reactor pressure boundary through in-service inspection. Let's assume you don't have that ability. How would you go about thinking about the uncertainty with regard to the integrity of whatever it might be in one of these advanced reactors? You no longer have ability to verify this assumption that you made in the PRA.

MS. DROUIN: I think that is when you get over and you have to move outside of the PRA and you have to start looking at such things as safety margins, as compensatory measures you put in place, inspection. You know, I think you have to identify what your issue is.

MEMBER RAY: Too hard to answer in the abstract, then.

MS. DROUIN: No, I mean, I wasn't trying to use the word issue in an abstract way.

CHAIR CORRADINI: Are you asking for an example?

MS. DROUIN: No, all I was trying to say is that once you know where your concern is, without telling me a little bit of something, I can't say, well okay, here is where we should put safety margins or here is where we should put compensatory measures in place, you know, or here is where we should put inspections. You know, focus more on those areas. I mean, I think you do the best you can trying to understand where your uncertainties are. And I am not talking from a PRA perspective but trying to say if I had these margins, or if I had these measures, or these inspections, you know, I am doing it in such a way that it will get those things that I can't model, I can't evaluate, but I captured it.

MEMBER RAY: You know, I guess I was looking at there is a final policy statement on advanced reactors that is extant and it was referenced in the recent update or whatever was done.

But anyway, the point was that one of the mandates in the original version of this thing and I think still is applicable today is to maintain the earliest possible interaction of applicants, vendors, and the government agencies with the NRC. And this issue of okay, if you don't provide me the ability to verify this attribute, this is what I am going to have to assume about that attribute when I license the plant is really what I am trying to get at.

MS. DROUIN: Okay but --

MEMBER RAY: Is there any interaction going on in that regard?

MS. DROUIN: Once you have made an assumption, that assumption can be modeled in the PRA and that does become a source of uncertainty. And so now you can get an idea, you can get knowledge of how important, how risk-important that assumption is.

MEMBER APOSTOLAKIS: But I think your question is are we going to get involved in this?

MEMBER RAY: Yes, are people being made aware that you can't take credit for something that you don't have the ability to verify, at least periodically? That is the simplest way I can put it.

And because I have found that people do have a tendency to do that. They say well this is good because I made it good. No, I can't check it but it is good. Trust me. And I am trying to see if that kind of feedback that no, in this world, we are going to have to trust but verify and if I can't verify, I can't trust.

MS. DROUIN: Well I think, hopefully that will come out because when you look at the PRA standard, you know, which the NRC has endorsed. Now, right now, it is still in the operating reactors. But I would anticipate that this same thing would be for the advanced reactors and probably even more so is that you have to identify all those assumptions that you have made. And you have to identify resources of uncertainty and you have to document, you know, what is the importance of these. You have to characterize them all. And when we say characterize them, what kind of impact are they having?

So, you have taken credit for something and you don't know how well buzzed it is but you are taking credit in that model in that assumption, then you have to come back and tell me, you know, how is that source or that assumption affecting my model.

MEMBER RAY: Okay, that is good enough. I don't want to --

MS. DROUIN: No, I was continue, then this goes on into NUREG-1855, which then comes in and tells you how do you deal with this now in your decision-making. So, I mean, I do think it is covered through all of this. It doesn't do it right now but that is one of the things that we are looking at in the next revision of this NUREG.

And I think that your issue has some uniqueness to it that we don't have in the operating that we are going to have to address.

MR. RUBIN: Let me approach it this way

with an example. Pressure boundary. Pressure boundary is clearly a very important component in terms of potential dose consequence. Pressure boundary fails. The bigger it is, I think we saw some curves, the higher the dose.

Special treatments are really where we start to control the uncertainty, starting from the manufacture of the material to the how you weld, the design of it. You keep moving along. Inspection in the installation --

MEMBER RAY: I made it good. I made it really good.

MR. RUBIN: Okay but then --

MEMBER RAY: I did all the things I could.

MR. RUBIN: You did all the things you could. I said okay, I am still worried about this failing. Okay? Okay, let me think about leak detection monitoring systems. That is going to be a special treatment for that particular concern. You go on and on and at some point you say I have exhausted everything I can think of as a special treatment to account for those uncertainties and you still at the end of the day may not be satisfied as a regulator and you say I am still going to assume it is going to fail, at some point. And that is where the deterministic judgment is going to have to be applied.

MEMBER RAY: Yes, and my only question was as simple as saying, what I tried to make succinct before, which is, if I can't verify an attribute and it is an important attribute, then I am going to have to assume failure and I want you to know that right now.

MR. RUBIN: In principle, that is kind of how it plays out.

MEMBER RAY: Okay.

MEMBER APOSTOLAKIS: Or I may demand that the defense-in-depth --

MEMBER RAY: You know, that is -- I know but I didn't say anything about that, George. The point is though that I just wanted to get the answer I got, I think.

MR. KRESS: Now that we have got to interrupt, let me ask you another PRA question or maybe this is for George, or Louis, or maybe even Nathan.

CHAIR CORRADINI: An oral exam question?

MR. KRESS: Yes. In these advanced reactors, the next generation, we have a situation where failure probabilities of various parts are varying with time because they are ancient. You know, like the graphite changes. And you get things like even the fission product release model may be a function of time because of the irradiation effects on this stuff. But a PRA is supposed to give you, let's say a CDF or something or a dose or something that is sort of for the lifetime of a thing. It is not a point in time. It is for the lifetime but it gives you a CDF per year or a frequency per year but you just calculate the lifetime and divide it by the number of years.

Can PRAs handle these time variant failure rates in some way or how do you deal with those for the advanced reactors?

MS. DROUIN: Well you know, there is work that is being done in that area but I think that there are ways you can deal with it without having to have your model explicitly be a dynamic model.

MR. KRESS: You might take the worst of all of these and say okay, --

MEMBER APOSTOLAKIS: Well for current reactors, we are handling aging outside the PRA because the timescale is so much longer that we have all these problems.

MR. KRESS: Yes, that's right. Over the timescale.

MEMBER APOSTOLAKIS: I think we are going to do the same thing here.

MR. KRESS: Maybe.

MS. DROUIN: You know, I think there are ways in the interim to deal with it. You know, until we are at the point where we have a PRA model that does, you know, to the point that we would like it, a dynamic model.

MEMBER APOSTOLAKIS: By the time when this model will be presented here, this committee will not be the same. The presenters will not be the same. So this is way into the future in my mind.

MR. KRESS: Well, I am looking for acceptance criteria for the whole PRA set of sequences.

CHAIR CORRADINI: Are we on track or are we kind of doing this?

MS. DROUIN: We are off track.

CHAIR CORRADINI: You want to bring us back on track so that we can finish?

MS. DROUIN: Yes.

MR. KRESS: Anyway, maybe it is a thought.

CHAIR CORRADINI: I don't mean to stop you unless you want to answer them. Keep on going.

MS. DROUIN: Okay. I'm sorry, Mike. Were

you going to say something?

CHAIR CORRADINI: No, it just got bright.

MS. DROUIN: Okay. The last test that is discussed in the plan is to actually develop, you know, this baseline PRA and this is a longer term effort. I mean, this is a task that is meant to support the reactor when it has been licensed and built and is being operated. And now how do we evaluate its performance. So, this would be used for example to support a reactor oversight-type process. You know, potential uses would be prioritization of review and inspection activities.

Now in developing this scope and level PRA, sorry, we would extend, we would start with the scope and level PRA that was developed in the other task and expand it to be this plant-specific model, something akin to a SPAR model.

Now the technical acceptability and the resources of it is going to really depend on the plant-specific PRA model that was developed by the utility. You know, the better their model, then that means the better information and data that we have to input. So that would be, you know, this give and take situation there.

Okay, where are we? In terms of the

regulatory guidance, you know, we haven't started writing this regulatory guide at this point in time but there is work that is, as I said, being done by ASME in developing the standards and we are participating on the consensus committee and we are participating on the working group. So we are very much involved in the effort.

MEMBER BLEY: Do they have a schedule?

MS. DROUIN: I will not speak to their schedule because I think if you ask the schedule right now, there is now way they are going to meet the schedule. So right now they have a draft and it is out for internal review. But it hasn't gone to ballot.

I know Carl's view. He was head of the working group but for someone who has been on the consensus committee for ten years and know how it works, it is a couple years away. I mean, recognize that it took us four years to get the first draft issued of the PRA standard for the operating reactors just for the level one.

MEMBER BLEY: But it is not just focused on gas reactors. It is more broad.

MS. DROUIN: The intent is to support the advanced non-LWRs but they are writing it in a technology neutral way. But I am just saying the process of getting something through the standard consensus process, I can tell you there are at least, at least two years if not longer before it will actually be issued.

Tools, methods, and data, you know, at this point in time, there are no activities in progress but may initiate some task for advanced reactors and particularly in the area of HRA, you know, system reliability, you know, treatment of uncertainties. And this all depends on you know, the funding and the resources.

Support for the reactor, oversight process, of course there is no activities anticipated in 2009. As I said, this is a very much a longer term effort. And so that concludes that presentation.

CHAIR CORRADINI: Thank you.

MS. DROUIN: You're welcome.

CHAIR CORRADINI: Questions? Okay, let's move on to the sodium fast reactor.

MR. MADNI: My name is Imtiaz Madni and I am here to present to you a brief information briefing on the status of sodium-cooled fast reactors in the advanced reactor research plant and what are the future plans. I am trying to organize myself.

This is supposed to be a very short presentation. So, --

CHAIR CORRADINI: We might have a question or two, but good.

MR. MADNI: We don't have concrete long-term plans. We have what we have done and what are our near-term plans for this area.

The primary objectives for the SFR, sodium-cooled fast reactor, SFR. As part of the ARRP, which is the Advanced Reactor Research Plan, our first deed to conduct a top level, simplified initial technical infrastructure survey. And that would identify the safety issues ore areas and leading from the there the technical areas and R and D areas.

So, and that is why identify potential R and D for the technical areas. And I have listed the technical areas that I have identified already in performing this first part of the R and D objectives, which is thermal fluids analysis, nuclear analysis, severe accident and source term analysis, fuels analysis, and materials analysis.

So these are areas where you can see what are the gaps in knowledge that we have and what are the areas of R and D research that we can engage in. If you have questions, I can go into some details or maybe if I just move on.

MEMBER ABDEL-KHALIK: Why isn't instrumentation included on that list?

MR. MADNI: Pardon?

MEMBER ABDEL-KHALIK: Why isn't instrumentation included on that list?

MR. MADNI: This is a ver initial infrastructure survey. So this will be leading into a starting point for material R and D plans, which will come from a PIRT. You develop a PIRT and this is a long-term process. I mean, instrumentation is like the bells and whistles.

MEMBER ABDEL-KHALIK: I mean, wouldn't you expect, because of the nature of sodium, that you would need special instrumentation?

MR. MADNI: Oh yes, you would. But we are talking about the guts of the technology. How is the LMR technology different from light-water reactors? The instrumentation will be a byproduct of that, of course. Because the technology is different you need different instrumentation in areas. For example, sodium is okay and things like that. You need remote handling for many things.

So, those are areas are the areas where you are going into details. This is a very preliminary piece of work that we have done. Remember that as far as R and D for SFRs is concerned, in 2003, the ARRP had nothing on LMRs. Nothing. So in 2006 staff developed this first infrastructure survey which was top level. It is not the same level of detail as the full HTGRs. So, we should understand that part of it, that this is very, very preliminary.

MEMBER APOSTOLAKIS: I would add, however, the PRA and I will tell you why. Because you look at the third sub-bullet there, severe accident and source term analysis --

MR. MADNI: Yes.

MEMBER APOSTOLAKIS: -- the natural inclination would be to go back to what was done traditionally for --

MR. MADNI: CRVR and --

MEMBER APOSTOLAKIS: Yes, and then of course, you have the major problem there of energetic scenarios.

If you go to the PRA and look at it in conjunction with the technology inter-framework, the frequency is awfully low. The technology inter-framework says that if the point value is below ten to the minus eight, maybe you shouldn't look at it. Now of course, you guys always have the option of saying but we want it anyway. But it seems to me that it would help you guide a lot of this stuff if you did that.

MR. MADNI: This will come in the next step.

MR. RUBIN: Let me try and explain what happened here. The Commission direction was to a limited getting started with.

MR. MADNI: Right.

MR. RUBIN: So we had a one-person infrastructure assessment.

CHAIR CORRADINI: Is that your team?

MR. RUBIN: That is my team.

CHAIR CORRADINI: That is the team?

MR. RUBIN: That is the team. We had 16 people look at Agency GRs in-depth. So we had to --

CHAIR CORRADINI: Stu --

MR. RUBIN: No, I agree. But that is the infrastructure assessment is I agree with --

MEMBER APOSTOLAKIS: I am trying to be constructive. I am not --

MR. RUBIN: -- for the survey.

MEMBER APOSTOLAKIS: -- criticizing.

MR. RUBIN: But this would be the infrastructure.

MEMBER APOSTOLAKIS: It seem to me if you put there the PRA, you will help yourself. That is all I'm saying.

MR. MADNI: Looking at what happened to the previous presenter, I am glad I didn't put it in.

(Laughter.)

CHAIR CORRADINI: You have risen in my ranks.

MEMBER APOSTOLAKIS: I can see a lot of effort being spent on the energetic hypothetical.

CHAIR CORRADINI: The point?

MEMBER APOSTOLAKIS: The point is you shouldn't.

CHAIR CORRADINI: Okay.

MEMBER APOSTOLAKIS: I mean, if I believe the present PRA, which I may not be willing to do that to a large extent, but my God, so many things have to go wrong. The frequency is so low, I may want to do something about it but not the crazy stuff that was going on in the '70s where you paint a tank model and then this, and that, and details. You are spinning your wheels around something that may be practically impossible. Okay? Like the French are beginning to use those experiments. That is all I am saying is when you do list like that, it would be a good idea to have some guidance from the rationalist point of view. Okay? I know people are resisting rationality.

CHAIR CORRADINI: We are structurally different.

MEMBER APOSTOLAKIS: I know. That is why you have a problem.

MR. MADNI: One thing I wanted to mention, since that issue was raised --

MEMBER APOSTOLAKIS: But why is all these -- all I am trying to be constructive here.

MR. MADNI: I try to see if I am understanding what you are saying.

For PRA, you still need something. You need some formal modeling that will guide the PRA.

MEMBER APOSTOLAKIS: Yes.

MR. MADNI: I mean, PRA cannot be without your fundamental knowledge of the physics of the problem, otherwise, you just have a whole bunch of expert opinions and you can take it anywhere you want.

MEMBER APOSTOLAKIS: And so at the same time, you cannot just pick an event like the hypothetical CVA and say well gee here is something that I can make a reel out of. I mean, you need a back and forth, an iterative method that says you know, look at the system, go back to the details, go back to the system, and --

MR. MADNI: And this will involve, I think this, the area of the CDAs is going to be addressed when we go into the details of the infrastructure.

MEMBER APOSTOLAKIS: That is what scares me when you say you will address it. I don't know to what extent you are going to go and do it.

MR. RUBIN: My idea would be the next time we have 15 people to do what MTS did and that would be an area that needs to -- but I call that an assessment.

CHAIR CORRADINI: Even though I might not agree with all the stuff that George says, I think all he is asking you to do is that as you go through your limited scope of information gathering, I think this has got to be on your list.

MR. MADNI: Yes, actually PRA is --

MEMBER APOSTOLAKIS: You agree with everything I say. That is all I am saying.

MR. MADNI: But PRA is on our list but only thing is in an eight minute presentation, I have to contain it to what I want to put on the slides.

MEMBER BLEY: You could have saved seven.

(Laughter.)

MR. MADNI: All right. So, another aspect of the objectives is to implement a knowledge management program. Because of the last maybe 40 plus years of experience that the NRC has had in licensing and regulating nuclear power plants, it has been predominately focused on LWRs. And there is not much experience base in the LMR field.

MEMBER APOSTOLAKIS: You would be able to do it though because pretty good --

MR. MADNI: Yes, we have some experts who have had first-hand experience in the design and operation of LMRs and most of them are retired.

CHAIR CORRADINI: Or dead.

MR. MADNI: Or dead. We are trying to get these people as part of this program to come and give agency-wide seminars, have them video-taped, have white papers, --

MEMBER APOSTOLAKIS: What are you going to say, please come to Washington before you die?

(Laughter.)

MR. MADNI: We don't tell them that.

MEMBER APOSTOLAKIS: At the federal rates.

MR. MADNI: We have already three experts who have come.

CHAIR CORRADINI: Don't name them.

MR. MADNI: They are all over 65 and they are all very active but they may not be active for very long. So we need to capture that. We have to acknowledge that we have 47, 48 percent young engineers at the NRC.

MEMBER APOSTOLAKIS: Who is going to train them?

MR. MADNI: So this is a very important part of the SFR.

CHAIR CORRADINI: All teasing aside, I guess I do have a question. The OECD and NEA has an ongoing project on knowledge management and they are doing it not in a more of a crosscutting manner, where they are taking specific phenomena that are somewhat important regardless of reactor type.

Are you aware of what they are doing? Is NRC at least participating in that? Because I actually think the way they are doing it, they are initially trying to capture experiments and all data to related to the experiments and the open literature to create a database so those that can actually look and not lose what has been done 10, 20, 30 years ago. And it kind of meets in with what you are doing. I guess if you are not doing it, given your limits in time and your thing, that could be a very nice synergistic way to get some information.

MR. MADNI: Okay, let me to explain to you something about this.

CHAIR CORRADINI: Okay.

MR. MADNI: We had a small program for knowledge management, 200k. When we get a national lab for 200k, you don't get too many hours.

CHAIR CORRADINI: Well definitely don't use a national lab.

MR. MADNI: We got good work out of them. Very good work. I was working with them, so we got good work out of them.

I tell you what we got out of 200k. Number one, we managed to get 100 plus documents covering licensing area, and operating experience, test reactors, prototype, demonstration, whatever key documents there were that you could get, they are all a part of the knowledge center now.

Number two, we have a desk reference, it is a very neat document. It is a PDF format in which you can actually you have an index and you can just click on the index, it takes you to the page. And you have a lot of, a variety of documents that are old and new. It is a mixture. And you can see what is the finished experience, what is the experience at Fermi when we had the meltdown and stuff like that.

CHAIR CORRADINI: So you have done this already, to some extent.

MR. MADNI: Yes, that is number two. And number three we have these technical experts. We have three technical experts. Their plane fare, their coming here, their subcontracts to prepare white papers was included in that 200k.

MEMBER APOSTOLAKIS: Are these from Argonne?

MR. MADNI: Pardon?

MEMBER APOSTOLAKIS: Argonne National Laboratory.

MR. MADNI: You mean, who is my contractor for the knowledge management? Oak Ridge.

MEMBER APOSTOLAKIS: Oak Ridge.

MR. MADNI: And then we also developed a training plan for a five-day training course on LMRs. So, we are going to try to get some more funds so that we can continue this work. And I am going to mention some of this stuff on future plans that we have developed a proposal for.

And along with that, we also in a small way are interacting with DOE in technical activities related to the ABR, Advanced Burner Reactor, and interacting with Toshiba and their partners whenever they have come to make presentations on the 4S.

CHAIR CORRADINI: Are you considering what things you want to look at versus fuel tank?

MR. MADNI: Pardon?

CHAIR CORRADINI: Are you considering what things you want to look at or gather information based on fuel type, whether it is oxide or metal?

MR. MADNI: Both. Both because metal has its own advantages, oxide its own advantages. For metallic fuel, you have a lot of advantages in terms of negative feedback. Axial expansion, radial expansion, all those things that it is more susceptible to.

And also the LMR design is very susceptible to shape of the design and all of that. Like for example, sodium void can be a serious problem for a very large reactor. But if you make that reactor skinny, then you have the predominant effect is leakage. And so you have actually a negative effect of sodium void.

So, you can really manipulate the effects based on -- so it is very sensitive to the shape of the design.

Anyway, so that is the R and D objective. Background --

MEMBER APOSTOLAKIS: Have you heard from any vendors that they might come some meeting assigned to you guys?

MR. MADNI: Pardon?

MEMBER APOSTOLAKIS: Has any vendor, have any vendors expressed interest in some meeting design, an SFR design for certification?

MR. MADNI: Well the initial attempts, yes. Yes, in the initial stages but we don't know where it is going to go. We are not in a position to be able to determine that. It is both for the AVR and for the regular SFR.

We have had Toshiba come to the NRC to make presentations on the 4S design but it is a very initial stage.

MEMBER APOSTOLAKIS: Has GE come here at all?

MR. MADNI: No. No, no. Because we have not, I don't think any decision has been taken as to what kind of design we are going to have for the MER. We don't know.

MEMBER APOSTOLAKIS: But GE is pushing its own design, the S-PRISM.

MR. MADNI: Yes, I know, S-PRISM --

MEMBER APOSTOLAKIS: Did they come at all here to say that you know, --

MR. MADNI: No because we have only two programs right now. One is the advanced recycling initiative and the other is the 4S design that is being presented. But we don't really have an active GNEP or GN4 program that is going to --

MEMBER APOSTOLAKIS: But if they come, you will because the Agency responds to those things.

MR. MADNI: Yes, they haven't come yet.

MEMBER APOSTOLAKIS: They haven't come.

MR. MADNI: They haven't come yet.

MEMBER APOSTOLAKIS: Okay.

MR. MADNI: All right. This is basically, this slides talks about the properties of sodium and how they influence the design of the LMR and the operation and the advantages of the LMR. I don't know if you want me to go through this. Skip? Okay.

LMR very compact core.

CHAIR CORRADINI: Next slide.

MEMBER APOSTOLAKIS: Electronically, we have to see the slide.

MR. MADNI: Okay. Now this is talking about what we have already done based on the R and D objectives that I had in the earlier slide.

CHAIR CORRADINI: So, just to clarify.

This knowledge management project that you did with Oak Ridge that developed these references, this is all for sodium fast reactors?

MR. MADNI: All for sodium.

CHAIR CORRADINI: Okay.

MR. MADNI: All for sodium. In fact, if you look at the LMR experience that the United States has, the very first reactor was a research reactor which was Clementine and that was using liquid mercury. After that it was EBR-1 which used sodium-potassium mixture. And thereafter, it has been all sodium not only in the United States, but all over the world it has been sodium, without exception.

MEMBER APOSTOLAKIS: So this Toshiba plant, is that real, they plan to come here or is it just we might?

MR. RUBIN: We have received letters from Toshiba expressing their intent to submit a design certification application for a 4S reactor.

We have had several meeting with them where they have gone through the design description and the safety analysis and details of various components in what you would call pre-application review. Recently we informed Toshiba, as we did others, that because of limited resources, we would only be able to engage in the future to a limited extent. And so at this point, it is on a shelf to do that design certification.

MEMBER APOSTOLAKIS: But they have not indicated --

MR. RUBIN: They would like to do it, we cannot accommodate them.

CHAIR CORRADINI: Is that because, as the last time we had a discussion about this, I think the Commission asked some questions and it was because of no customer. But Toshiba, is Toshiba willing to pay the needed -- I mean, for a certification you are going to have to have some sort of this is not going to be -- reimbursement, thank you. I didn't want to use the money word but money. So, a fee.

So, Toshiba is in a position that wants to proceed with that, regardless?

MR. RUBIN: Do you want to speak to that, Tom?

MR. KENYON: I'm sorry, I didn't hear the question. We were just --

MR. RUBIN: Our situation, vis-a-vis Toshiba 4S, where are we today?

MR. KENYON: Well, we have a letter of intent from Toshiba that they are coming in in fiscal, I think fiscal year either the end of 2010 or beginning of 2011. And if they come in with a design certification application, then we will assign appropriate review staff to take a look at that. It has to do with how the resources are allocated, whether or not there is a C of O applicant interested in building the design.

I'm not sure what the Commission would do if they come in with a national design certification. If they do, that means that they --

CHAIR CORRADINI: You don't what the Commission would do if they what? I'm sorry.

MR. KENYON: If we actually do receive the design certification application.

CHAIR CORRADINI: Meaning you wouldn't be ready for it.

MR. KENYON: No, I don't -- we are looking into that right now and whether or not we need to get ready for it.

CHAIR CORRADINI: Okay. Thank you. Thank you.

MR. MADNI: All right. Next one.

Here is a list of key safety issues associated with SFRs that need to be considered when we are reviewing these designs. The first is the performance of passive decay heat removal. Is it enough? Do we have adequate decay removal, in case you don't have any pumping power to remove the decay. And that is an area that we need to do some R and D.

And the other one is the proof inherent reactor shutdown characteristics.

MEMBER APOSTOLAKIS: You know, you just said the magic words. I would change the title of this SFR R and D areas. These are not safety issues. The are affecting safety but they are not safety issues. The designer will come back and say I do have heat removal capabilities.

MR. MADNI: Actually the R&D are going to come out of these.

MEMBER APOSTOLAKIS: I know, but for communication purposes, I would change the title. These are interesting stuff for you to explore.

MR. MADNI: A proof of inherent reactor shutdown characteristics. This is for example, you have let's say heat up of the core and there is no safety mechanism. And then all of a sudden you find the Doppler feedback and you have the expansions and all of that and then you find the reactor shutting itself down. So that is a very important part of the safety of LMRs. It comes from more nuclear analysis, this one.

CHAIR CORRADINI: With only a certain sort of fuel.

MR. MADNI: Huh?

CHAIR CORRADINI: FFTF could not demonstrate that above 20 percent power. EBR-II demonstrated full power. So I mean, the fuel type does matter.

MR. MADNI: Yes.

CHAIR CORRADINI: Okay.

MR. MADNI: The presumed design and the safer design they were designed to overcome some of the shortcomings that they observed in CRBR and FDF. EBR-II was remarkable experience, truly remarkable, 30 years of wonderful experience.

Sodium-water and sodium-air reactions are important safety issues because if they there is any leakage in the tubes or the steam generator, then you have interaction of sodium and water and it is explosive. It is very highly exothermic.

CHAIR CORRADINI: Do you have any bilateral agreements with France before they shut down PHENIX in 2009 to get -- because of any group that has an enormous amount of experience relative to sodium-water and sodium-air interactions it is CEA or I should say EDF and CEA for PHENIX. Are there any bilaterals that you can exchange information in this regard?

MR. MADNI: See because again this is an initial attempt so I have listed at the end of --

CHAIR CORRADINI: Oh, okay, fine.

MR. MADNI: -- one of my slides establish collaborations internationally.

CHAIR CORRADINI: Okay, thank you.

MR. MADNI: And I mentioned I think the four experimental test facilities, one of them is PHENIX. So we need to do all of that. I appreciate your comment because we can put down that one area of focus.

And sodium-air reaction is not as violent as with gasoline. Gasoline will burn four times as fast as sodium in air but nonetheless, it is an external reaction.

So, for sodium-water, you need --

CHAIR CORRADINI: Let her put hot sodium in a room with air versus hot gasoline, I think --

MR. MADNI: No, light gasoline.

CHAIR CORRADINI: Oh, light it. Excuse me. You don't have to light sodium. It just kind of goes on its own.

MR. MADNI: That's true but if you see a gasoline fire and you see a sodium reacting with air, it is not as violent as the gasoline that is burning.

MEMBER APOSTOLAKIS: In any case, it doesn't look good to the public. You don't want that. I think that is in fact why Super PHENIX was shut down it was minor leaks. It was a difficult decision to shut it down because they were not safety issues.

MR. MADNI: The sodium-air reaction, that is the reason we have the guard vessel and the we have the inner gas cover and all of that.

And sodium-water, we have mostly double boil tubes for the steamer a little bit good inner gas leaking. And we also have leak detection.

Core melt prevention mitigation, the only point I would like to mention here is that because the fuel of an LMR is highly enriched, maybe up to 20 percent, it is not in the most critical arrangement. So if you have relocation of fuel, you could end up with a super critical mass of fuel.

CHAIR CORRADINI: That is low probability.

MR. MADNI: But you have to make sure that you have enough evidence of safety from that point of view.

MEMBER APOSTOLAKIS: Yes, there has been a lot of work on that.

MR. MADNI: We have had a lot of integral tests in our own facilities but now we will have to look to others.

CHAIR CORRADINI: So I have a question that I know you are going to say you don't have time or money for but since the Agency developed it and the French and the Germans have honed it to a fine thing, where do you send relative to the SIMMER code for these sorts of analyses? It was developed here, shipped to Germany and France and now they are using it totally for their safety codes.

MR. MADNI: Well, the original SIMMER were developed in 1982 by I think it was --

CHAIR CORRADINI: Jay Boudreau, Mike --

MR. MADNI: Los Alamos.

CHAIR CORRADINI: -- Stevenson.

MR. MADNI: Then SIMMER-I was also developed by Los Alamos, an improvement. Then the SIMMER-III and SIMMER-IV. These have been by international collaboration.

CHAIR CORRADINI: Well mainly Peter Royl at KFK.

MR. MADNI: Yes, it is also Japan. Japan, France and Germany are joined together and they have actually developed SIMMER-III and SIMMER-IV.

CHAIR CORRADINI: So is there a bilateral that you have access to those tools?

MR. MADNI: This is one of the areas I want to pursue because we must get the codes in-house. This is one of the things we must do. We must get the codes in-house.

CHAIR CORRADINI: Okay, thank you.

MR. MADNI: Fuel performance, thermal stresses and fatigue in piping and components. My survey did not focus too much on fuel performance and the other one. That would come later on.

And the amount we had, I put something for fuel performance as well as thermal stresses and fatigue due to high temperatures. What is it, creep behavior and so forth. But this requires some more effort.

This is a slide that shows a summary of LMR experience in the U.S. I don't know if you want me to go through it.

CHAIR CORRADINI: Skip.

MR. MADNI: This is world experience.

Okay, the U.S. has not operated an SFR for over ten years and has not designed and constructed one for almost 30 years. So in order to get back to where we were, we need to redo the infrastructure. We have lost a lot of the capabilities. Most of our test facilities have been shut down and they cannot be started up. The only one that we can think of starting up, which is a substantial facility, which is FFTF. If that one can be started, because it has not been completely put out of commission like EBR-II.

TREAT, yes, TREAT is fine.

MEMBER APOSTOLAKIS: Your interest should be in the regulatory infrastructure.

MR. MADNI: Technology.

MEMBER APOSTOLAKIS: Tell me you don't care what the industry out there does. Maybe it has to design something.

So what you really care about is that this Agency does not review the design --

MR. MADNI: Actually that is not that.

MEMBER APOSTOLAKIS: That is true.

MR. MADNI: It is not 30 years -- 30 years we have not designed itself but we have reviewed designs that have been with GE and Rockwell International. SAFR and PRISM.

MEMBER APOSTOLAKIS: Yes.

MR. MADNI: We have PSERs for both of them. NUREG-1365 and something like that.

MEMBER APOSTOLAKIS: Right.

MR. MADNI: Yes, so we do have design reviews.

MEMBER APOSTOLAKIS: I was in fact surprised that it is only ten years, ten, twelve years since a NUREG was issued.

MR. MADNI: Well we have not constructed any LMR for the last 30 years.

CHAIR CORRADINI: Let's keep on.

MEMBER APOSTOLAKIS: We have to say something, Mr. Chairman.

MR. MADNI: So, EBR-II, FFTF and TREAT we already talked about. Most integral facilities are outside the U.S., PHENIX, the one you mentioned, JOYO, BOR-60 and FBTR test reactor in India.

Several test programs have been and are being carried out in these facilities. Collaborations to make use of their facilities, I mentioned that here and also collaborations to get data from them. That is another bullet that I have added for my own self.

So this is something that we are going to address. We just don't have the funds right now to work on this.

This is something about what we have accomplished in the knowledge management program, which we talked about.

We have developed plans for additional work and once that is available, we will continue to get more experts and record their experiences before it becomes too late. So that is another one. And also develop a complete course content for a five-day LMR training course.

This could be very interesting part of talk, this knowledge management.

Potential next steps for R and D activities. If the NRC technical review priorities increase, then we will go into conducting a detailed in-depth infrastructure survey and assessment with a PIRT to provide the basis for development of a detailed R and D plan. And the R and D plan again will be in these areas, at least, the ones that we have identified and others like is on PRA, whatever else we can put in there. And this will be to support regulatory activities, including evaluation of technical bases of the applications that we get in the future.

And we will increase the interaction that we already have with DOE and vendors. And then I have also mentioned evaluate existing models and analytical tools, super system code series, if your member that was developed in Brookhaven National Lab. Super System Code --

MEMBER APOSTOLAKIS: Which national lab?

MR. MADNI: Brookhaven National Lab. That one right now we have versions of Super System Code used in Korea, Germany, and other places. So it is mainly systems analysis --

CHAIR CORRADINI: So that is five --

MR. MADNI: Coolant.

CHAIR CORRADINI: Two contained.

MR. MADNI: Exactly. It is not parameter. Yes, it is a systems code, yes.

It has been modified, upgraded, and has been used extensively in writing up the PSER for PRISM. If you look at the safety evaluation report for PRISM, you find a substantial section on calculations done by a Super System Code.

This Super System Code was developed by our group when I was at Brookhaven. I worked on LMRs in the 1970s, so that was ages ago. After that I have lost it and coming back.

SASSYS and SAS4A, these were developed by, I believe, Argonne. SASSYS was mainly for the systems and SAS4A was for the ACDAS. A hypothetical core to sub-reactions.

And then the SIMMER. SIMMER is we talked about it already. And then of course, developmental needs for validating these capabilities. More test facilities and so forth. So that is what I presented and what I was supposed to give you in eight minutes. I don't know how long it took.

CHAIR CORRADINI: A bit longer, but okay.

Questions from the committee?

MEMBER APOSTOLAKIS: I have asked all my questions.

CHAIR CORRADINI: Thank you very much.

MR. MADNI: Thank you.

CHAIR CORRADINI: So, just to wrap up, Stu, did you want to say anything as a wrap-up? Otherwise, I would like the committee to comment.

MR. RUBIN: Just that we appreciate the opportunity to come and talk to you and part of it is to introduce you to what we have learned in the last year or so and to get feedback from you, which we have. We anticipate we will be seeing more of you in specialized groups.

CHAIR CORRADINI: I guess that is why I wanted to ask. So, from a guidance standpoint, given what we had, which is a two-day kind of run-through of the research plan as it is now in the current draft, is it does staff want to see a letter with some opinion about the research plan as we have it or does staff have more detailed in-depth discussions about certain aspects of the plan or certain research topics?

MR. RUBIN: Well I think we have plans to meet with the full ACRS in March or April time frame.

CHAIR CORRADINI: Yes, March or April time frame.

MR. RUBIN: And if that is the context of a letter, I think we would very much like to have a letter coming out --

CHAIR CORRADINI: You would?

MR. RUBIN: -- to the full committee, yes.

CHAIR CORRADINI: On the plan as been delivered.

MR. RUBIN: As the plan as you have read and been briefed on it now and then will be briefed in a more compact way to the full ACRS.

So, we would very much like to have communicated your views on if we are going in the right direction, the right pace, very specific things that you think we need to focus on or not focus on.

CHAIR CORRADINI: Okay.

MR. RUBIN: The usual.

CHAIR CORRADINI: The usual.

MR. RUBIN: But be sure the Commission has told us to get started and we are into our third year. They said in 2007 you need to get started. We didn't get started. '08 --

CHAIR CORRADINI: And December 31st.

MR. RUBIN: But certainly a technical assessment of what we are doing is very good.

CHAIR CORRADINI: All right. With that as at least the framing, I would like to go around and get people's opinions. Dennis.

MEMBER BLEY: The two days' presentations were excellent. And I think the only real strong things for me is it is such a gigantic catalogue of things to do, there needs to be structure in several ways. One is structure in the timeline of how this is all going to fit together in identifying the key places where it can get jammed up. And the other is structure and it is probably, it ain't some probabilistic thinking to really start at the lower level identifying priorities, the key issues that you have really got to wok on because it is, what was mapped out is more than can possibly be done, it seems to me.

MEMBER SHACK: I guess my reaction is

similar to Dennis's. You know, I think the high-level plan is very good. I just, you know, the schedule to support the licensing seems impossible to meet. I think you need a more specific concrete design in order to prioritize just where you are going. But it seems to me as a conceptual design, you know, in looking over and obviously taking the PIRTs and working with them, it is just a good start. You really need a customer with a more specific design, I think, to focus in.

MEMBER ABDEL-KHALIK: I fully agree with the comments made. My biggest concern is the schedule. 2013 is just, it just doesn't seem too realistic.

And you need to specifically develop detailed sort of timelines to prove to somebody that you can actually do it within the time frame that you think you are going to be doing it.

MEMBER BLEY: Or see why you can't and be able to readjust.

MEMBER ABDEL-KHALIK: Right.

MR. KRESS: I thought the program plan was very comprehensive. And it did show to me that the staff has a good grasp on the issues and the phenomena and I think they deserve kudos for it. I agree with the fact that it may be too comprehensive and needs to be, you know, it would help to have a specific design, but I think it is an excellent piece of work and a good start.

I have some specific other comments. I don't know if you want them now or if you want them later.

CHAIR CORRADINI: Well you are going to send us a report.

MR. KRESS: I will send you a report.

CHAIR CORRADINI: And Maitri and I will pass it on to all the members --

MR. KRESS: Okay, good. I will do it that way.

CHAIR CORRADINI: -- in anticipation of our full committee meeting. Okay?

MR. KRESS: Okay, I will have those to you maybe tomorrow or Monday.

CHAIR CORRADINI: You know, you can take the holiday off if you want to.

MR. KRESS: I don't take holidays.

CHAIR CORRADINI: Harold.

MEMBER RAY: I am going to repeat what I said earlier and I also endorse what has been said by others already. It seems to me like the rather than despair over the magnitude of the work and the short time available and the limited resources, I guess I am focused on, in order to make this work, it is important to become more specific sooner rather than later because the subject matter is so broad, that I just don't think the resources to explore the full range of everything are going to be available.

So, if you want to get the thing done, then it really needs to be driven by some more clarity, greater clarity about what exactly is it that we are trying to accomplish with some specifics. But at that point, I think it is essential that the NRC have a plan to, as the policy statement I referred to says, to engage with the applicant because we are in a new area here with a lot of questions that I would hate to see us trying to band-aid after it was too late to do something different than what had been decided on.

And that was really the motivation for a lot of my comments was that it is possible to do something, if you do it soon enough, perhaps, but as time goes on, then we later on find well we have got to create some solution because there isn't any alternative at this point in time.

With that, I will stop. And I don't know how to articulate that but we will work on it, I am sure after the full committee.

CHAIR CORRADINI: Dr. Apostolakis.

MEMBER APOSTOLAKIS: The views that have been expressed bound my views.

CHAIR CORRADINI: Okay. So I want to --

MEMBER APOSTOLAKIS: A best estimate, however.

CHAIR CORRADINI: You want to say something now? I wanted to take it one more place, but go ahead, I'm sorry.

MR. RUBIN: If I could just respond to everything that has been said here, you have to look at what we are doing in the context of the licensing strategy. The licensing strategy does talk about, can we be more specific about the design, which is going to help us narrow what we are doing. The second big step is pre-application review, which starts in 2010, where we will have that very much more specific design information and dialogue which will help us move faster and more specifically and we have three years in the pre-application review to really start to ramp up our specificity and speed of getting to be where we need to go. And then licensing review.

So, we don't anticipate staying at this

fuzzy level until the license comes in. We are going to ramp that up. At the same time, the number of resources we have specified in the licensing strategy, allows us to staff up. You will have more people in these areas, as defined by the resources to implement the licensing strategy and that includes research. So it will become more specific and we will have more people in each of these areas to get the job done.

CHAIR CORRADINI: So, I would like to clarify one thing on that though, Stu, just so I understand. So what is going to change and when, approximately, but what is going to change in 2010 that takes it to that next level. Is that the three-point designs? And is Jim here?

I guess I need some -- because my next question to the committee before I lose some people to travel is when we get together again, what should we get together for? That is, should we get together for a specific research topic, such as fuels? Should we get together for a specific discussion about what are the range of the commonalities of the design from the three groups working with the DOE and the INL? What is next and, looking head, I would want to couple it to what you expect to be there in 2010.

So, what do you see as different from the

DOE side that is going to take you to this next level of pre-application?

MR. RUBIN: Well in terms of the next time we meet, it will be after the ACR span. The ACR span will be where we are today, in terms of what we are doing, resources, what we know.

After that, we will then have a decision, hopefully at some point in time and we will become more specific and we will be able to accelerate and whether it be --

CHAIR CORRADINI: So there will be a point design? That is what you think is the change --

MR. RUBIN: The strategy talks about one design.

CHAIR CORRADINI: Now I am going to turn to the other side. By 2010 will there be a design?

MR. KINSEY: The current direction of the DOE -- well first of all, backing up to the licensing strategy, it describes the fact that the typical LWR pre-application period is generally two years. They recognize that there will be more and different challenges in this regime. So that was expanded to three years. And as Stu mentioned, that period runs from 2010 to 2012.

The way we are working within the DOE,

INL, and NRC space, is trying to use 2009 wisely so that we can identify issues and be moving forward so that when a point design, one or more point designs are selected, they will be well down the paths so that they can use the 2010 to 2012 pre-application period efficiently.

CHAIR CORRADINI: So can we just back up a little bit there?

MR. KINSEY: Yes.

CHAIR CORRADINI: You changed the verbiage from one to one or more. Can you --

MR. KINSEY: The --

CHAIR CORRADINI: -- expand on that? Because I want to make sure you two are on the same page because I don't want to --

MR. RUBIN: We are working against a licensing strategy.

MR. KINSEY: The licensing strategy document has an assumption that there will be one design and that it will be selected in March of 2009. So the schedule and the resources that are described in the strategy are based on those assumptions.

CHAIR CORRADINI: Okay.

MR. KINSEY: And in actuality, the DOE --

CHAIR CORRADINI: Okay, that is the

actuality. I want to understand that.

MR. KINSEY: The DOE in the relatively near term is going to be putting out an offer of financial assistance to the industry. It is unknown at this point what number or level of responses will be received. It is expected there will likely be more than one response. Obviously it hasn't been determined yet how many of those responses may be accepted but there is a potential for more than one to be accepted that would allow the agencies to pursue more than one design, recognizing that if that path is chosen, there will need to be an adjustment in resources and schedule, potentially.

MR. RUBIN: And at that point, we would have to go back to the Commission with the new proposal and we will see what kind of guidance we get, in terms of reviewing two designs, getting ready for two designs, resources, for more designs. And right now our plan and our success is geared toward one design. Decision this year. Three years to get engaged. And on that basis we are confident we can get it done.

MR. KINSEY: And again, in the very near term, we are working to try to focus on activities where, you know, in the past couple of months and in the next couple of months where the design isn't critical, we are getting issues on the table so we have common knowledge of the issues and challenges, understanding that quickly and soon we need to select the design so that we can focus those efforts.

CHAIR CORRADINI: But quickly and soon won't be March and when it is, it may not be one. So, I still see something like that in terms of where your current expectation is and where your guys are going. Am I misunderstanding?

MR. RUBIN: If that were to come to pass, then our schedule and success would be highly at risk --

CHAIR CORRADINI: Okay.

MR. RUBIN: -- to say the least.

CHAIR CORRADINI: Other comments from the committee?

All right. What I will try to do is write up what I heard and send it to Maitri for a proper cleaning and then send it out to everybody so you can get a feeling. So as we come up to the potentially March or April for the letter which you are requesting, we will be on, hopefully we will be on the same page.

All right, thank you very much.

MS. BANERJEE: Public comment.

CHAIR CORRADINI: I'm sorry? Oh, public. I apologize. Are there members of the public who want to make comment? Excuse me. Going once, going twice.

Okay. Thank you very much. Meeting adjourned.

(Whereupon, at 4:12 p.m. the foregoing matter was adjourned.)

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Neutronics Analysis to address Out-of-Reactor Issues for NGNP

Mourad Aissa
Office of Nuclear Regulatory Research
January 15th, 2009

Non-Reactor Safety R&D Objectives

- Validate nuclear analysis tools to address out-of-reactor material safety and safeguard review associated with onsite storage, transport, and disposal of HTGR spent fuel and irradiated graphite.

Safety Issues

- Ensure subcritical conditions for commercial nuclear material with could have significantly higher U-235 enrichment than the current 5 wt%

- Ensure radiation-shielding methods address issues unique to HTGR systems

Planned R&D For NGNP Out-of-Reactor Safety

- Adapt and validate SCALE code system for the analysis of storage of HTGR spent fuel and irradiated graphite.

- Address waste management issues related to storing HTGR fuel onsite.

Planned R&D – Area 1

- Extend sensitivity and uncertainty capabilities to address burnup of 80 to 150GWD/MTU for HTGR fuel.
- Enhance radiation-shielding methods and data to address issues unique to HTGR systems.
- Enhance nuclear data processing methodology for HTGR systems including graphite specific issues that continue to arise because of the difficulty in handling the unique scattering characteristics of graphite (crystalline structure with lots of coherent scattering)

Planned R&D - Area 1

- Identify criticality safety issues of fissile system with graphite, and develop guidance on handling of fuel with enrichment greater than 5 wt%

- Adapt SCALE for the analysis of fuel with enrichment greater than 5 wt% and validate against relevant data.

Planned R&D – Area 2

Adapt and validate SCALE for the analysis of storing HTGR spent fuel and irradiated graphite onsite.

- Engage in international experimental programs on HTGR spent fuel and irradiated graphite, review inter-comparison studies, and work to stay engaged with potential international data-gathering activities (IAEA, OECD, South Africa, China, etc.).
- Characterize HTRG spent fuel (vs. LWR spent fuel) and irradiated graphite, identify/justify areas where more work is needed and/or more experimental data will be required for onsite storage of HTGR spent fuel and irradiated graphite.

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Advanced Reactor Research Plan for Digital I&C

Including Advanced Process Monitoring

Paul Rebstock
Office of Nuclear Regulatory Research
January 15, 2009

DI&C Research Objectives

To develop the regulatory infrastructure necessary to support the review of new and advanced reactor applications

- Including
  - "glass" control rooms
  - Un-reviewed technologies such as Field-Programmable Gate Arrays
  - Advanced sensors
  - Advanced control paradigms
- Also applicable to plant upgrades

DI&C Technical / Safety Issues

- Process sensors and modeling for new parameters and for extended ranges
  - 3D time-at-temperature mapping
  - 3D flux mapping
  - High temperature/pressure gas mass flow
- Challenging environmental conditions
- Advanced reactor control schemes, including multi-module control

Planned Areas of DI&C Research

(serving both Advanced Reactors and New Reactors)

- Advanced Reactor Research Program Section activities have been condensed to three key areas:
  - Advanced Instrumentation
  - Advanced Controls
  - Advanced Diagnostics & Prognostics

Advanced Instrumentation

Objective: to provide technical information to the NRC staff and to develop regulatory acceptance criteria for advanced reactor instrumentation

Status: work to begin in FY09

Advanced Controls

Objective: to review advanced reactor control designs and determine if applicable regulatory guidance is adequate or needs improvement

Status: work to begin in FY09

Advanced Diagnostics and Prognostics

Objective: to investigate issues arising from the integration of Advanced Diagnostic & Prognostic (AD&P) facilities into nuclear power plants, including impact on regulatory requirements and approaches to digital system quality assurance

Status: work to begin in FY09

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Protecting People and the Environment

Advanced Reactor Research Plan for Graphite Materials

Dr. Makuteswara Srinivasan
Office of Nuclear Regulatory Research
January 15, 2009

Presentation Plan for Graphite Research

1. Objectives
2. Background
3. Status of Code and Standards Activities
4. Review of NGNP Graphite PIRT Results
5. Current Research Activity
6. Future Plans
7. Summary

Graphite R&D Objectives

- Develop scientific information to establish independent technical bases for regulatory and safety decisions on graphite and composite materials used in HTGRs; address uncertainty in behavior of graphite under HTGR environments.
- Use research results to confirm materials specifications, codes, and standards and to provide information and data for NRC HTGR EM (graphite dust) and for evaluating HTGR PRAs.

Background

- The lack of Codes and Standards for HTGR nuclear graphite components has been a significant technical issue.
- During FY 2002 – 03, NRC contracted ORNL to:
  - Organize and facilitate a working group under ASME to develop graphite codes and standards for HTGRs;
  - Organize and coordinate the ASTM Nuclear Materials subcommittee to develop graphite material specification and test standards for properties important for HTGRs.

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Technical Considerations for Codes Specific to Graphites for HTGRs (ASME)

- Dimensional Stability (Affects Core Geometry and Ability to Insert and Withdraw Control Rods/Fuel Elements)
- Service Stress in Relation to Graphite Strength and Strength Distribution, Probabilistic Brittle Materials Design
- Prevention of Fracture During Reactor Operation
- Fatigue Limit
- Creep Limit
- Degradation and Life Limitation Due to Oxidation (Chemical Reaction) (Criterion For Replacement)

ASME Graphite Code Development Current Status

- Scope of the ASME SC III SG on graphite core components
  - Establish rules for materials selection, design, fabrication, installation, examination, inspection, and certification of graphite core components, reactor internals and fuel blocks.
- Majority of members are based outside the U.S.A.: France, Japan, Korea, South Africa, the United Kingdom.
- Half of its meetings are held outside the U.S.A.
  - Reflects ASME Nuclear Codes & Standards’ endeavor to meet the needs of stakeholders worldwide and draw their expertise into the code development process.

ASME Graphite Code
Current Status of Draft Development

Article	Subject	Status
X000	General Requirements	*Under development*
1000	Scope and Boundaries of Jurisdiction for Components	*Completed*†
2000	Materials	*Completed*†
3000	Design	*Under development*
4000	Machining and Testing	*Completed*†
5000	Installation and Examination	*Completed*†
8000	Certificates and Stamping	*Completed*†
9000	Glossary	*Under development*

† draft being reviewed by subgroup and under balloting

ASME Graphite Code Current Status

All are currently under development. First consideration of significant portions expected by December 2009.

Appendix	Subject
Appendix-1	Graphite Material Specifications
Appendix-2	Creation of a Material Datasheet
Appendix-3	Generation of Design Data for Graphite Grades
Appendix-I	Graphite as a Structural Material
Appendix-II	Irradiation Damage to Graphite
Appendix-III	Oxidation and Its Effects on Graphite
Appendix-IV	Recommended Practice for Stress Analysis of an Irradiated Part

Nuclear Graphite Specifications
ASTM

- Purity and Chemical Composition
- Physical Properties (Density, Helium Permeability, Oxidation Weight Loss Due to Radiolysis, Air-and Water-Ingress)
- Thermal Properties (Thermal Expansion Coefficient, Thermal Conductivity)
- Mechanical Properties (Young's Modulus, Strength, Strength Distribution, Fracture Resistance, Wear and Erosion Resistance, Effects of Oxidation)
- Degree of Anisotropy

Summary of the NGNP Graphite PIRT (April 2007)

Summary of the Number of Phenomena Affecting Each Figure of Merit (FOM)

"Figure of Merit"	No. of Phenomena
Ability to maintain passive heat transfer	22
Maintain ability to control reactivity	25
Thermal protection of adjacent components	22
Shielding of adjacent components	11
Maintain coolant flow path	23
Prevent excessive mechanical load on the fuel	14
Minimize activity in the coolant	19

Overall Summary of Phenomena Contributions to PIRT Rankings for Graphite

Phenomena Ranked as High Importance and Low Knowledge (I-H, K-L)

1. Irradiation-induced creep (irradiation-induced dimensional change under stress), leading to fuel element/control rod channel distortion/bowing.
2. Irradiation-induced change in CTE, including the effects of creep strain, leading to fuel element/control rod channel distortion/bowing.
3. Irradiation-induced changes in mechanical properties (strength, toughness), including the effect of creep strain (stress), leading to graphite fracture.
4. Graphite failure and/or graphite spalling leading to blockage of fuel element coolant channel.
5. Graphite failure and/or graphite spalling leading to blockage of control rod channel.

Overall Summary of Phenomena Contributions to PIRT Rank for Graphite

Phenomena Ranked as High Importance and Medium Knowledge (I-H, K-M)

Current external research is expected to provide adequate information for regulatory needs for these phenomena:

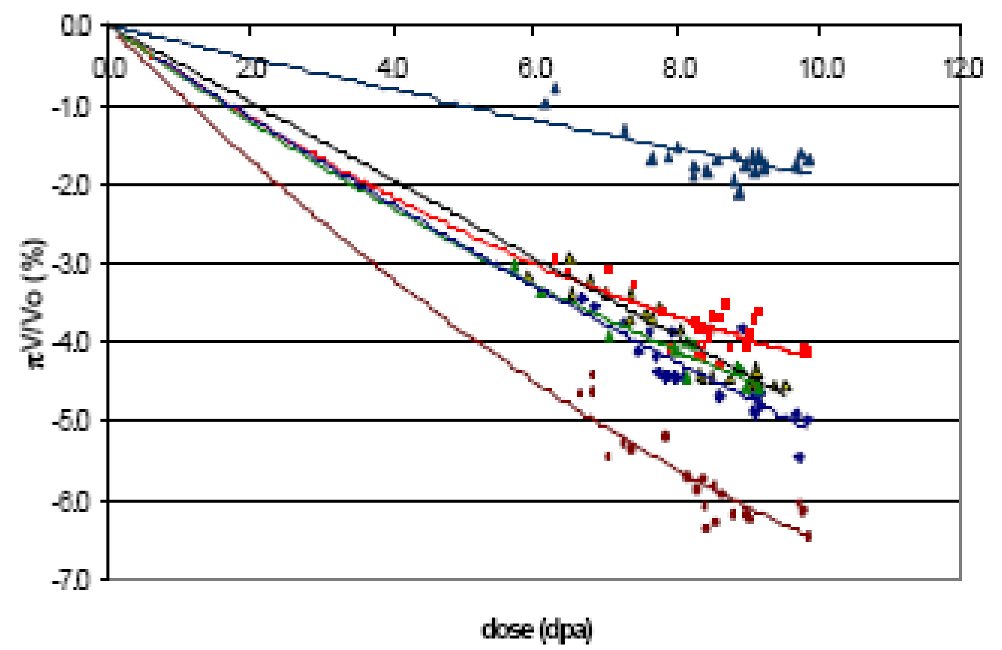
1. Statistical variation of non-irradiated properties
2. Consistency in graphite quality over the lifetime of the reactor fleet (for replacement, for example)
3. Irradiation-induced dimensional change
4. Irradiation-induced thermal conductivity change
5. Irradiation-induced changes in elastic constants, including the effects of creep strain
6. Degradation of thermal conductivity
7. Graphite temperature

NRC Research may be needed for:

Tribology of graphite in (impure) helium environment

Monitoring Worldwide Research on Nuclear Graphite

EU RAPHAEL Sub-Project: Irradiation of Nuclear Graphite at HFR Petten



12 different graphites (Vendor, raw materials, and processing)

- Irradiation at 750 °C and at 950 °C
- Current irradiation underway to 16 dpa for 750 °C .
- Current irradiation underway to 7 dpa for 950 °C.
- PIE completed for 750 °C irradiation.
- Results are being analyzed and interpreted.

Current NRC-Sponsored Research – HTGR Graphite

- Research at ORNL
  - Compare and evaluate NGNP PIRT on graphite with the DOE planned research (Jan 2009)
  - Conduct a workshop with international experts (Mar 2009)
    - Compare and contrast the above with international VHTR graphite programs.
    - Identify safety-related graphite technology data and information gaps
    - Recommend appropriate remedial research need.
    - Publish a report (May 2009)

Strategy for Graphite Research

1. Participate in codes and standards and national/international topical area meetings
2. Participate in international and national graphite irradiation programs (e.g., irradiation creep, thermal conductivity, and dimensional change tests)
3. For specific area, e.g., graphite tribology and dust generation and characterization, and air- and water-ingress effects, conduct research to provide technical safety information.
4. On C(graphite)-C(graphite) and ceramic insulation, based on lessons learned from graphite and metallic materials research experience, monitor ongoing activities from other sources; participate in codes and standards development activities when necessary.

Summary of Graphite Research

1. **Participate in code committees and monitor worldwide graphite research related to HTGRs.**
2. **Keep specific research options open, pending DOE HTGR design selection and research not conducted by DOE or NGNP applicant.**
3. **Follow-up on future research, based on planned workshop outcome which is expected to provide information on gaps between PIRT-identified research and research done by DOE.**
4. **Conduct research related to graphite dust generation, and air and water ingress effects on graphite properties to support NRC EM development.**

ABBREVIATIONS

ASME	American Society for Mechanical Engineers
ASTM	American Society for Testing Materials
CTE	Coefficient of Thermal Expansion
DOE	U.S. Department of Energy
dpa	Displacements Per Atom
EM	Accident Analysis Evaluation Model
EU	European Union
FOM	Figure of Merit
HTGR	High Temperature Gas Cooled Reactor
NGNP	Next Generation Nuclear Plant
ORNL	Oak Ridge National Laboratory
PIRT	Phenomenon Identification and Ranking Table
PRA	Probabilistic Risk Assessment
RAPHAEL	ReActor for Process heat, Hydrogen and Electricity Generation
SG	Sub Group
VHTR	Very High Temperature Reactor

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Advanced Reactor Research Plan for Metallic Components' Analysis

Drs. Amy Hull and Shah Malik
Division of Engineering
Office of Nuclear Regulatory Research
January 15, 2009

Metallic Components

R&D Objectives

- Ensure that sufficient technical bases are developed for regulatory decisions involving critical structures and components for future U.S. (V)HTGRs and LMRs.
- As needed, conduct research on metallic components to evaluate and quantify degradation processes, metallurgical aging and embrittlement, carburization, decarburization, and better understand NDE, and ISI needs.
- Review currently available (international) procedures for design against fatigue, creep, and creep-fatigue. Facilitate the update of ASME Code procedures to incorporate correlations developed from more recent research.

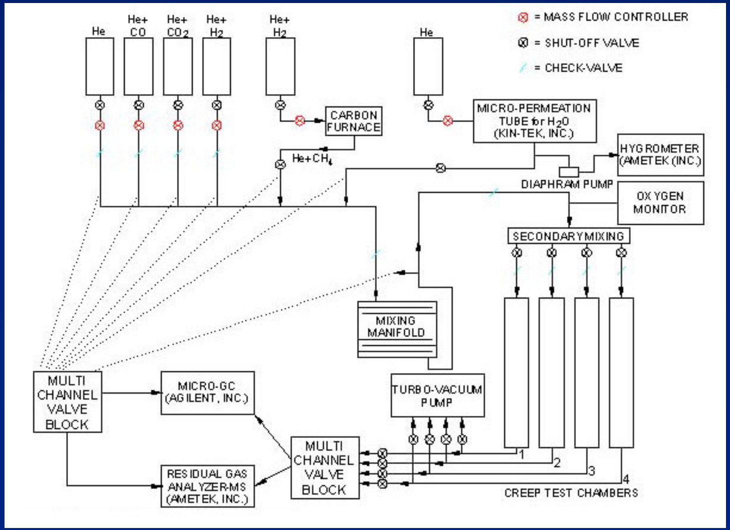
Metallic Components

Key Safety and Licensing Issues

- Development of material fabrication and design codes and standards
- Development of inspection requirements
- Quantification of material performance and variability (including scaling and property prediction)
- Assessment of aging-related degradation mechanisms.

Metallic Components: Background

- The 2003 ARRP identified major issues for HTGR operation.
- During FY 2002 – 04, NRC contracted ANL to:
  - – Review and evaluate codes and standards for metallic components in HTGRs (NUREG/CR-6816);
  - – Evaluate effects of HTGR environments on degradation of metallic components and conduct confirmatory testing in high T/high P helium loop (NUREG/CR-6824).



Schematic of ANL's helium loop with controlled levels of He impurities for creep test program,

NGNP High Temperature Materials PIRT (NUREG/CR-6944, Vol. 4, Mar '08)

PIRT Rank	No. of Phenomena
I-H, K-L	16
I-H, K-M	1
I-M, K-L	6
I-M, K-M	17
I-L, K-H	10
I-L, K-M	4
I-L, K-L	0
I-H, K-H	1
I-M, K-H	3

Importance rank	Definition
Low (L)	Small influence on primary evaluation criterion (Figure of merit)
Medium (M)	Moderate influence on primary evaluation criterion
High (H)	Controlling influence on primary evaluation criterion

Knowledge level	Definition
H	Experimental simulation and analytical modeling with a high degree of accuracy is currently possible
M	Experimental simulation and/or analytical modeling with a moderate degree of accuracy is currently possible
L	Experimental simulation and/or analytical modeling is currently marginal or not available

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Overall Summary of Phenomena Contributions to PIRT Rank for Metallics

Phenomena Ranked of High Importance and Low Knowledge (I-H, K-L)

I.D. No.	Phenomenon
5, 35	Crack Initiation & Subcritical Crack Growth (RPV, IHX)
11, 46	Compromise of Surface Emissivity (RPV, internals)
38	Inspection, NDE (IHX)
16, 17, 36, 37, 56, 57	Design Methods & Material Property Control during Fabrication & Manufacturing (RPV, IHX, valves)
47	Irradiation- Induced Creep (internals)

Metallic Components

Key R&D Issues for Safety/Licensing

- Updating creep-fatigue design rules, for high-temperature use
- Assessing degradation phenomena, such as, carburization, decarburization, and internal oxidation
- Assessing impact of corrosion mechanisms
- Assessing emissivity requirements and retention for the life of RPV and core barrel candidate materials

Planned R&D Areas

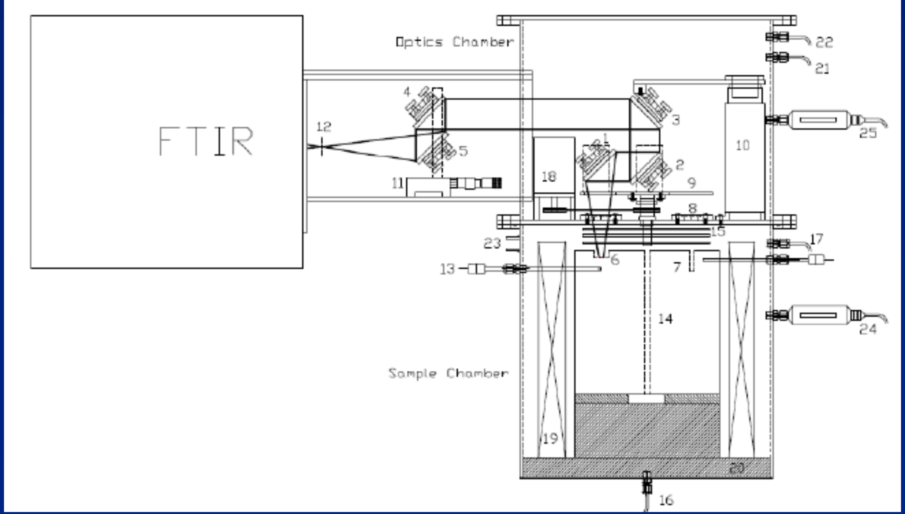
- Monitor worldwide research on high temperature materials
  - Prioritize safety-significance of materials issues
- Facilitate development of codes & standards for high-temperature HTGR candidate metallic materials
  - Assess degradation of metallic components
  - Review existing literature and studies on HTGR materials and environmental effects
  - Conduct confirmatory testing as needed
- Investigate application of NDE test techniques and inservice inspection technology

Ongoing Metals R&D

- Cooperative Agreement for Experimental Research on Advanced VHTRs (3-yr project initiated FY07) at Wisconsin Institute of Nuclear Systems
  - Emissivity of Materials for Passive Safety
- HTGR ASME BPV Code Roadmap Development (11/08 start)
  - Linkage between components & systems approach
- Gen IV / NGNP Materials Project
  - NDE and ISI Technology for HTRs (11/08 start)
- Modeling of creep and creep-fatigue crack growth processes in HTGR, VHTR materials
  - Reactor vessel, internals, and intermediate heat exchanger (IHX) (7/08 start)

Emissivity of Materials for Passive Safety

- Focus on RPV, core barrel, and RCCS
  - critical material parameter governing extent of radiated heat.
- Measurement of spectral emissivity (0.9 to 10 μ m) of T91, T22, and SA 508, and 316SS at 300, 500, and 700^{0}C in air and He
- Measurements of angular dependence emissivity,
- Investigation of the role of transients on emissivity,
- Investigation of the role of surface roughness,
- Investigation of long-term changes in emissivity, and
- Characterization of oxide layers, correlation with emissivity.



Schematic of Experimental Emissivity Facilities at WINS

Modeling of Creep and Creep-Fatigue Crack Growth Processes

Background

- Breaching to secondary system due to creep and creep-fatigue (C-F) crack growth in reactor vessel or IHX could develop pathway for fission products release

Objectives

- Develop an independent capability and expertise to understand the phenomena of creep and C-F crack growth processes
  - For effective evaluation and establishment of regulatory technical bases

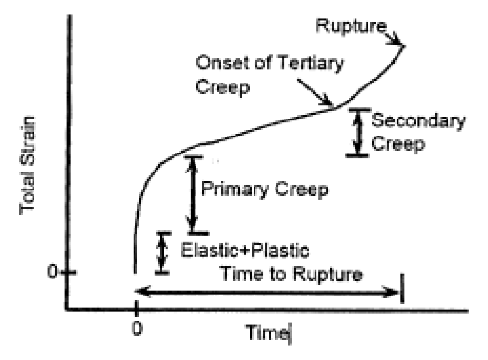
Scope of Work

- Document current state of knowledge of creep and C-F crack growth processes
  - Emphasis on materials in ASME Sect III NH, and potential VHTR materials such as Ni-base alloys for high temperature strength and oxidation resistance
- Identify critical areas where there is a lack of knowledge and/or insufficient data
- Make recommendations on approaches to address the issues
- Perform confirmatory research and conduct scoping tests for critical items

Key Aspects of Creep and Creep-Fatigue Crack Growth Processes

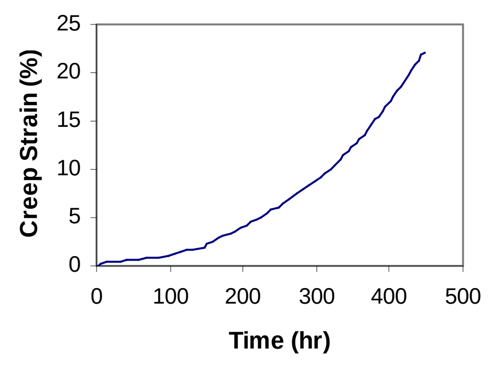
Deformation Behavior

- **Cyclic plasticity**
- **Primary creep**
- **Secondary creep**
- **Tertiary creep**



Typical creep curve for Cr-Mo & Cr-Mo-V steels, and stainless steels; exhibiting all three stages of creep

Pseudo-tertiary creep behavior
No secondary creep

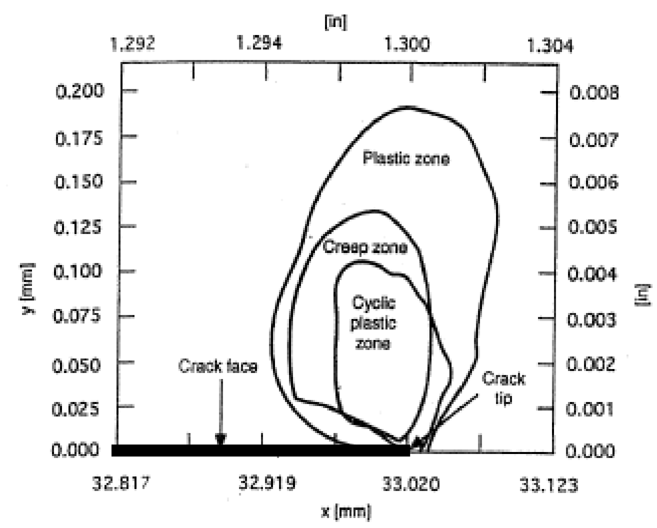


Creep curve for nickel-base alloys at elevated temperatures

Fracture Mechanics

- **Fracture mechanics parameters for characterizing crack growth in different regimes**

$$\Delta K,\ \Delta J,\ K,\ J,$$
$$C(t),\ C^*,\ C_h^*,\ C_t$$



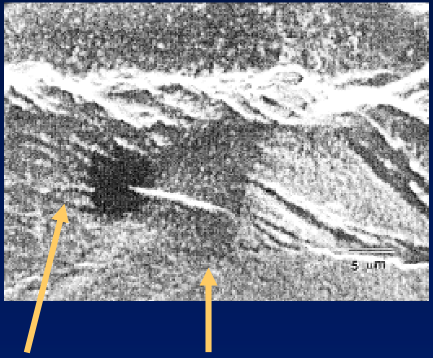
Saxena (1998) – Crack tip deformation zones under creep-fatigue load, from finite element calculations

Key Aspects of Creep and Creep-Fatigue Crack Growth Processes – Cont'd

Crack Growth Mechanisms

- **Transgranular - Alternate slip mechanism (cycle dependent -- fatigue)**
- **Intergranular - Grain boundary cavitation (time dependent -- creep)**
- **Their interaction**

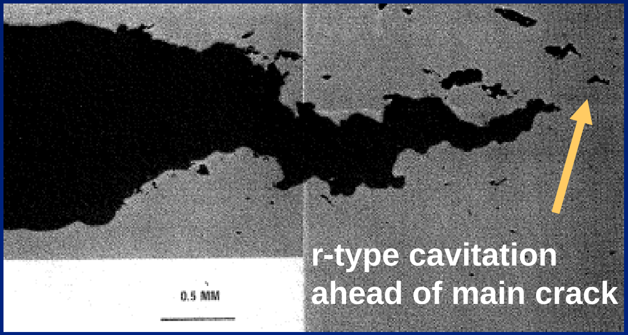
Hour and Stubbins (1989) – Alloy 800H, fatigue crack growth



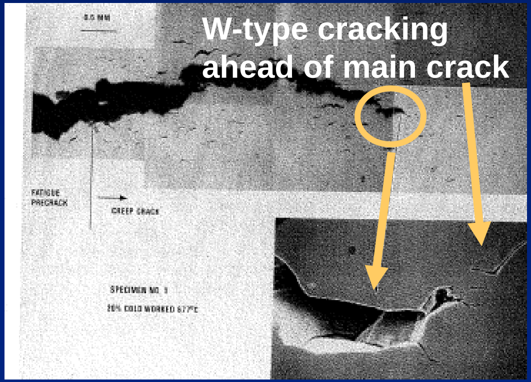
striations transgranular fracture surface

Additional Considerations

- **Loading wave-form effect**
- **R-ratio (min stress/max stress) effect**
- **Crack closure**
- **Environmental effects (coolant impurities, oxygen, etc.)**



r-type cavitation ahead of main crack



W-type cracking ahead of main crack

Foulds (1989) – Alloy 800H, creep crack growth

Flaw Evaluation Procedures based on Developed Crack Growth Correlations

Issues to be addressed before correlations can be applied with confidence		
• Transferability – Need to establish the range of validity for applying correlations from fracture specimens to structures – Quantify effects of crack-tip constraints	**• Extrapolation** – Applications typically involve long times and low stresses – Data usually generated from accelerated tests, with short times and high loads – Need to establish restrictions on extrapolation based on the understanding of operative mechanisms	**• Additional Degradation Mechanisms** – Data from air test are relied upon to generate correlations – Need to understand and quantify any additional degradation mechanisms – Establish environmental factors on crack growth correlations to mitigate non-conservatism

- **Flaw evaluation procedures similar to ASME Code Section XI for LWRs could be formulated based on the developed crack growth correlations**
- **Upon further validation, procedures can be implemented in modular probabilistic computer code for independent assessment of licensee submittals**

Strategy for Metals R&D

- Maintain staff awareness and expertise; participate in Codes Committees, technical meetings, international programs
  - Gen IV/ NGNP Materials Program
  - ASME Section XI HTGR SWG
  - ANS 53.1, *Safety Standards for MHRs*
  - International C-F Round Robin Testing

- Existing R&D programs based on phenomena with high importance, low knowledge rankings in NGNP Metals PIRT
  - Emissivity for passive safety
  - Creep and creep-fatigue crack growth processes

- Further refinement of NGNP metals PIRT prioritizations
  - Monitor relevant international R&D, and updates on HTGR specifications to determine need for confirmatory testing

- Scoping studies on NDE and ISI Technology for HTRs

Back-up Slides

NGNP Metallic Materials

NUREG/CR-6944, Vol. 4 PIRT, March 2008

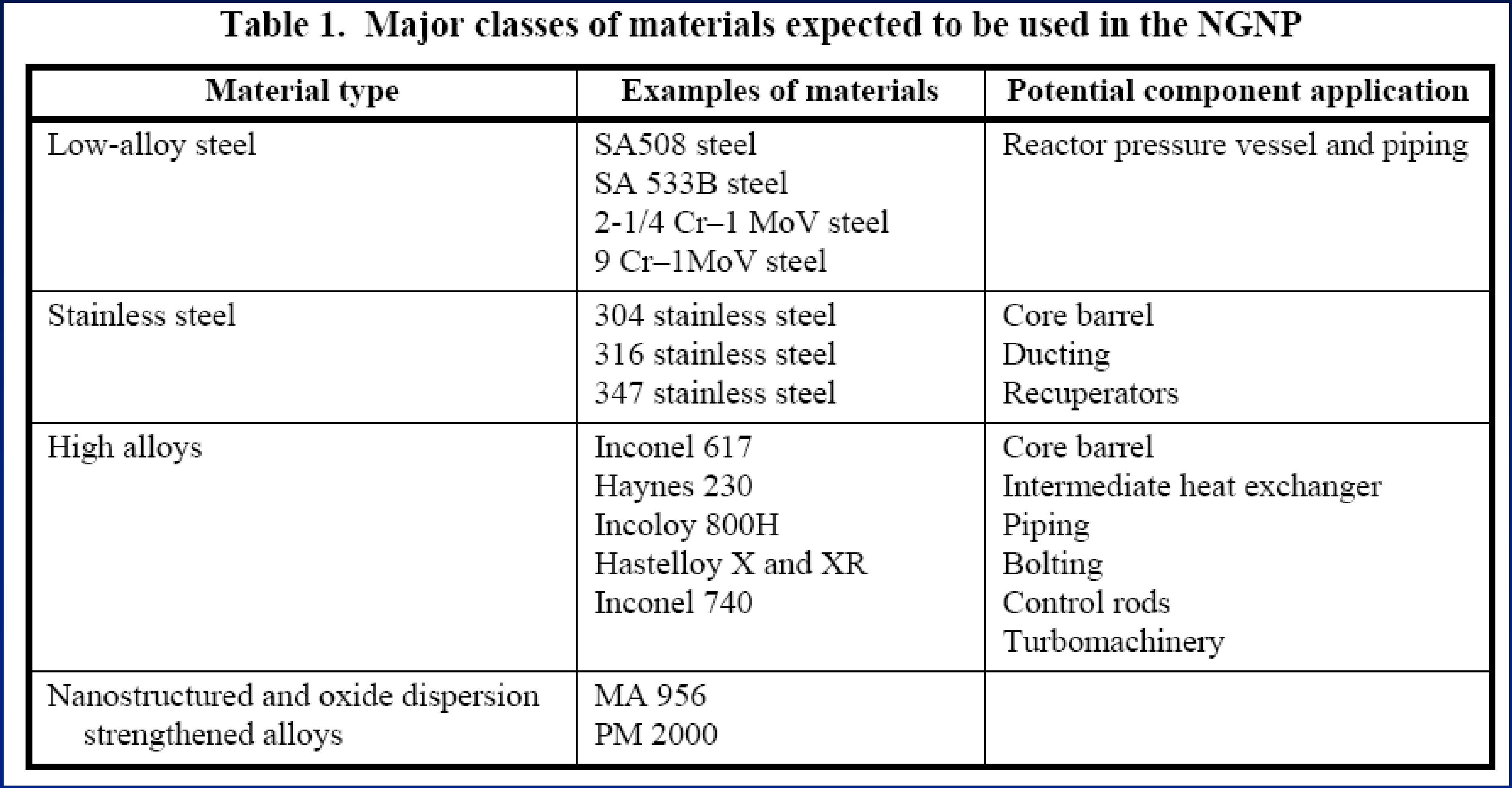


Table 1. Major classes of materials expected to be used in the NGNP

Material type	Examples of materials	Potential component application
Low-alloy steel	SA508 steel SA 533B steel 2-1/4 Cr–1 MoV steel 9 Cr–1MoV steel	Reactor pressure vessel and piping
Stainless steel	304 stainless steel 316 stainless steel 347 stainless steel	Core barrel Ducting Recuperators
High alloys	Inconel 617 Haynes 230 Incoloy 800H Hastelloy X and XR Inconel 740	Core barrel Intermediate heat exchanger Piping Bolting Control rods Turbomachinery
Nanostructured and oxide dispersion strengthened alloys	MA 956 PM 2000	

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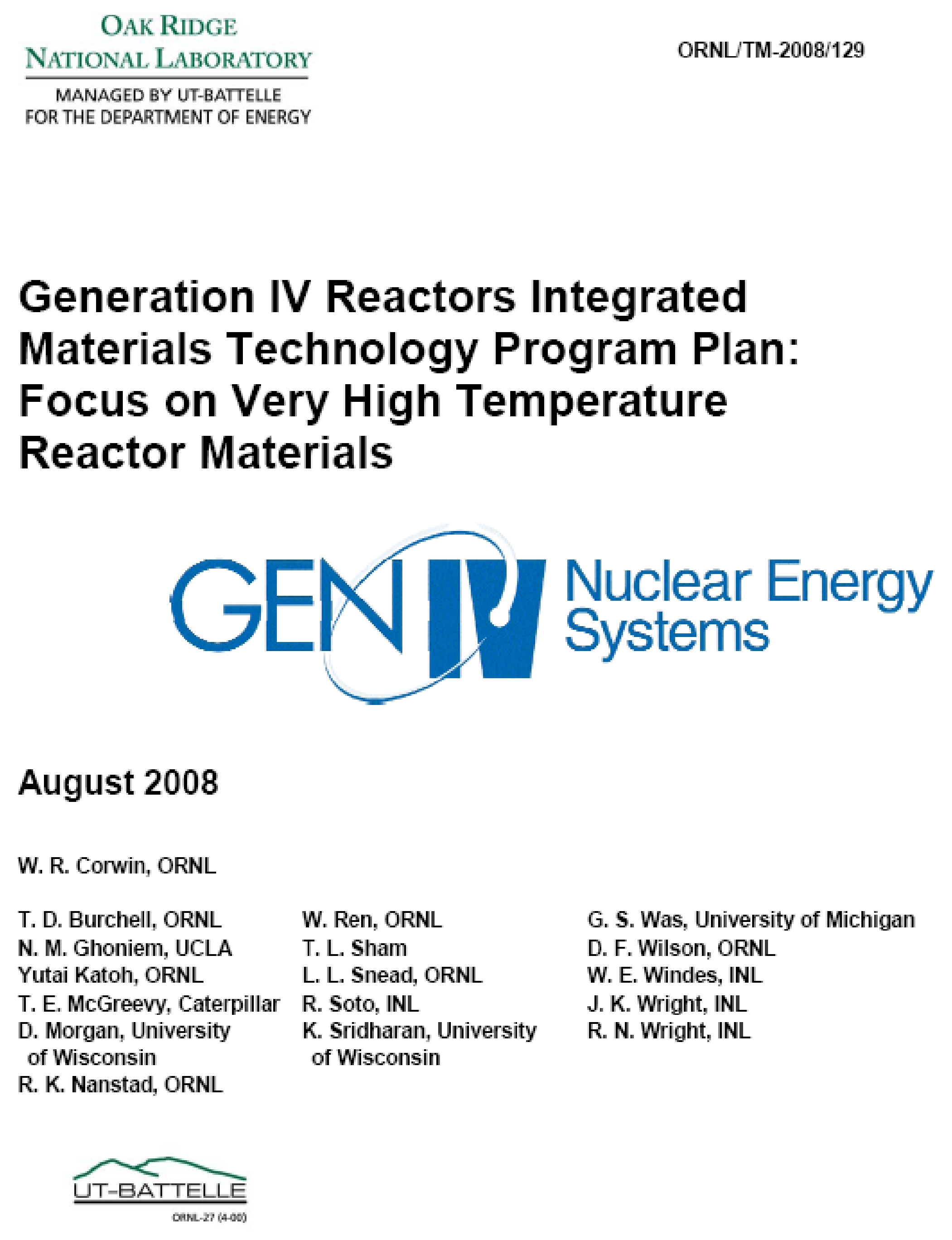
ORNL/TM-2008/129

Aug 2008

on VHTR Materials

Under DOE Funding



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FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2008/129

Generation IV Reactors Integrated Materials Technology Program Plan: Focus on Very High Temperature Reactor Materials

GEN IV Nuclear Energy Systems

August 2008

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From: ORNL/TM-2008/129 (Aug 2008)

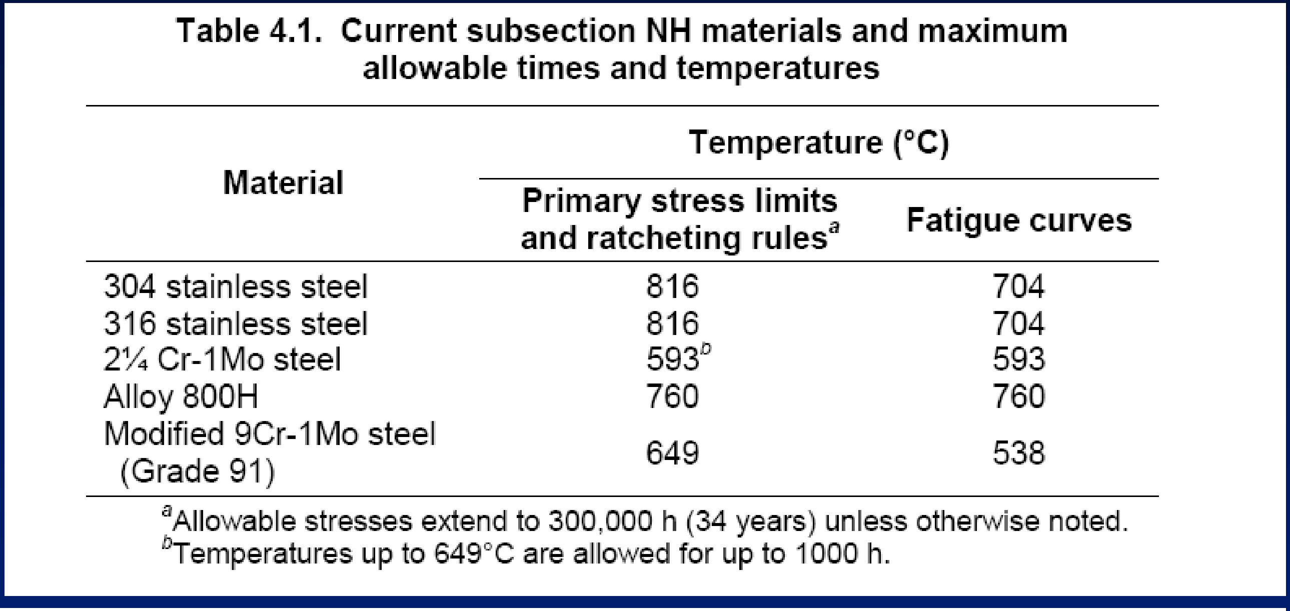


Table 4.1. Current subsection NH materials and maximum allowable times and temperatures

Material	Temperature (°C)	
	Primary stress limits and ratcheting rules[a]	Fatigue curves
304 stainless steel	816	704
316 stainless steel	816	704
2¼ Cr-1Mo steel	593[b]	593
Alloy 800H	760	760
Modified 9Cr-1Mo steel (Grade 91)	649	538

[a] Allowable stresses extend to 300,000 h (34 years) unless otherwise noted.
[b] Temperatures up to 649°C are allowed for up to 1000 h.

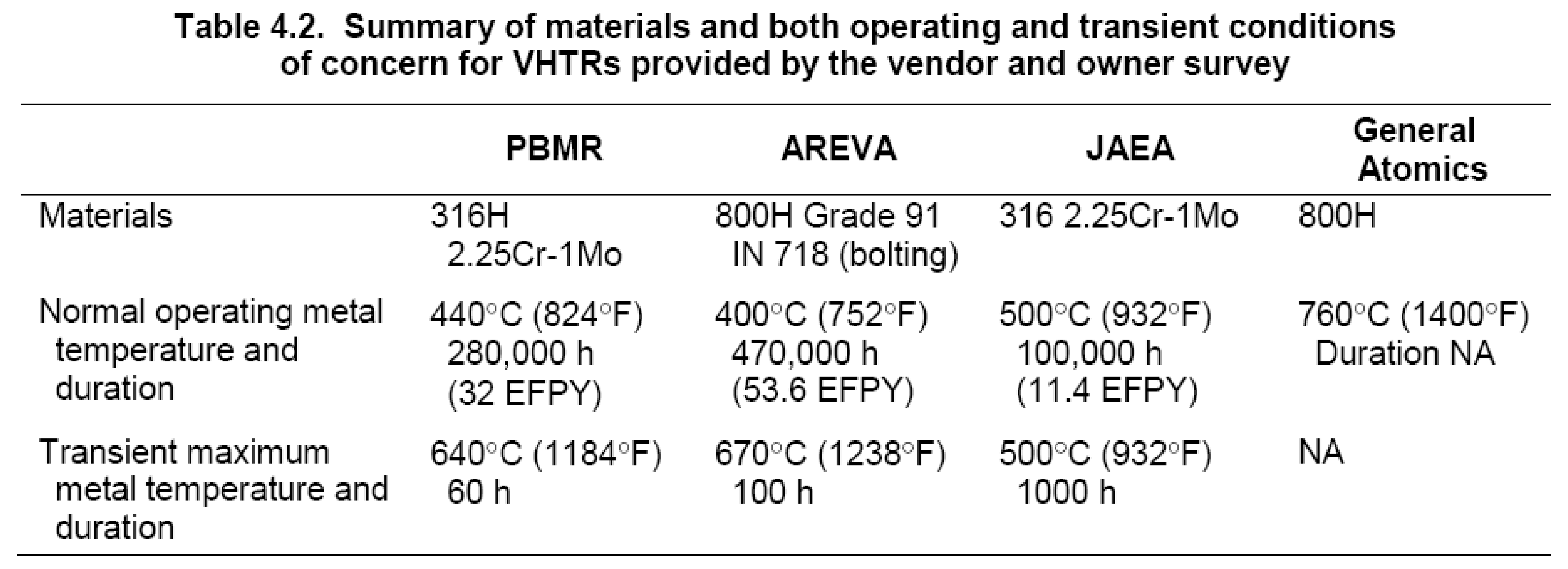
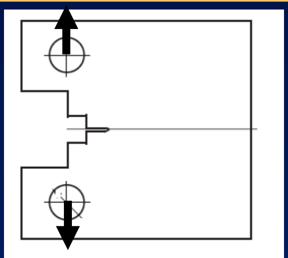


Table 4.2. Summary of materials and both operating and transient conditions of concern for VHTRs provided by the vendor and owner survey

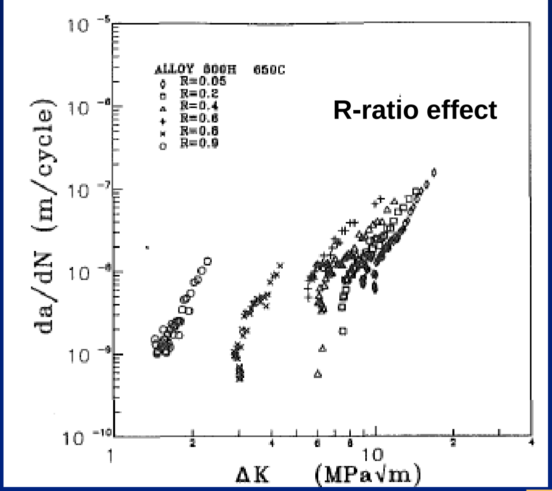
	PBMR	AREVA	JAEA	General Atomics
Materials	316H 2.25Cr-1Mo	800H Grade 91 IN 718 (bolting)	316 2.25Cr-1Mo	800H
Normal operating metal temperature and duration	440°C (824°F) 280,000 h (32 EFPY)	400°C (752°F) 470,000 h (53.6 EFPY)	500°C (932°F) 100,000 h (11.4 EFPY)	760°C (1400°F) Duration NA
Transient maximum metal temperature and duration	640°C (1184°F) 60 h	670°C (1238°F) 100 h	500°C (932°F) 1000 h	NA

Current Approaches for developing Creep-Fatigue Crack Growth Correlations from Test-Specimen Data based on Fracture Mechanics Parameters

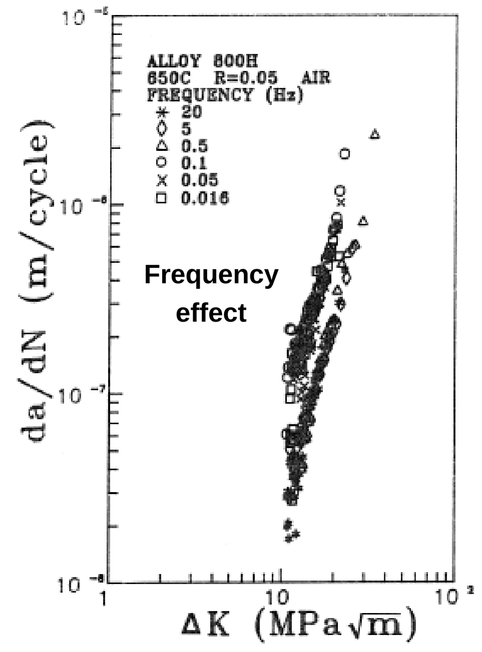
Fatigue, creep, creep-fatigue crack growth tests to develop crack growth data using fracture specimens



Hour and Stubbins (1989) – Alloy 800H, Fatigue crack growth data

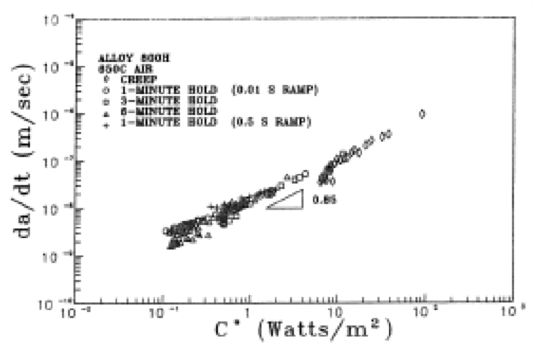


Hour and Stubbins (1989) – Alloy 800H, Fatigue crack growth data



Axial tests for tensile & creep properties

Hour and Stubbins (1989) – Alloy 800H, Creep-fatigue crack growth data



Crack Growth Correlations

$$\left(\frac{da}{dN}\right)_{Creep-Fatigue} = \left(\frac{da}{dN}\right)_{Fatigue} + \int_{Hold\ Time} \left(\frac{da}{dt}\right)_{Creep} dt$$

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Advanced Reactor Research Plan for Probabilistic Risk Assessment

Kevin Coyne
Office of Nuclear Regulatory Research
January 15, 2009

PRA R&D Objectives

- Develop the necessary review guidance to ensure the applicant’s PRA is of sufficient technical acceptability to support the licensing basis for advanced reactors.
- Develop PRA tools needed to support the NRC’s advanced reactor oversight process.

Licensing Issues related to PRA

- Four options for the NGNP licensing strategy were considered:
  - Deterministic (Option 1)
  - Risk-Informed and Performance-Based with less emphasis on the PRA (Option 2)
  - Risk-Informed and Performance-Based with greater emphasis on the PRA (Option 3)
  - New Body of Risk-Informed and Performance-Based Regulations (Option 4)
- Option 2 was the selected licensing strategy

Licensing Issues related to PRA (continued)

- Under Option 2, the PRA would be used to
  - Complement a deterministic approach to licensing basis event selection with probabilistic insights (to the extent supported by the NGNP PRA methods and data)
  - Establish defense-in-depth requirements (in conjunction with deterministic engineering judgment)
  - Select special treatment requirements for nonsafety-related SSCs (in conjunction with deterministic engineering judgment)
- Will likely need Commission direction in the areas of risk metrics, quality and scope of PRA, and PRA maintenance.

Technical and R&D Issues (PRA)

- Develop regulatory guidance for determining PRA technical acceptability
- Develop methods, tools, and data needed to support the PRA technical acceptability review
- Develop PRA tools needed to support the reactor oversight process for advanced reactors

Regulatory Guidance for PRA Technical Acceptability

Objective: Develop regulatory guidance on PRA Technical Acceptability for advanced reactors

- Draft Regulatory Guide
  - Identification of PRA Licensing Uses
  - PRA scope needed to support intended uses
  - PRA technical elements, characteristics, and attributes needed for PRA adequacy
- Development of PRA consensus standards
  - ASME/CNRM appointed a working group that is developing a draft standard for Probabilistic Risk Assessment for Advanced Non-LWR Nuclear Power Plant Applications
  - Current draft proposes to be reactor technology neutral and addresses PRA design life cycle stages
- Issue final Regulatory Guide for PRA Technical Acceptability
- Not yet determined if guidance will be included in RG 1.200 or a new RG

Develop Tools, Methods, and Data

Objective: Identify tools, methods, and data needed to support the PRA technical acceptability review.

- Specific tasks will be based on experience obtained during the development of PRA technical acceptability guidance
- Several potential research areas have been identified:
  - PRA scope and radiological sources outside the core
  - Treatment of uncertainties
  - Passive component and system reliability
  - Risk impact of latent errors during the design, construction, and testing phases
  - Human reliability analysis methods for advanced reactors

PRA Support Needed for the Advanced Reactor Oversight Process

Objective: Develop a baseline probabilistic systems analysis tool for NRC use

- Potential uses of analysis tool include
  - Prioritization of review and inspection activities
  - Support for the reactor oversight process
- Task will extend the scoping-level PRA developed during the Risk-Informed Infrastructure Development Plan
  - Resource needs will depend on the quality of the applicant’s PRA

Status of PRA R&D Tasks

- Regulatory Guidance
  - Participation on ASME Committee on Nuclear Risk Management and working group on Non-LWR PRA Standard
- Tools, Methods, and Data
  - No activities in progress
  - May initiate R&D tasks for advanced reactor HRA, system reliability analysis, and treatment of uncertainties in FY2009 if funding becomes available.
- Support for the Reactor Oversight Process
  - No activities anticipated in FY2009

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Advanced Reactor Research Plan for Sodium-Cooled Fast Reactors (SFRs)

Imtiaz K. Madni
Office of Nuclear Regulatory Research
January 15, 2009

SFR R&D Objectives

- Conduct a limited-scope, initial SFR technical infrastructure survey
  - to identify significant technical, safety and R&D issue areas and needs, and identify potential NRC SFR R&D for the following technical areas:
    - Thermal Fluids Analysis
    - Nuclear Analysis
    - Severe Accident and Source Term Analysis
    - Fuels Analysis
    - Materials Analysis
- Implement an SFR Knowledge Management Project
  - Technical Document Capture
  - Technical Seminars
  - Plan for Training Course
- Participate in NRC/DOE SFR technical activities (e.g., ABR) and NRC/vendor SFR technical activities (e.g., 4S)

Background: LMRs and Sodium

- Most LMRs cooled by Sodium, hence focus on SFRs
- Thermophysical & T/F properties of Sodium (Na) superior to Pb or He
- High BP (897ºC)
  - high Operating T (high efficiency ~40%), high margin to boiling
  - single-phase, atmospheric pressure
- High k
  - high power density (smaller size core)
- Activation and reaction with water
  - requires separation of steam cycle from primary system (IHTS)
  - primary & secondary Na loops: pool/loop type
- Reaction with air
  - guard vessels, cover gas
- Does not corrode structural materials
- Tends to bind chemically with radioactive FPs
  - contributes to scrubbing

Background

- For SFR designs, this is a whole new R&D area
  - 2003 ARRP had no input on SFRs & made no reference to SFRs
- The staff conducted an initial limited-scope technical infrastructure needs survey
  - Conducted at a higher level than HTGR infrastructure assessment
  - Notes gaps in NRC information & capabilities and provides a reference for considering future R&D activities
  - Identifies key SFR safety and technical issues and needed areas for infrastructure R&D
  - Provides a starting point for follow-up in-depth SFR technology infrastructure assessment
- Toshiba plans to submit 4S design for NRC licensing review
- DOE may develop an SFR design as an advanced burner reactor (ABR)

SFR Safety Issues

- Passive decay heat removal performance
- Proof of inherent reactor shutdown characteristics
- Sodium-water and sodium-air reactions
- Core melt prevention and mitigation (re-criticality)
- Fuel performance
- Thermal stresses/fatigue in piping and components

US LMR Experience

Country	Reactor	Location	Purpose	Startup/ Shutdown	Power (MWt)	Power (MWe)	Type	Fuel	Coolant
USA	**Clementine**	Los Alamos	Research	1946/1953	0.025	0		Pu	Hg
	EBR-1	Idaho	Research	1951/1963	1	0.2	Pool	Pu	NaK
	EBR-2	Idaho	Test	1964/1993	62.5	20	Pool	U (enr)	Na
	SEFOR	Arkansas	Test	1969/1972	20	0		U-Mo	Na
	Enrico Fermi-1	Michigan	Test	1965/1972	200	61	Loop	MOX	Na
	FFTF	Richland	Test	1980/1992	400	0	Loop	MOX	Na
	CRBR	Oak Ridge	Prototype	Not built	975	380	Loop	MOX	Na
	SAFR	-	Modular Adv	Not built	900		Pool	U-Pu-Zr	Na
	PRISM	-	Modular Adv	Not built	840	280	Pool	U-Pu-Zr	Na
	ABR	-	Prototype	Not built	TBD	TBD	TBD	TBD	Na
	Toshiba 4S	Galena	Small Modular	Not built	30	10	Pool	U-Zr	Na

Country	Reactor	Location	Purpose	Startup/ Shutdown	Power (MWt)	Power (MWe)	Type	Fuel	Coolant
USA	**Clementine**	Los Alamos	Research	1946/1953	0.025	0		Pu	Hg
	EBR-1	Idaho	Research	1951/1963	1	0.2	Pool	Pu	NaK
	EBR-2	Idaho	Test	1964/1993	62.5	20	Pool	U (enr)	Na
	SEFOR	Arkansas	Test	1969/1972	20	0		U-Mo	Na
	Enrico Fermi-1	Michigan	Test	1965/1972	200	61	Loop	MOX	Na
	FFTF	Richland	Test	1980/1992	400	0	Loop	MOX	Na
	CRBR	Oak Ridge	Prototype	Not built	975	380	Loop		
RUSSIA	**BR-1/BR-2**	Obninsk	Research	1956/	0.1	0	Loop	Pu	Hg
	BR-5/BR-10	Obninsk	Test	1959/	5/10	0	Loop	PuO2	Na
	BOR-60	Dimitrovgrad	Test	1969/	60	12	Loop	MOX	Na
	BN-350	Aktau (Kazakh)	Prototype	1973/1999	1000	150/Desa	Loop	UO2 (enr)	Na
	BN-600	Beloyarsk	Prototype	1980/	1470	560	Pool	UO2 (enr)	Na
	BN-800	Beloyarsk, S.Urals	Demonstr	Under Constr	2100	800	Pool	MOX	Na
ITALY	**PEC**	Brasimone	Test	Constr stopped 1987	120	0	Loop	MOX	Na
JAPAN	**JOYO**	Oaral	Test	1978/	100	0	Loop	MOX	Na
	MONJU	Ibaraki	Prototype	1995/1995	714	280	Loop	MOX	Na
UK	**DFR**	Dounreay	Test	1963/1977	72	15	Loop	U-Mo	Na
	PFR	Dounreay	Prototype	1976/1994	600	250	Pool	MOX MOX	Na
FRANCE	**Rapsodie**	Cadarache	Test	1967/1983	40	0	Loop	MOX	Na
	Phenix	Marcoule	Prototype	1974/	560	250	Pool	MOX	Na
	Super Phenix	Creys Malville	Demonstr	1985/1998	3000	1240	Pool	MOX	Na
INDIA	**FBTR**	Kalpakkam	Test	1985/	42.5	12.4	Pool	(Pu+U)C	Na
	PFBR		Prototype	Under constr	1210	500	Pool	MOX	Na
GERMANY	**KNK-II**	Karlsruhe	Test	1972/1991	58	21	Loop	MOX	Na
	SNR-300	Kalkar	Prototype	Terminated 1991	730	327	Loop	MOX	Na
	SNR-2	Kalkar	Demonstr	Never built	3420	1460	Pool	MOX	Na
CHINA	**CEFR**	Beijing	Test	Under constr	65	25	Pool	MOX	Na
	CPFR		Prototype	Being designed		600	Pool	MOX/Metal	Na

Major *SFR* Test Programs

- The US has not operated an SFR for > 10 years, and has not designed and constructed one for almost 30 years.
- Hence to design, construct, and operate an SFR will require re-establishment of all necessary infrastructure
- EBR II, FFTF, and IFR TREAT have been used extensively as integral test facilities in the US
  - EBR-II has been permanently decommissioned.
  - FFTF is on cold standby. Hence, it can be resurrected to use as an integral test facility
- Most integral test facilities are outside the US
  - PHENIX (France)
  - JOYO (Japan)
  - BOR-60 (Russia)
  - FBTR (India)
- Several test programs have been/are being carried out in these facilities.
  - collaborations to make use of their test facilities

SFR Knowledge Management

- Ongoing SFR Knowledge Management program
  - Accomplishments
    - ~100 LMR safety, licensing, and technology documents added to NRC Knowledge Center
    - 3 agency-wide seminars by experts presented (on EBR II, FFTF, Core)
    - Desk Reference developed
    - Outline for 5-day training course developed
  - Plans developed for additional FY09 work (subject to funding)
    - Add more documents
    - identify 3 more SFR related topics for agency-wide seminars
    - develop 5-day SFR course content

Potential Next Steps for *SFR* R&D Activities

If NRC SFR technical review priorities increase:

- Conduct detailed, in-depth SFR infrastructure assessment, with a PIRT, to provide basis for development of detailed NRC R&D plans
- Develop detailed NRC R&D plans in areas of
  - thermal fluids analysis
  - nuclear analysis
  - severe accident and source term analysis
  - fuels analysis
  - Materials analysis
  - to support regulatory activities, including evaluation of technical bases of SFR applications
- Increase interaction with NRR/NRO/DOE on ABR R&D activities and with Toshiba on 4S if review priorities for these SFRs increase
- Evaluate existing SFR models and analytical tools e.g.
  - SSC code series
  - SASSYS-SAS4A
  - SIMMER
  - and development needs for NRC SFR transient/accident analyses capability

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Advanced Reactor Research

Structural/Seismic Analysis

Herman L. Graves
Office of Nuclear Regulatory Research
January 15, 2009

Structural Analysis-Objectives

- Develop data and information, and ensure analytical capability, to independently confirm the technical basis for performance of safety-important HTGR core structures and civil structures for licensing basis event conditions.

Background

- Issuance of Regulatory Guide 1.208, “A Performance-Based Approach to Define The Site-Specific Earthquake Ground Motion,” 3/07.
- Issuance of NUREG/CR-6896, “Assessment of Seismic Analysis Methodologies for Deeply Embedded Nuclear Power Plant Structures,” 2/06.

Structural Analysis Safety/Technical Issues

Safety

- Maintain safety-related SSC structural support
- Protect against external events and hazards
- Confine radionuclides during accidents
- Maintain capability to limit chemical attack

Technical:

- Concrete structural integrity under long-term elevated temperature, inspection methods
- Concrete structural integrity for vessel support system during conduction cool down, inspection methods

Structural Analysis Technical Issues

- Develop structural models for reactor vessel internals and core support structures to evaluate assumptions and assess limitations of existing codes for nonlinear configurations.
- Concrete structures in HTGRs may be subjected to sustained high temperature. Research needed to address transient aspects of high temperature of structure during heating and cooling.

Structural Analysis Tech. Issues, cont.

- In the multimodule HTGR plant, the nuclear island consists of several modules constructed at various stages and placed on a common foundation mat. Both the seismic capacity and the seismic response of the plant depend on the overall foundation size of the plant and the interaction of various modules.

Related PIRT Insights

NRC R&D Plans

- Core supports (accidents), graphite base.
- Lower plenum hot streaking (normal operating), carbon steel.
- Effectiveness of reactor cavity cooling system.

Reference: NUREG/CR-6944

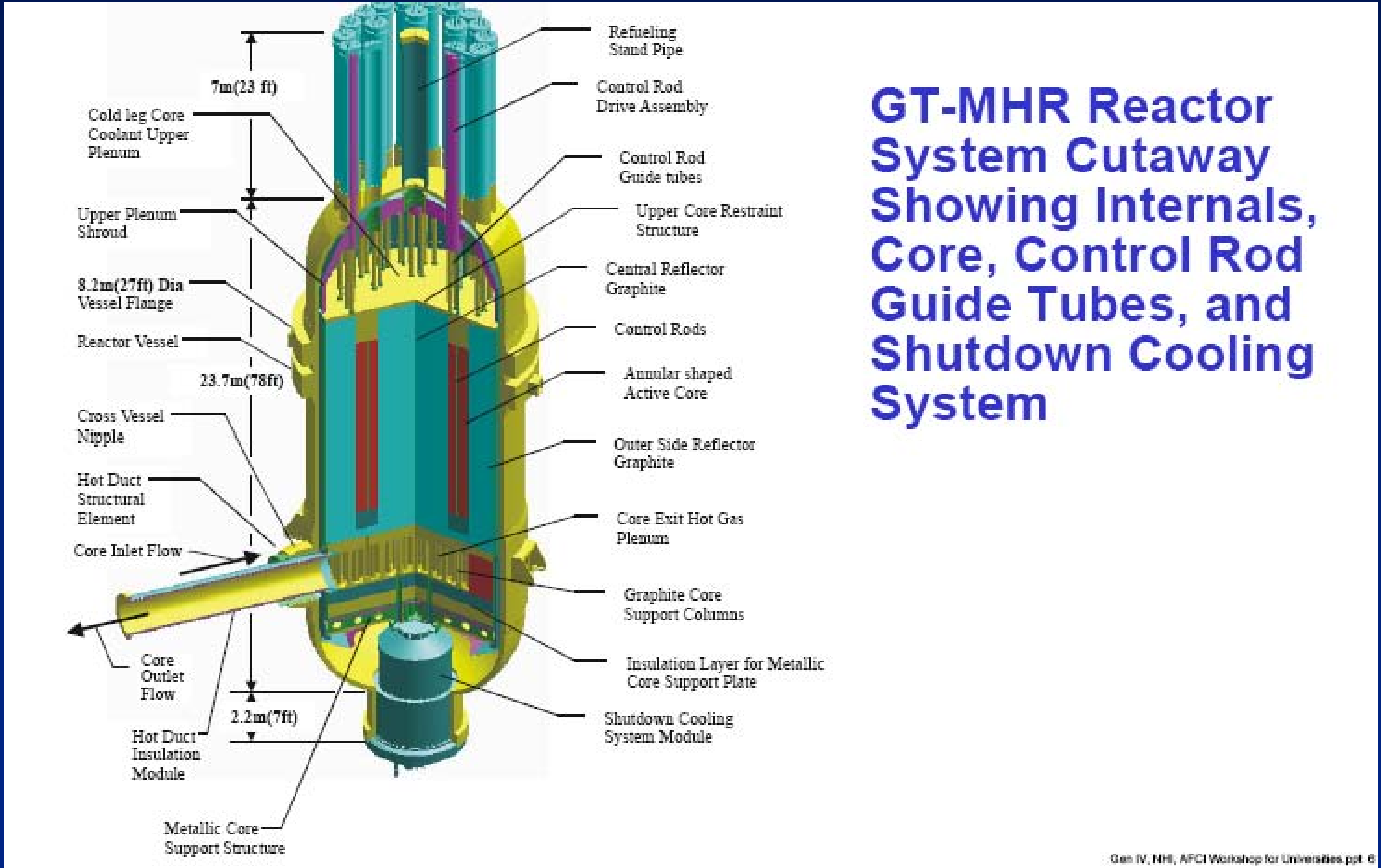
Structural Analysis R&D Areas

- Nonlinear Seismic Analysis of Reactor Vessel and Core Support Structures
- Effect of High Temperature on Concrete
- Seismic capacity of multimodule plant

Nonlinear Seismic Analysis of Reactor Vessel and Core Support Structures

Objective: Conduct research to determine nonlinear response during horizontal and vertical earthquakes.

- Evaluate assumptions and limitations of existing finite element codes for applicability to nonlinear configurations of HTGR reactors internal structures.
- Conduct research on the nonlinear and dynamic structural analysis of advanced structures with long fuel sleeve/tubes and core support structures whose seismic margin might be controlled by core structural design.



GT-MHR Reactor System Cutaway Showing Internals, Core, Control Rod Guide Tubes, and Shutdown Cooling System

Gen IV, NHI, AFCI Workshop for Universities.ppt 6

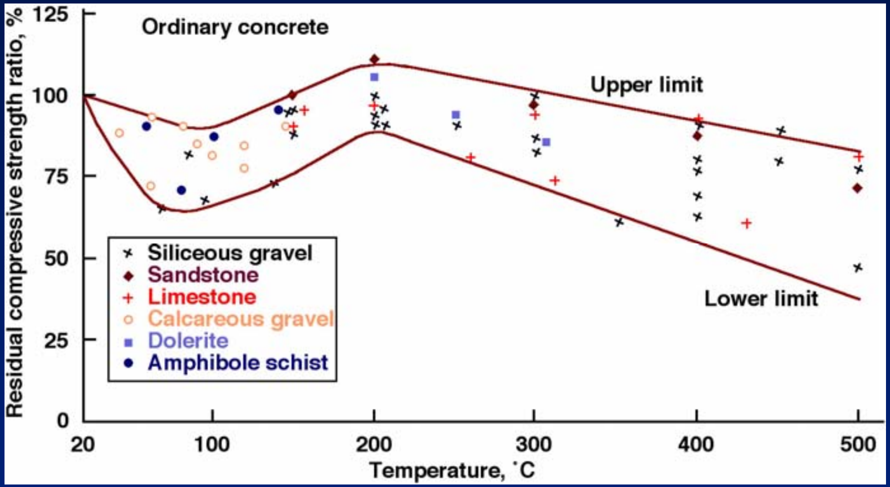
Effect of High Temperature on Concrete

Objective: Conduct research to determine concrete performance (i.e., ability to carry loads) under high temperatures. The research effort will focus on accumulating the existing database and evaluating the impact of high temperature on concrete properties.

- In the current American Concrete Institute (ACI) Code, the temperature limits specified for concrete are: **Normal operation** (long term), surface 150ºF (65° C) , local 200ºF (93° C) , and **Accident** (short term) surface 350ºF (177° C) , local 650ºF (343° C) . For some of the advanced reactor designs being considered the operating temperature of the primary reactor vessels are greater than those for currently licensed nuclear power reactors.

- This research will include data accumulation and expansion of existing data bases. Significant information regarding high temperature effects is available in the literature, including journals, conference transactions, and proceedings.

Mechanical Properties - Compressive Strength

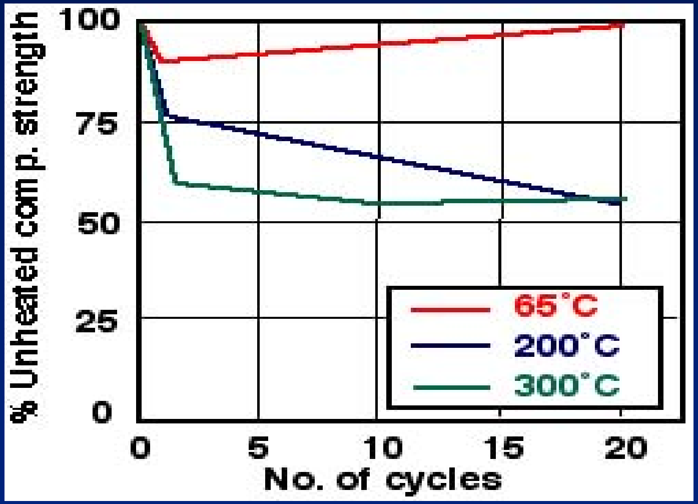


Temperature, °C	General Effect
20-200	Some strength loss
120-300	Strength gain
200-250	Strength approx. constant
>350	Decrease strength

-Original concrete strength, type of cement, aggregate size, heating rate, and water-cement ratio have little affect on relative strength vs temperature.

-Aggregate type, interaction between aggregate and cement paste, and presence of stress during heating are main factors influencing compressive strength at elevated temperature.

Mechanical Properties - Thermal Cycling



- **Thermal cycling:**

-Reduces compressive, tensile, and bond strength as well as modulus.

-First thermal cycle produces largest percentage reduction at T>200˚C.

Effect of High Temperature on Concrete

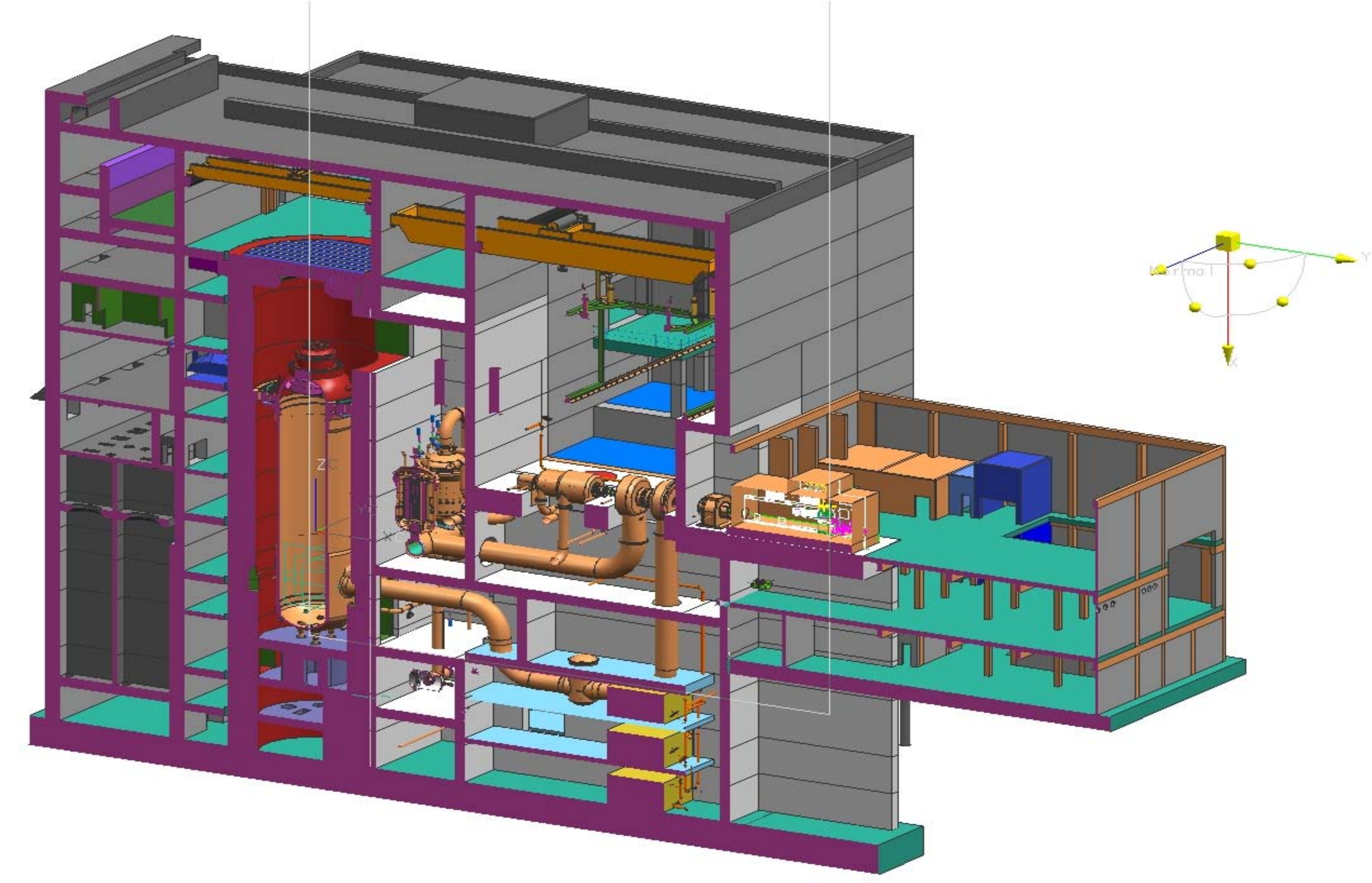
- Contract issued to Oak Ridge National Lab- Aug. 07.

- Tasks- (a) Gather and Evaluate existing concrete high temperature data applicable to HTGR structures and components; (b) evaluation of concrete physical properties (stiffness, strength, bond, etc); and (c) review of design and evaluation criteria.

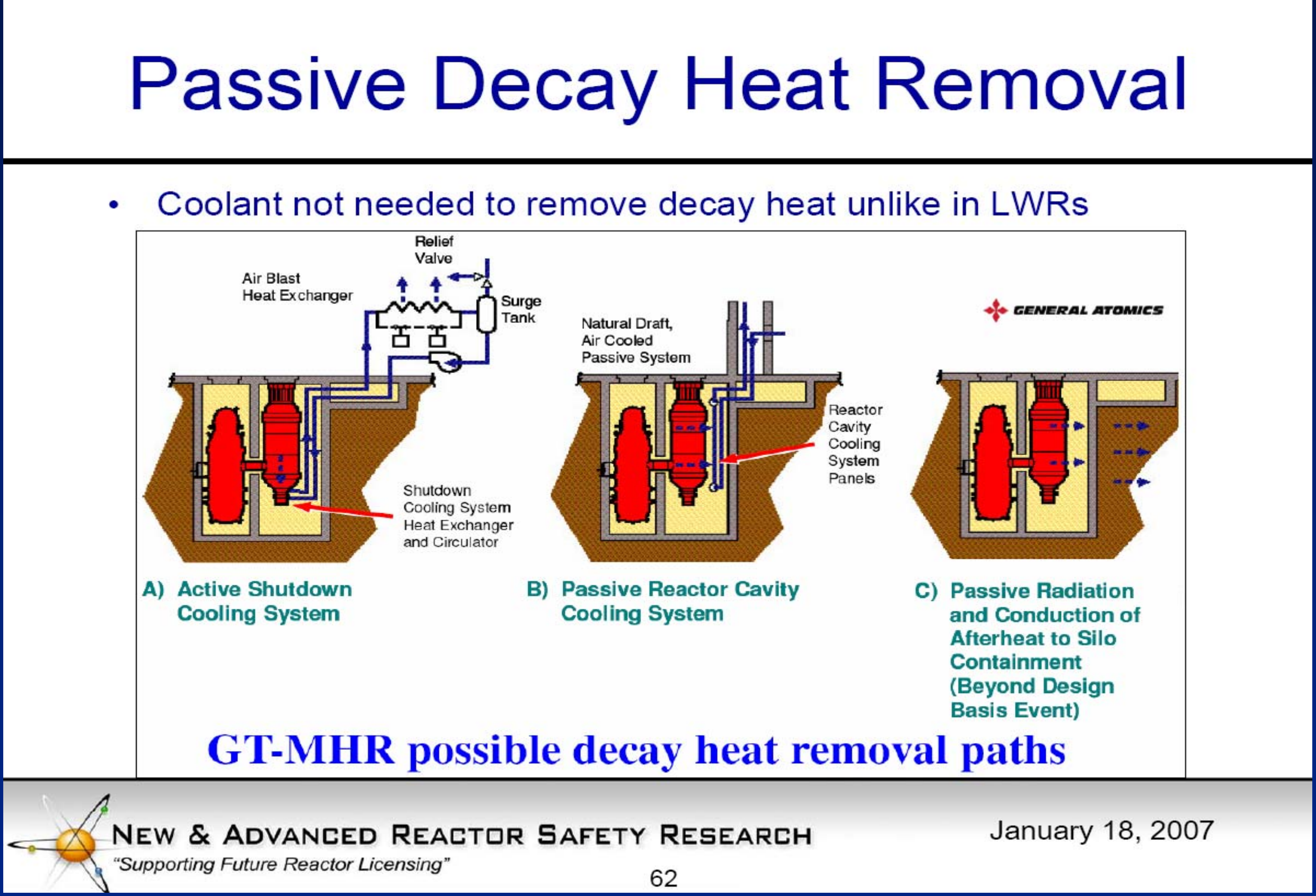
Seismic Capacity of Multimodule Plant

- Variation in seismic response results in part from overall dimensions (footprint size) of the modular unit foundation (i.e. site with two modular units responds differently than a site with more than two modular units).

PBR Reactor Building Module



Related PIRT Insights



Passive Decay Heat Removal

- Coolant not needed to remove decay heat unlike in LWRs

A) Active Shutdown Cooling System

B) Passive Reactor Cavity Cooling System

C) Passive Radiation and Conduction of Afterheat to Silo Containment (Beyond Design Basis Event)

GT-MHR possible decay heat removal paths

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"Supporting Future Reactor Licensing"

January 18, 2007

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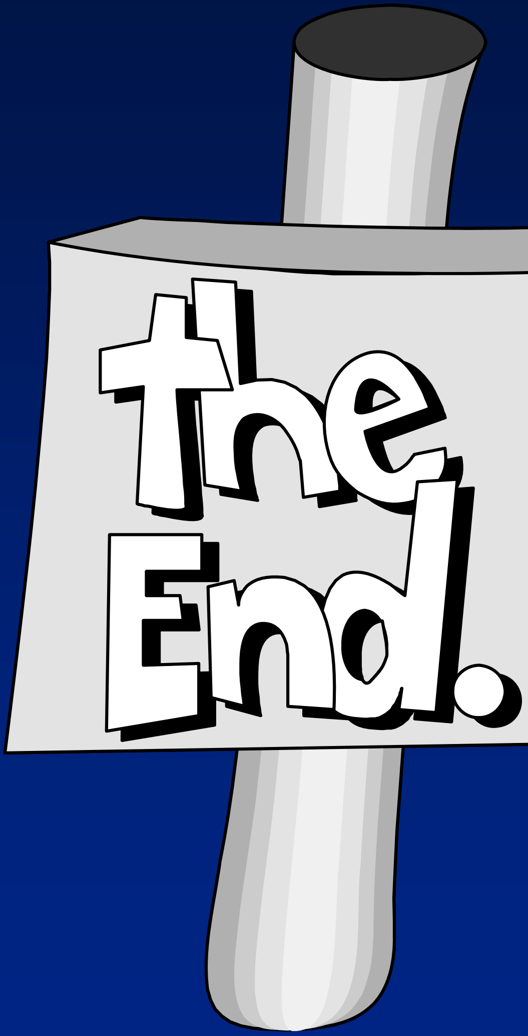
Structural Analysis-Summary

- Codes and standards recognize concrete strength tends to decrease with temperature. Code limits ensure predictable behavior.
- Analytical models used to predict response of structures to thermal loads that exceed code limits are complex. Existing analysis methods are conservative.
- For design conditions that exceed established limits, experimental work may be necessary to characterize mechanical and physical concrete properties to avoid conservatism.

Structural Analysis-summary cont.

- In the seismic R&D – cooperative research with South Africa (PBMR, PTY) could possibly address foundation size issue, i.e., plant sites with more than one module.


the End.